Urban air pollution from combined heat and power plants

A measurement-based investigation

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1. Summary

Combined Heat and Power (CHP) is a way of increasing the efficient use of primary energy used in electrical power generation. CHP recovers waste heat produced in electricity generation for use in space and water heating, displacing the use of gas in boilers. CHP has been viewed as beneficial from a climate change perspective but there is a risk that this return to power generation in urban areas will increase air pollution (EPUK, 2012). Air pollution projections by Williams et al (2018) found that widespread adoption of combustion-based CHP in urban areas could offset the air pollution improvements being brought about by other polices at reginal, national and European scales.

King's College London was commissioned by the Greater London Authority (GLA) to look at air pollution in two locations where CHP plants were thought to having an impact on local air quality:

- Bloomsbury, in central London, where the GLA identified eight small combustion-based CHP engines (each below 1MW) within close proximity.
- A small-scale CHP plant (200 kW – electric) in suburban London.

Both locations had nearby air quality monitoring sites. The project relied on a data analysis approach and used long-term air pollution measurements combined with wind speed and direction data. Statistical methods were used to resolve and quantify the impact of the different local air pollution sources.

The central London location was selected by the GLA due to the density of combustion-based CHP plants in the local area and the presence of a nearby air quality monitoring site. The largest of these CHP plants formed part of the Bloomsbury Power Consortium district heating system. This included two gas-fired CHP units that together generate 1450 kW (electric) along with boilers. Other CHP plants, each less than 250 kW (electric, where known), have been installed in local hotels and offices to the north and east of the monitoring site. The Bloomsbury air quality monitoring site is one of the longest established monitoring sites in London. It is classified as an urban background site and was installed in 1992 to measure air pollution in central London away from the immediate influence of local sources such as roads or industry. Measurements from the monitoring site have never met the European Union Limit Value for nitrogen dioxide of 40 µg m^{-3} which should have been met in 2010.

Despite a 42m flue to promote plume dispersion, air pollution from the Bloomsbury Power Consortium district heating system's 1450 kW (electric) gas-fired CHP plant and boilers were detected at the nearby monitoring site in Russell Square at a distance of 235 m. It was estimated that this gas-fired CHP plant and heating added around 1.5 µg m^{-3} to the annual mean NO_2 concentration. This was around 3% of the annual mean concentration of 48 µg m^{-3} in 2015. The Bloomsbury plant did not cause any breaches of the short-term limit value of 200 µg m^{-3}. Further combustion-based CHP plants to the north and east of Russell Square could not be resolved in the measurement data, however, it is likely that space heating and combustion-based CHP systems were contributing to the daily variation in NO_2 concentrations measured in Russell Square.

At the suburban London location, a gas-fired CHP plant (around 200 kW electric) was detected at an air quality monitoring site around 25 m away.

The smaller suburban London plant operated without a measurable impact on local concentrations until around the end of September 2014, when very high concentrations were recorded at the air quality monitoring site. From this point onwards, this CHP plant added around 15 µg m^{-3} to annual NO_2 concentrations in the adjacent street canyon. It caused the monitoring site to exceed the short-term EU Limit Value of 200 µg m^{-3} (hourly) when wind blew the CHP exhaust towards the monitoring site. Some hourly mean with concentration peaks that were greater than 1,000 µg m^{-3}. A maintenance intervention appears to have eliminated these short-term peaks from June 2016 until the monitoring site closure in early 2017. It is important to note that the high emissions from this CHP plant persisted for around 21

months and was unknown to the operators until detected by the near-by air quality monitoring sites. This raises concerns about the need for on-going maintenance and emissions verification from all sizes of combustion-based CHP plant.

The emissions rate from the suburban combustion-based CHP plant cannot be determined from this study but it can be placed in context. A traffic counter some 200 m from the monitoring site suggests a daily traffic flow of around 13,600 vehicles per day passed the monitoring site at a similar distance to this CHP plant. This included CHP at site B was around 450 kW. This is comparable to the engines used in the buses and trucks that passed close to the monitoring site. However individual buses and HGV did not give rise to the very large NO_2 concentrations that came from the CHP system. Buses and HGV are subject to emissions controls and annual emission inspections as part of their road worthiness. This is not the case for CHP plant.

Environmental Protection UK and the Institute of Air Quality Management (EPUK & IAQM, 2017) provide criteria to judge the significance of air quality impacts. The additional NO_2 concentrations from both gas-fired CHP plants would be considered as "substantial", the highest criteria.

This study highlights the need to consider local air quality impacts of combustion-based CHP district energy schemes and raises important air quality concerns for polices that bring energy production back into urban areas and for the regulatory regime. Neither of the plants in this study were sufficiently large to require environmental permits and inspection by local authority or the Environment Agency. However, the Bloomsbury Heat and Power plant will be subject to the Medium Sized Combustion Plant EU Directive 2015/2193 by 2030.

To further investigate the local impacts of CHP plants in London we recommend:

- Data analysis for other monitoring sites that are close to combustion-based CHP plants.
- A bespoke measurement programme to provide greater detail on the impacts of CHP on air quality.

2. Introduction

The dramatic changes in London's air from the 1950s and 1960s were brought about by changes in the way in which we heat homes and buildings, and in the way, that we generate electricity. Coal and oil burning has been displaced by natural gas combustion and large-scale power generation has been largely relocated away from the urban area.

The new challenge of climate change requires us to think again about current and future urban energy use. The need to reduce climate change emissions requires us to reduce the CO_2 intensity of both power and heat generation. Combined heat and power (CHP) has been one of the ways to do this.

CHP is a way of increasing the efficient use of primary energy used in electrical power generation. In the UK power generation efficiency in 2016 was 49.5% for gas and 35% for coal plants (BEIS, 2017) with the remaining low-grade heat normally being dumped. However, by combining heat and power generation this low-grade heat can be used for industrial processes, space and water heating, and even for cooling using absorption chillers. This can increase efficiency to 80% or more (EPUK, 2012). Utilising this waste heat requires electricity generation and heat use to be close to each other and larger scale-installations require the development of district heating networks. Despite the construction of a large-scale CHP and district heating system in Manchester in 1911 the development of such systems has been a topic of debate in the UK. In 2010 combined heat and power made up less than 6% of UK electricity generation compared with over 50% in Denmark. In the UK, competition from direct heating by distributed gas networks and the privatisation of the electricity sector has hampered the development of CHP and district heating in the UK (Kelly and Pollitt, 2010). Policies within London Development plan 2017 require the identification of Heat Network Priority Areas and for boroughs and developers to create energy master plans for large developments, although this needs to be balanced against local air quality impacts. Although CHP can be cost effective, the development of CHP also must be balanced against other technologies especially electric heat pumps which can provide heat with lower carbon dioxide intensity (Gregg, 2017). Although beneficial from a climate change perspective there is a risk that a return to power generation in urban areas might increase air pollution (EPUK, 2012). Air pollution projections by Williams et al (2018) found that widespread adoption of combustion-based CHP in urban areas could offset the air pollution improvements being brought about by other polices at national and European scales.

Overall in 2016 the total energy from CHP in the UK fell slightly, mainly due to the closure of industrial CHP plants. However, 1,580 plants were installed in buildings, mostly leisure centres, hotels and in the health sector. The majority were reciprocating gas engines (BEIS, 2017).

King's College London was commissioned by the Greater London Authority to look at air pollution in two locations where combustion-based CHP plants were thought to having an impact on local air quality:

- Bloomsbury, in central London, where the GLA identified eight CHP engines within close proximity (measurement site A).
- A small-scale combustion-based CHP plant in suburban London (measurement site B).

This report looks in detail at each measurement location. Data mining techniques were used to separate source influences at each location to quantify the local contribution from the CHP sources.

3. Pollutants

The study focuses on concentrations of nitrogen oxides (NO_X) and nitrogen dioxide (NO_2) as these are the main pollutants of concern from gas-fired CHP plants. EU Directives and UK set limits for NO_2. Since 2010 the annual mean must not be more than 40 µg m^{-3} and the hourly mean must not exceed 200 µg m^{-3} for longer than 18 hours per year.

NO_X describes the sum of gaseous nitrogen oxide (NO) and NO_2 concentrations. Combustion sources emit both NO and NO_2. As emissions travel away from a source they are diluted and NO is oxidised to NO_2. Looking at concentrations of NO_X allows us to study a source without the complexity of the NO to NO_2 oxidation and provides a more straight-forward view of source behaviour.

Site visits

Dr Gary Fuller and Timothy Baker from King's made several visits to measurement site B during its operation. Specifically, for this project Dr Fuller also visited both sites on 15th March 2018.

Air pollution measurements

NO_X, NO and NO_2 were all measured by the EU reference method (chemiluminescence). Equipment subject to fortnightly calibrations traceable to National Metrological Standards. Fortnightly calibrations were undertaken by council staff. All measurements were collected by King's each hour. Following validation using the most up to date calibration factors, measurements were published each hour on the London Air Quality Network web page (www.londonair.org.uk). Twice yearly independent performance audit was undertaken by the National Physical Laboratory (site B) and by Ricardo Energy and Environment (site A). This was followed by a second stage of retrospective quality assurance and quality control to produce a final "ratified" dataset.

Meteorological measurements

Metrological measurements were taken from London City Airport.

Data analysis

Following validation and ratification, all measurements were placed in the London Air Quality Network database at King's. Database programmes (MS-SQL queries and stored procedures) were created to assemble the data required for the project and to undertake the calculations to produce a time series of measurements and source apportionment results for the study period. These were then analysed using bespoke programmes created in R and data analysis tools from the R-OpenAir project (http://www.openair-project.org/). This is a suite of standardised tools created at King's, using NERC and DEFRA funding that is now used world-wide.

4. Results and discussion

Site A

Location

Site A is the Defra Automatic Urban and Rural Network monitoring site in Russell Square in central London. Site A was selected by the GLA due to the density of combustion-based CHP plants in the local area as shown in Figure 1. The largest of these plants is to the west of the monitoring site and forms part of the Bloomsbury Power Consortium district heating system serving the local university campuses. This includes boilers along with two gas-fired CHP systems that together generate 1450 kW (electric) (Bloomsbury Heat & Power, 2018). These exhaust through a 42m high flue located 235 m from the monitoring site. Other combustion-based CHP plants have been installed in local hotels and offices to the north and east (Broomfield, M et al; *Pilot study on the air quality impacts from Combined Heat and Power in London, 2018*).

The current monitoring site is in the north-east corner of the square at the rear of a café. It is classified as an urban background site and was installed in 1992 to measure air pollution in central London away from the immediate influence of local sources such as roads or industry. Prior to February 2002 the monitoring location was around 62 m to the southeast of the current site. To avoid complicating the analysis with the site relocation, only measurements from 2002 onwards were considered in this report.

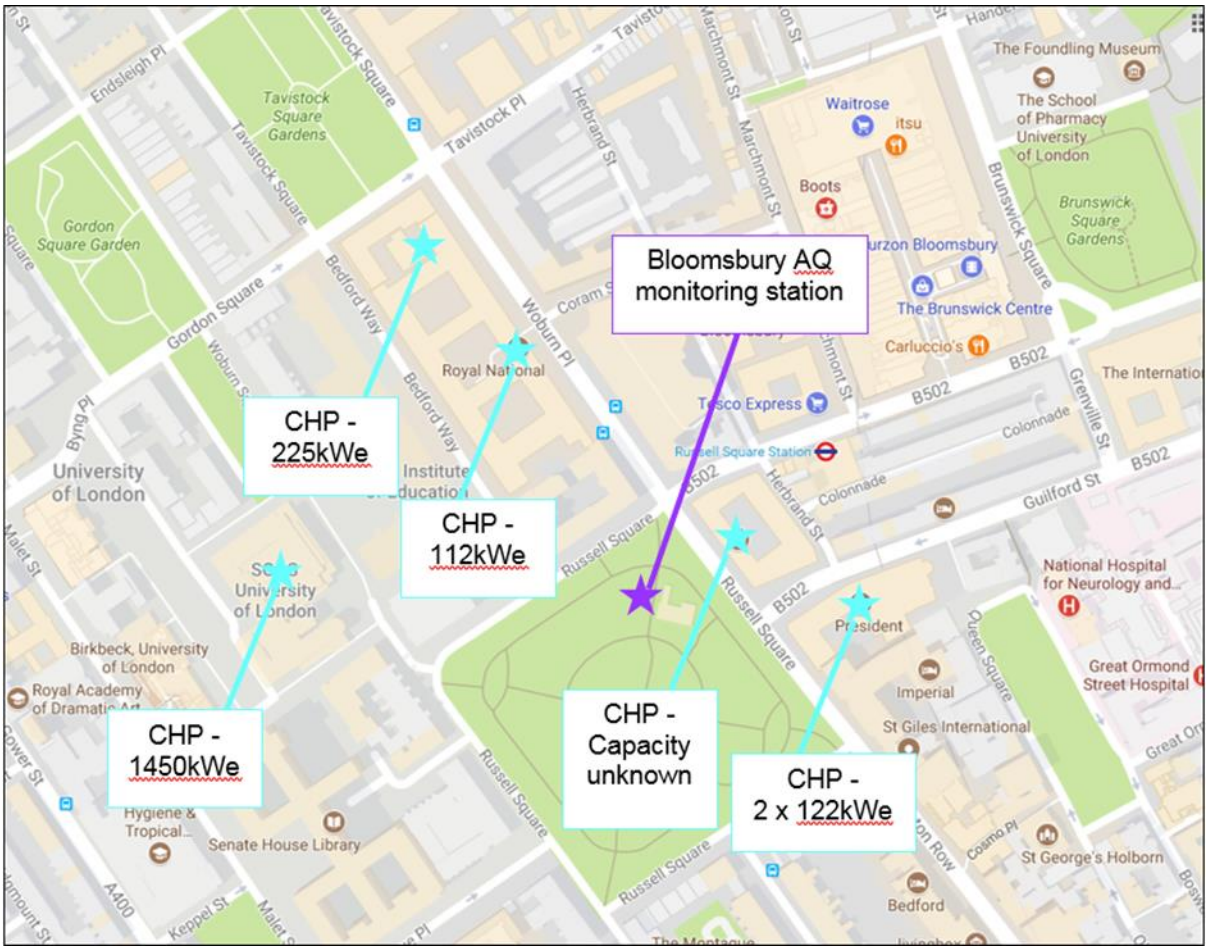

Figure 1 Bloomsbury AURN site and nearby CHP plants (map supplied by GLA).

Results

Measurements from the monitoring site are shown in Figure 2 with annual mean concentrations in Table 1. It is clear from Figure 2 that concentrations at the monitoring site were broadly stable until around 2015 when there has been a marked decrease. The measurement site has never achieved the annual mean EU Limit Value but has always met the hourly mean limit. A downward trend in NO_2 concentrations is clear. As shown in Table 1, this decreased from 57 µg m^{-3} in 2005 to 48 µg m^{-3} ten years later in 2015. It reached 42 µg m^{-3} in 2016, the latest year with fully ratified measurements.

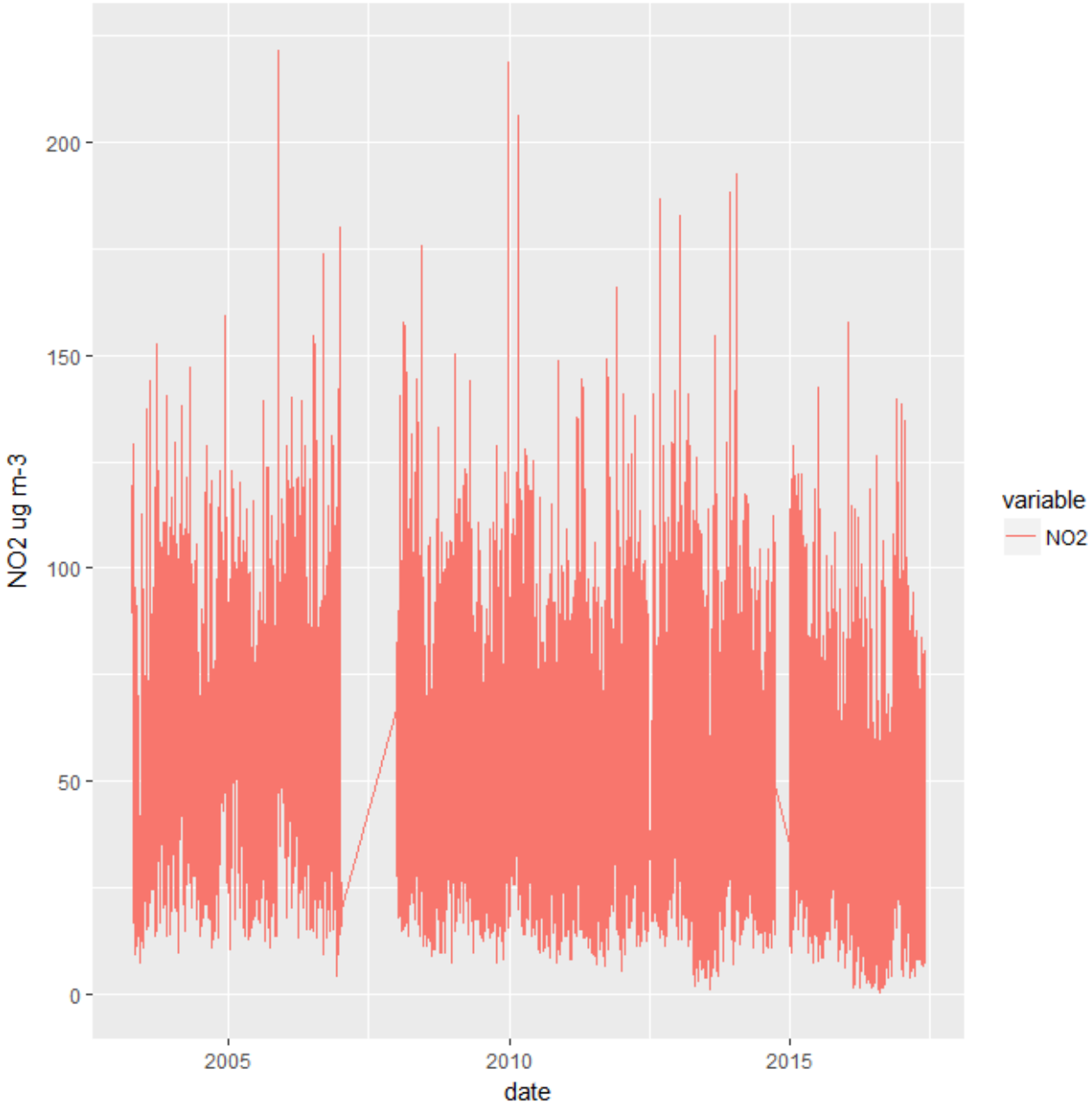

Figure 2 Hour mean NO_2 concentrations from site A.

Year	Annual mean µg m^{-3}	Hours > 200 µg m^{-3}
2005	57	1
2010	55	1
2015	48	0
2016	42	0

Table 1 NO_2 concentrations at Bloomsbury compared with the EU Limit Values.

Analysis of NO_X and NO_2 concentrations by wind speed and direction is shown in Figure 3. This shows that the greatest mean concentrations of NOx and NO_2 reach the monitoring site on winds between west and north.

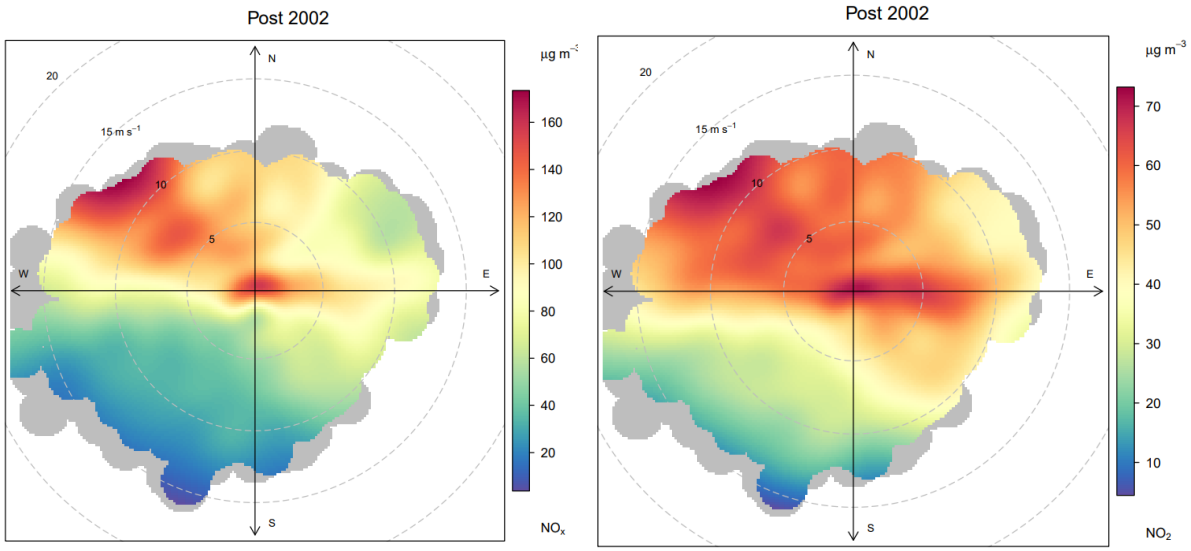

Figure 3 Bi-variate polar plot for NO_X and NO_2 at Bloomsbury AURN from March 2002 to end of 2016.

The probability of exceeding the 10th, 50th and 95th percentiles for NO_X and NO_2 is shown in Figure 4. Concentrations greater than the 10th percentile affected the monitoring site on all wind directions except from the south-west. Concentrations that exceeded the 50th percentile largely came from wind directions between west through north to east with concentrations above the 90th percentile (the greatest 10% of measurements) coming from the north-west and east (for NO_X); and from north-west (for NO_2).

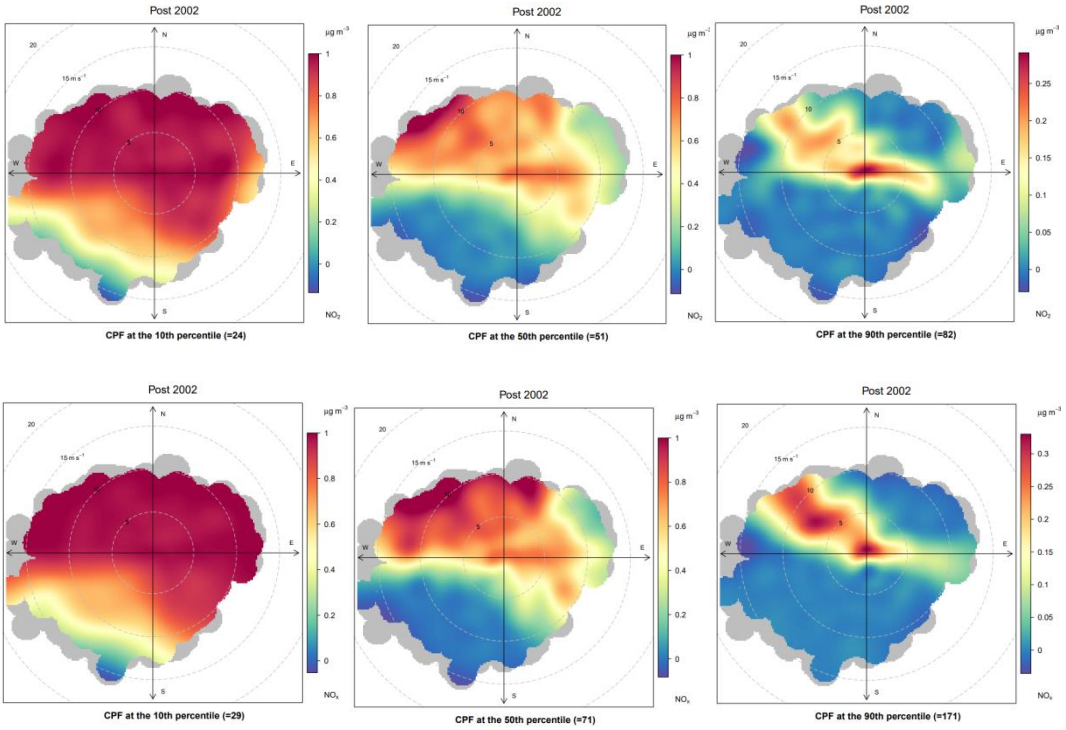

Figure 4 Bi-variate polar plots for NO_2 (upper) and NO_X (lower). Left hand plots show the probability of exceeding the 10th percentile, centre plots show the probability of exceeding the 50th percentile and the right-hand plots show the probability of of excceeding the 50th percentile and the right hand plots show the probability of exceeding the 90th percentile.

The increment in NO_2 concentrations above the London-wide mean background concentration, averaged by wind speed and direction, is shown in Figure 5 (left). The increment above background shows greatest concentrations on wind directions from the north-west. As with site A k-means clustering was used to separate the data into separate clusters. Testing different cluster solutions from two upwards, a six-cluster solution was found to be the lowest number of clusters that resolved the source to the north-west, that appears in the left-hand figure, and was indicated in Figure 4.

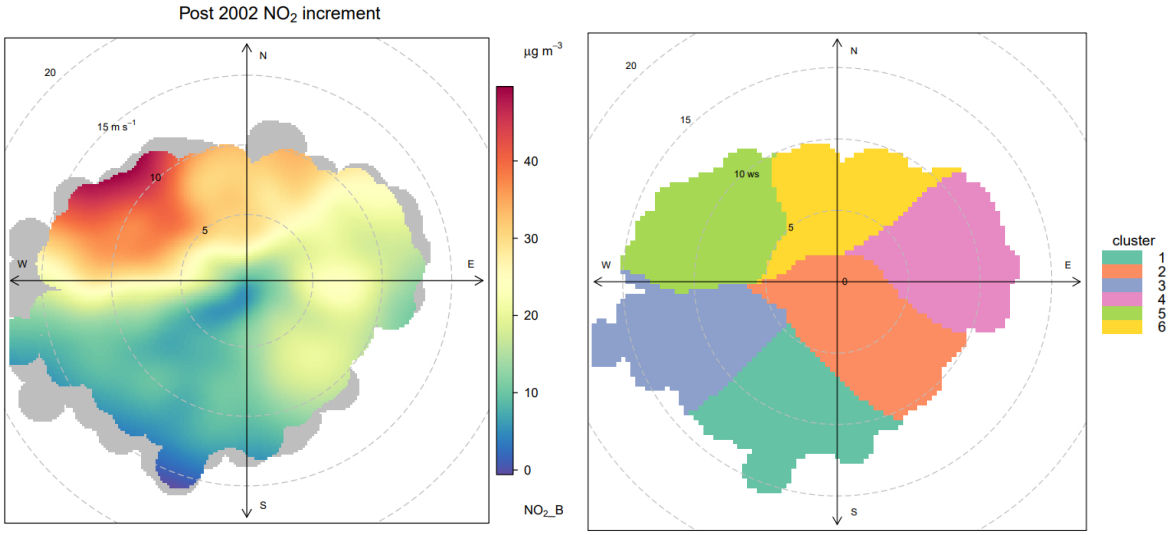

Figure 5 Increment in NO_2 concentration above background for the Bloomsbury site for the post 2002 period. The left-hand panel shows mean concentrations and the right-hand panel shows the data set divided into six clusters using k-means.

The variation in time for NO_2 for each cluster is presented in Figure 6. This shows the mean concentration in each cluster averaged by hour, day of week and month of year. The source to the north-west (cluster 5) produced the greatest mean concentrations, with sources from the north (cluster 6) producing slightly lower mean concentrations. The daily pattern for all sources showed lowest concentrations overnight with an increase from about 6 am for all source clusters. There was no clear weekday pattern. Seasonal patterns varied between the source clusters with cluster 5, 3 and 1 showing greater concentrations in winter than summer.

The university campuses to the west of the monitoring site have little traffic and it is highly likely that the local source resolved in cluster 5 is the Bloomsbury Heat and Power chimney, 235 m from the monitoring site. Source clusters to the north and east would be most impacted by local traffic. The variation of NO_2 along nearby Euston Road is shown in Figure 7. This shows a clear weekday weekend variation that is not exhibited by the largest source clusters in Figure 6 (clusters 4, 5, and 6). The sources to the north (cluster 6) and east (cluster 4) would be expected to be influenced by traffic, especially that along Woburn Place. The mismatch of the day of week variation of clusters 4 and 6 and that from local traffic may indicate the combination of traffic along with CHP and space heating.

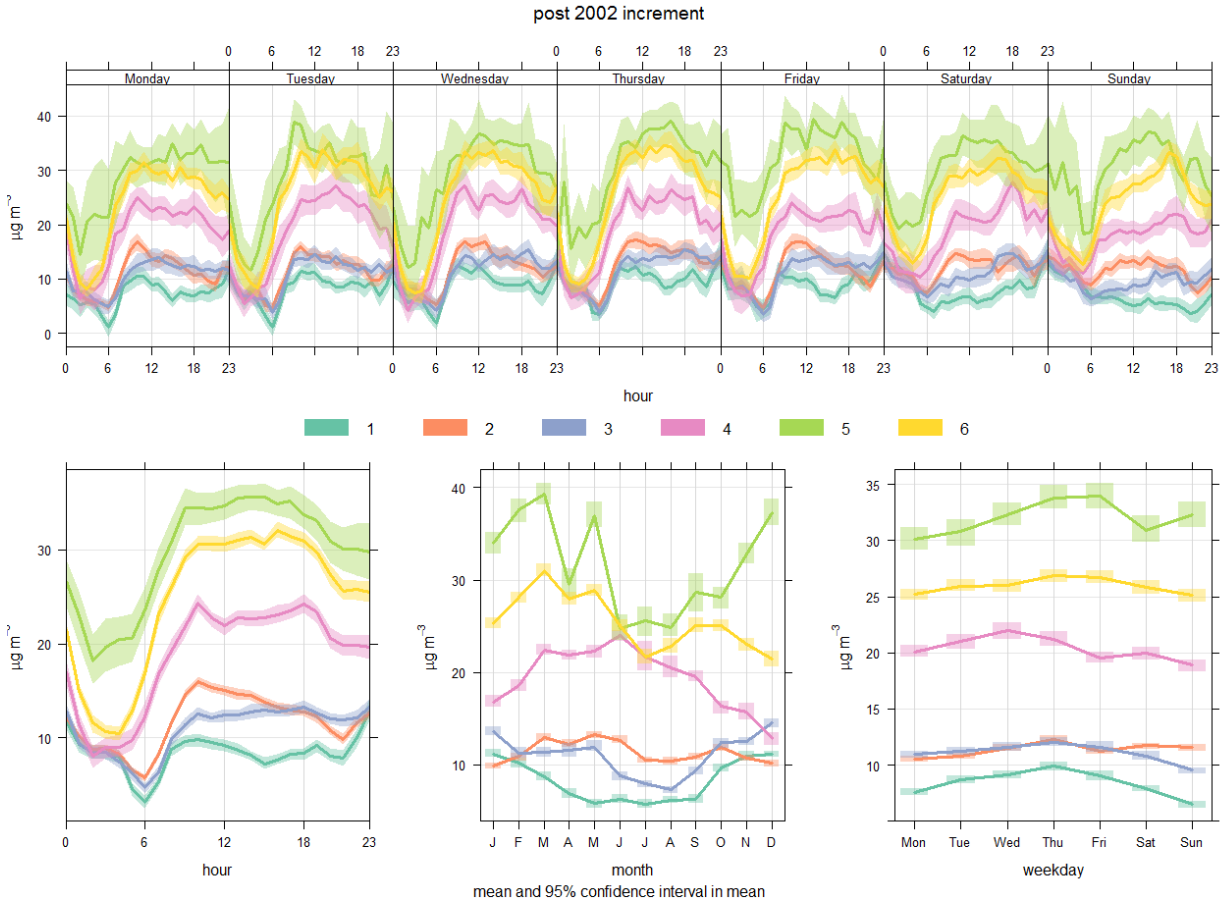

Figure 6 Mean concentrations of NO_2 from each cluster for the Bloomsbury site AURN, post 2002.

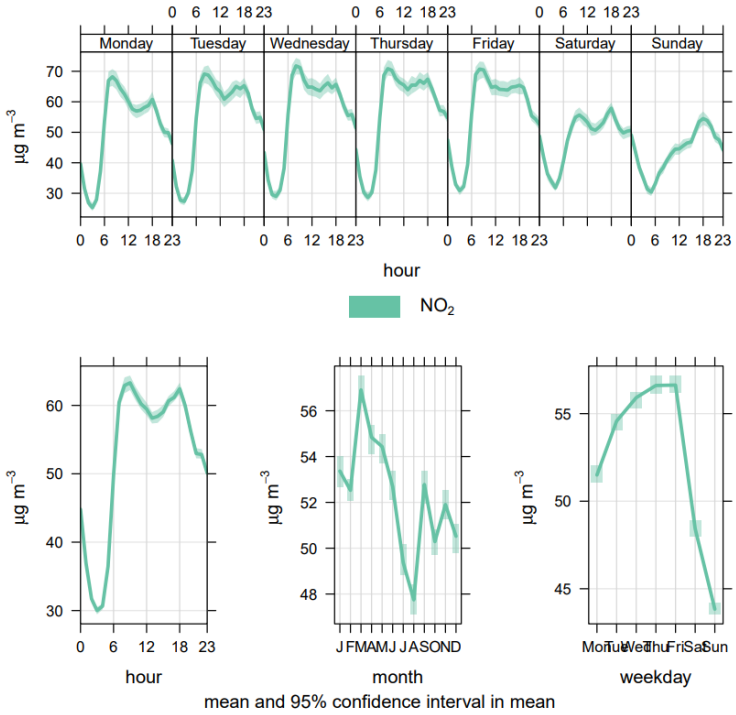

Figure 7 Mean concentration of NO_2 from the CD9 roadside monitoring site in Euston Road (2011 to 2018).

The frequency of wind direction is not equal in all directions. The wind speed and direction weighed contributions from each of the source clusters are shown in Figure 8. The greatest contribution to the mean concentration arose from wind directions from the south-east (cluster 2) and the north (cluster 6). Despite the greatest mean concentrations arising from cluster 5, in the direction of the Bloomsbury Heat and Power, the contribution to the long-term mean was not dominated by this source. For the post-2002 period, the mean NO_2 increment above the London background was 15 µg m^{-3}. The Bloomsbury Heat and Power source in Cluster 5 contributed around 1.5 µg m^{-3} and cluster 6 contributed around 3.5 µg m^{-3}. If these CHP plants had not been present it is likely that the decrease in NO_2 would have been greater than that shown in Table 1.

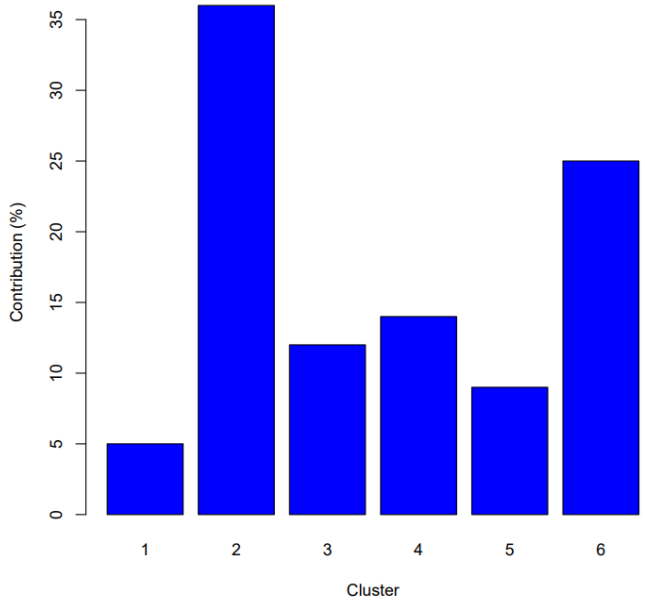

Figure 8 Time weighted contribution of each source cluster to mean NO_2 increment at the Bloomsbury AURN site.

Site B

Location

Site B was located on a main road in London. The air quality monitoring site had been installed to measure air pollution alongside a busy suburban street with both housing and pedestrian exposure. The monitoring site was installed in an office building located on the north side of a street canyon that is orientated south-west to north-east. The south side of the canyon is comprised of two storey buildings with shop fronts at street level with homes above. The west side comprises shops and offices to a height of around 10 m. Further back from the road the block on the west side is dominated by an office building over 100 m high. The sampling point was located around 4 m above the street level. A combustion-based CHP plant was located at roof level with the exhaust around 15 m above the street and around 25 m from the monitoring site. This CHP plant did not have an exhaust stack but instead exhausted through an exhaust pipe around one metre above the installation. Information from the building owners and public documents suggest that the CHP is around 450 kW thermal and 200 kW electric. This CHP is fuelled by natural gas and was installed prior to 2012.

Results

Measurements from the monitoring site are shown in Table 2. The monitoring site experienced many operational problems and did not achieve 90% data capture required to formally assess EU Limit Values. However, mean concentrations were above the EU Limit Value concentration of 40 µg m^{-3} each year. The three years with good data capture, from 2013 to 2015, suggest an increasing trend in mean NO_2 concentrations. The hourly mean limit value of 200 µg m^{-3} was not met from 2014 onwards.

Year	Data capture %	Annual mean µg m^{-3}	Hours > 200 µg m^{-3}
2010	38	55	2
2011	0	-	-
2012	39	48	0
2013	85	40	10
2014	88	52	181
2015	70	57	156
2016	18[1]	74	93

Table 2 NO_2 concentrations at site B compared with the EU Limit Values.

The time series of hourly mean NO_2 concentrations are shown in Figure 9 with hourly mean NO_X concentrations in Figure 10. The period after September 2014 was characterised by frequent peak concentrations of NO_2 of greater than 500 µg m^{-3} and NO_X concentrations of 4,000 µg m^{-3} or greater. The maximum hourly mean NO_2 concentration was greater than 1,500 µg m^{-3}

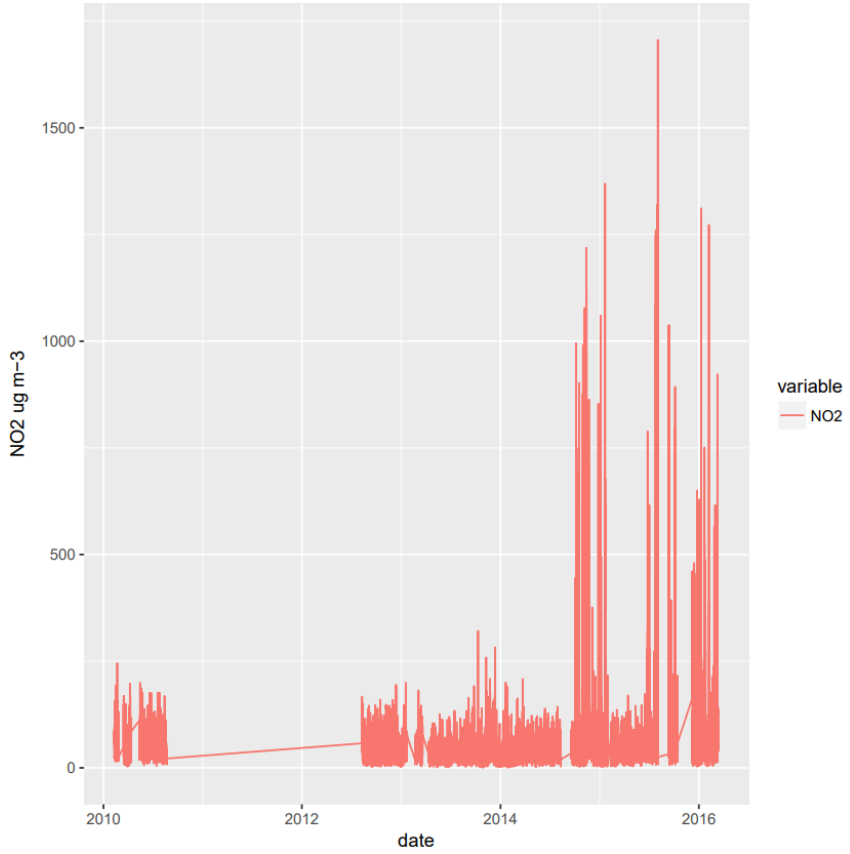

Figure 9 Hour mean NO_2 concentrations from site B.

[1] Prior to equipment fault. Data that passed LondonAir quality standards.

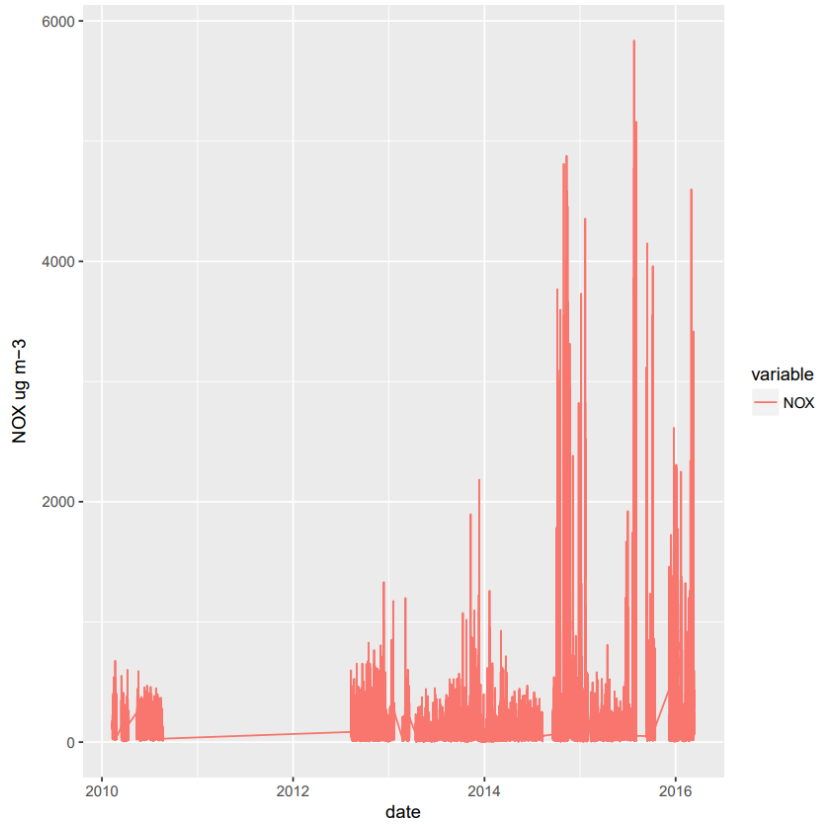

Figure 10 Hourly mean NO_X concentrations from site B.

The advent of large peak concentrations also affected the daily mean NO_2 concentrations as shown in Figure 11, which shows daily mean concentrations over 400 µg m^{-3} in August 2015.

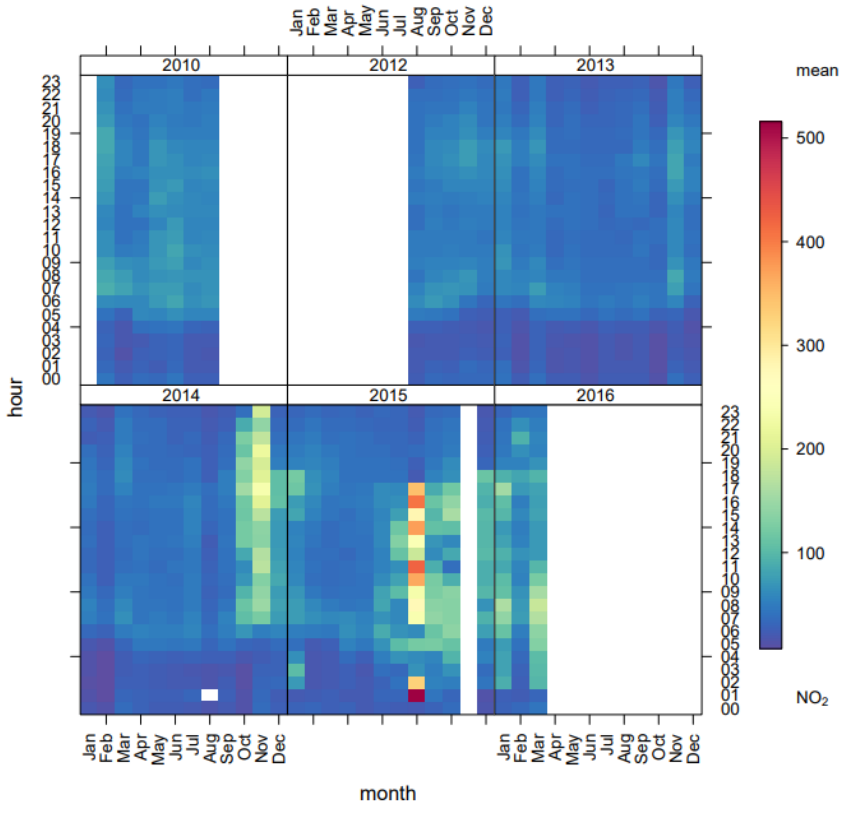

Figure 11 Daily mean concentrations of NO_2 from site B.

Analysis of the wind speed and direction conditions that blow pollution to a monitoring site can provide valuable insight into the origin of local sources. This is normally plotted as a bi-variate polar plot representing the compass direction of the wind origin on a radial axis and windspeed as distance from the origin. The mean concentration is shown on a colour scale. Figure 12 shows the bi-variate polar plot for site B during 2013 when the monitoring site was not subject to short term concentrations peaks. Greatest mean concentrations were measured on wind directions from the north-west sector. Although the road lays to the east of the monitoring site, the recirculation of air in the wake of the buildings that form the street canyon would mean that winds from the north-west bring air from the road onto the monitoring site. The greatest mean concentrations of NO_2 were around 60 µg m^{-3} and those for NO_X were over 200 µg m^{-3}.

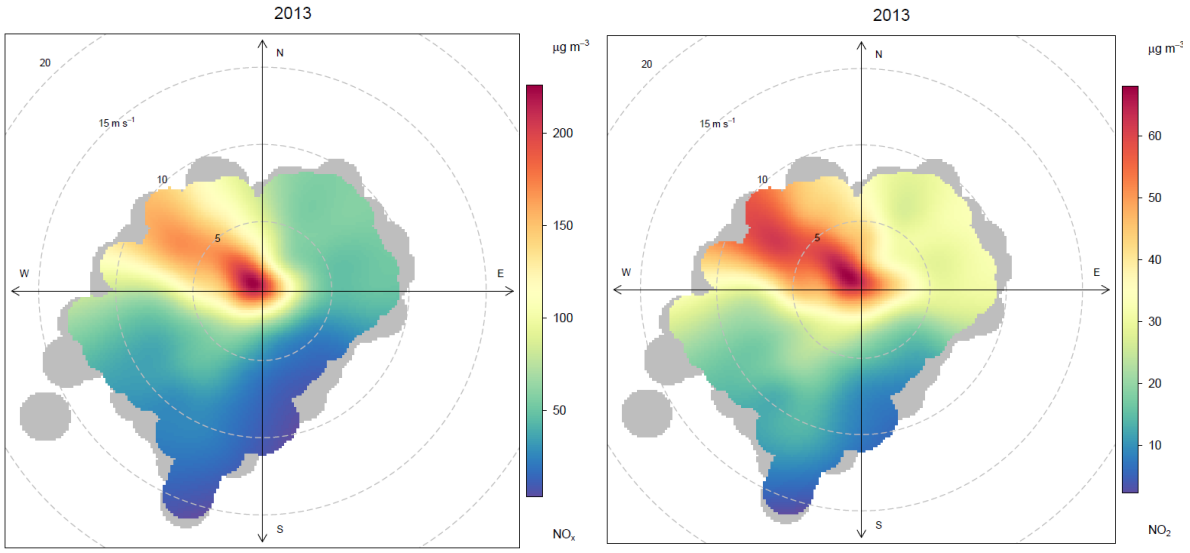

Figure 12 Bi-variate polar plot for NO_X and NO_2 at site B in 2013.

The bi-variate polar plots of measurements from 2015 clearly show the impact of a new source on winds from the south-east as shown in Figure 13. Note the change of scale between Figure 12 and Figure 13. The source on the north-westerly wind direction was still present but is masked by the change of scale in Figure 13 due to the magnitude of the new source. This was clearly different to the source that dominated the site in 2013. Due to the recirculation of air in the canyon the new source was most likely to the south-west of the monitoring site, consistent with the location of the CHP plant exhaust. During the site visit on 15th March 2018 winds from the south-east were seen to bring the plume from this CHP exhaust into the street canyon and towards the monitoring site location.

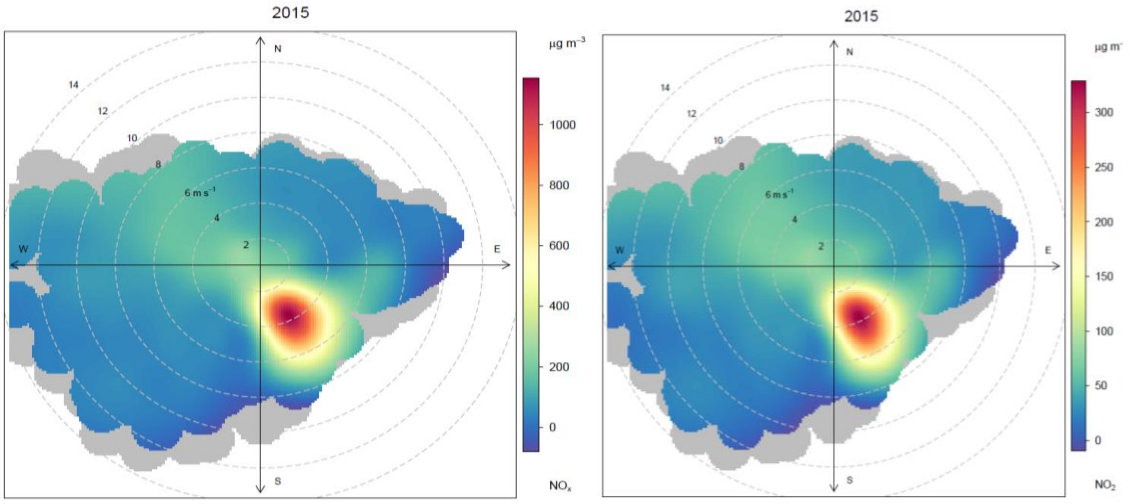

Figure 13 Bi-variate polar plot for NO_X and NO_2 at site B in 2015.

The source changes between 2013 and 2015 can be clearly seen in Figure 14. This shows the probability of NO_2 concentrations exceeding the 10th, 50th and 90th percentiles for that year. During 2013, wind directions from the north-west caused concentrations to exceed the 50th and 90th percentiles (i.e. 32 and 74 µg m^{-3}, respectively). By contrast, in 2015, the source in the north-west was still present at concentrations at the 50th percentile (38 µg m^{-3}) but the new source during south-east winds dominated when considering the probability of exceeding the 90th percentile (i.e. 90 µg m^{-3}).

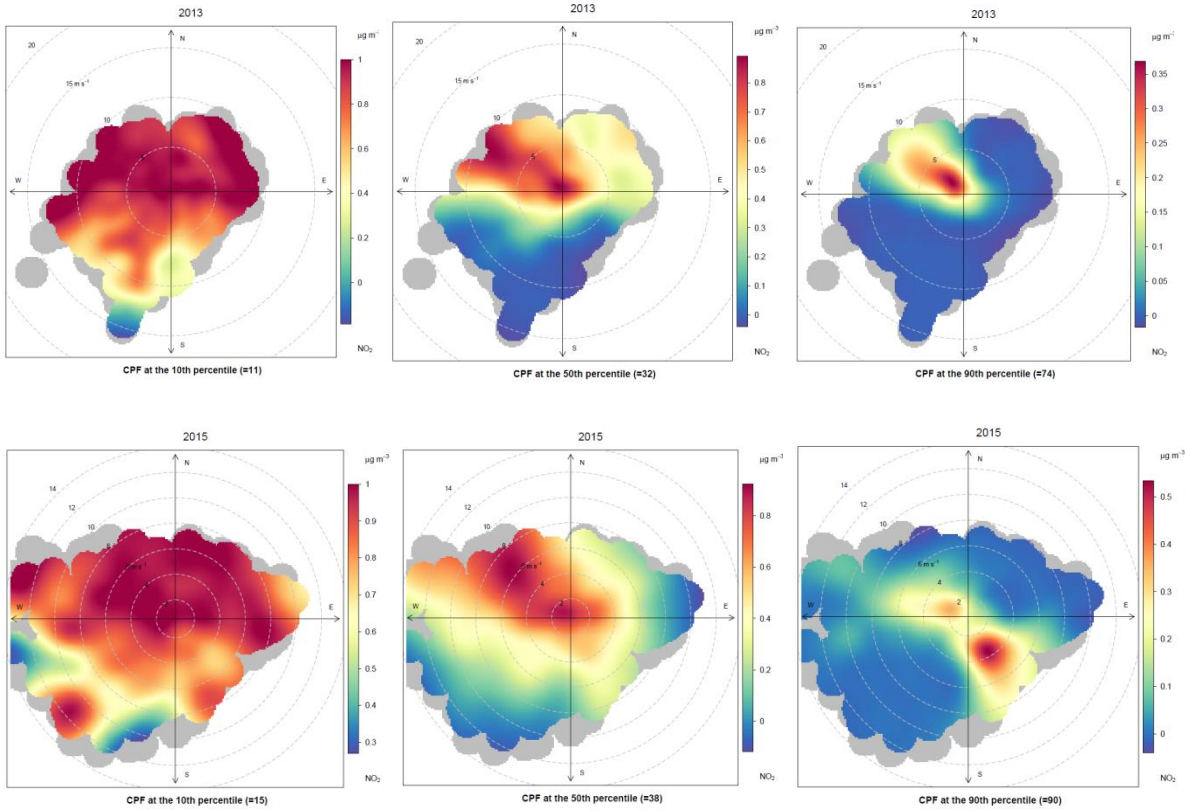

Figure 14 Site B, bi-variate polar plots for NO_2 during 2013 (upper) and 2015 (lower). Left hand plots show the probability of exceeding the 10th percentile, centre plots show the probability of exceeding the 50th percentile and the right-hand plots show the probability of of excceeding the 50th percentile and the right hand plots show the probability of exceeding the 90th percentile.

An alternative way to view the impact of local air pollution sources is to look at the difference between the measured concentration and that at distant background location. Each background monitoring site has its own local sources and for this reason a composite mean was used calculated from measurements at all background monitoring sites in the London. The difference, or increment, in concentrations between site B and the mean London background from September 2014 onwards is presented in Figure 15. This clearly shows the source on wind directions from the south-east.

K-means clustering was used to separate the data from the south-east source from the other local sources in the increment. A two-cluster solution is also shown in Figure 15. The variation in time for NO_2 for each cluster was then plotted in Figure 16. This shows the mean concentration in each cluster averaged by hour, day of week and month of year. The source to the south-east (cluster 2) produced far greater mean concentrations than sources in the other wind directions (cluster 1) with greatest concentrations during the day time and lowest concentrations at night. The source to the south-east does not appear to have operated over-night at the weekend but there was no other clear weekday or seasonal pattern.

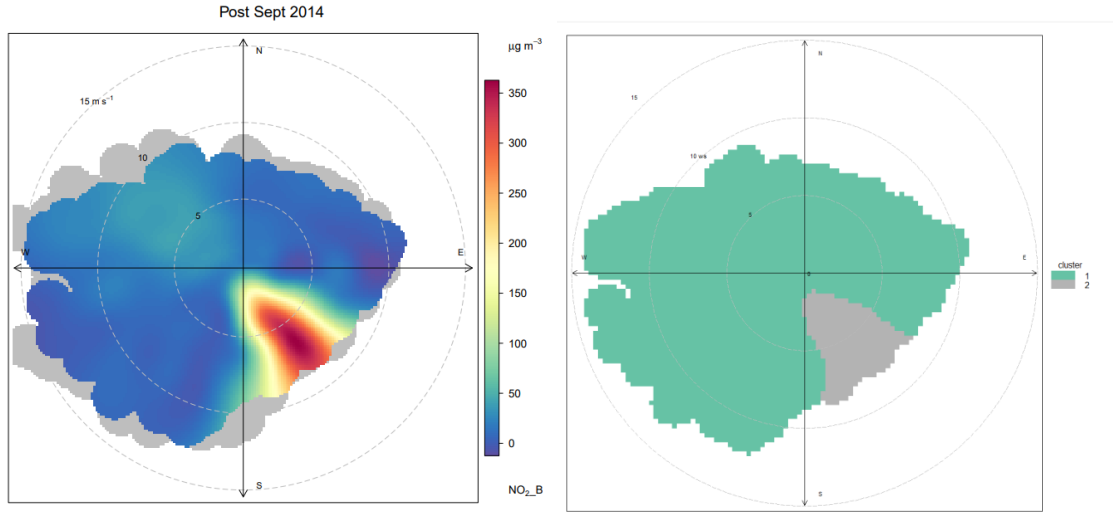

Figure 15 Increment in NO_2 concentration above background for site B for the period September 2014 onwards. The left-hand panel shows mean concentrations and the right-hand panel shows the data set divided into two using k-means.

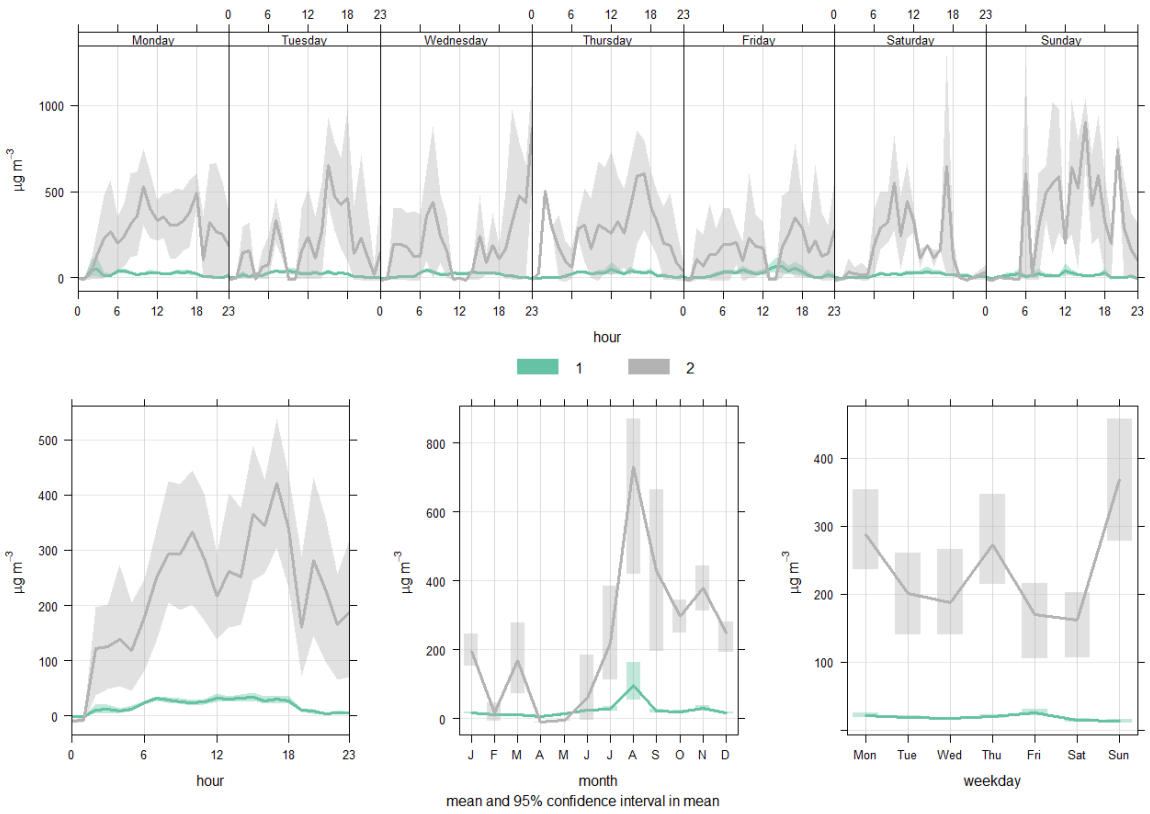

Figure 16 Mean concentrations of NO_2 from each cluster for site B, post September 2014.

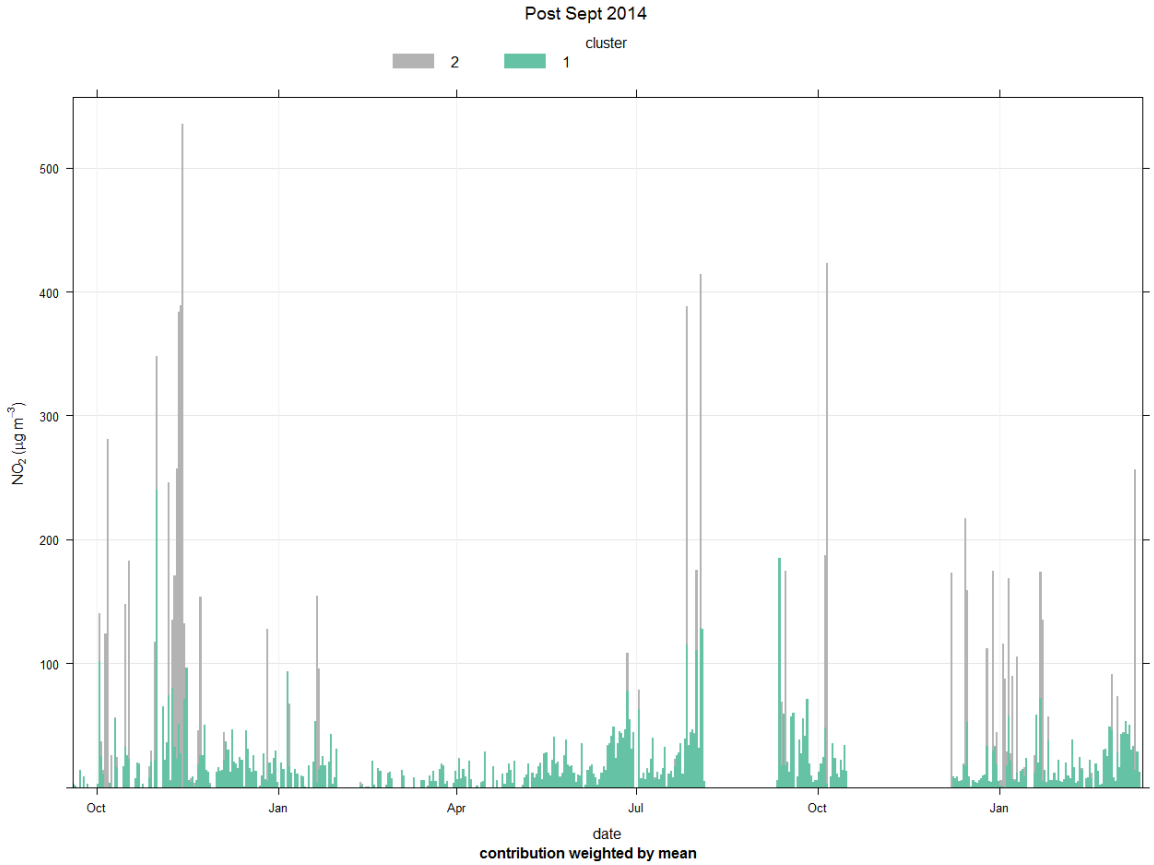

Figure 17 The increment in daily mean NO_2 showing the contribution from each cluster for post-September 2014 at site B.

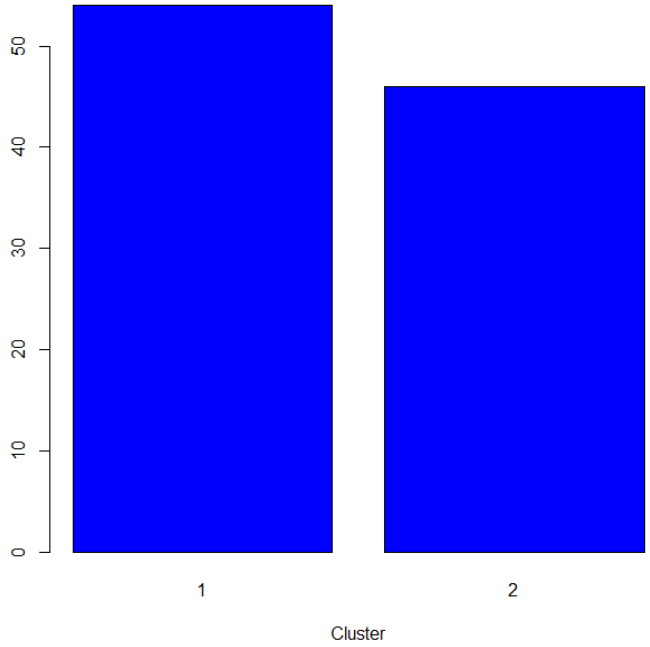

Figure 18 Time weighted contribution of each source cluster to the annual mean NO_2 increment at site B post September 2014.

The daily mean increment in NO_2 from the two clusters is shown in Figure 17. This clearly shows that cluster 2 was responsible for the peak concentrations but did not impact the monitoring site all the time. Weighting the mean concentration by the frequency of occurrence allows us to determine the contribution of the two source clusters to the annual mean concentration. As shown in Figure 18 the contribution to the annual mean was similar for the two clusters, with cluster 1 being responsible for around 55% of the increment and cluster 2 (source during south-east winds) contributing around 45%. This means that cluster 2, which was attributed to the CHP, contributed around 15 µg m^{-3} to the annual mean concentration measured at site B. This was broadly consistent with the increase in annual mean NO_2 at site B from mean of 44 µg m^{-3} (2012 to 2013) to 55 µg m^{-3} (2014 to 2015).

Looking at peak concentrations only, as the best measure of the CHP plume, it was found that primary emissions of NO_2 accounted for 26% of the NO_X emission.

During 2016 meetings were held between the local authority, King's and the CHP operators where data on the peak concentrations from the CHP plant were presented. We believe that a maintenance intervention was made in late June 2016. Due to multiple component faults[2] in the measurement equipment, data from January 2017 onwards did not meet the quality standards required by the London and national AURN networks, as laid out in EU Standards. The instrument did continue to sample until the site closed in January 2017 due to relocation of the council offices. Although the NO_2 during this time was mostly likely underestimated it is possible to look at the frequency and relative magnitude of the peak NO_2. During the period after September 2014 this gas-fired CHP caused NO_2 peaks that were more than 10 times the annual mean concentration and some greater than 1,000 µg m^{-3}. Following the June 2016 intervention, the equipment detected one peak greater than four times the long term mean but the frequency and magnitude of short-term peaks were similar to pre-September 2014. It should be remembered that the fault was unknown to the CHP operators and persisted for 21 months.

[2] NO_2 converter efficiency was found have dropped from the required 95% to 66% and a switching valve leak was suspected.

5. Conclusions

This report looked at the impact of combustion-based CHP plants in two locations. The first location was selected by the GLA due to the high number of CHP plants in the local area. The largest of these plants formed part of the Bloomsbury Power Consortium district heating system. This included two gas-fired CHP systems that together generate 1450 kW (electric) along with boilers for space and water heating. Other combustion-based CHP plants, each less than 250 kW (electric, where known), are located in local hotels to the north and east of the monitoring site. The second location was in suburban London where a gas-fired CHP plant had been detected at the vicinity of an air quality monitoring site. This CHP plant was around 200 kW (electric).

Despite a 42 m flue, NO_2 from Bloomsbury Power was detected at the nearby monitoring site in Russell Square was at a distance of 235 m. The CHP plant and boilers added around 1.5 µg m^{-3} to the annual mean NO_2 concentration at the monitoring site but did not cause any breaches of the short-term limit value of 200 µg m^{-3}. Further CHP plants identified to the north and east of Russell Square could not be separated from traffic emissions. However, it is likely that space heating and CHP systems to the north and east were modifying the daily variation in NO_2 concentrations measured in Russell Square but individual CHP plants could not be resolved in the ambient air quality measurements.

It appears that the smaller suburban London plant operated well without measurable impact on local concentrations until a fault developed around the end of September 2014. From this point onwards, this CHP added around 15 µg m^{-3} to annual NO_2 concentrations in the adjacent street canyon. It is likely that the street canyon would have breached the annual mean limit value due to traffic emissions, but the additional contribution from this CHP plant, would have made attainment of the EU Limit Value much more difficult. The combination of background NO_2 from elsewhere in London and that from the gas-fired CHP was sufficient to exceed the limit without an additional contribution from local traffic. When the wind blew the emissions from the CHP towards the monitoring site, peak hourly-mean NO_2 concentrations could be greater than 1,000 µg m^{-3} and this CHP plant caused a breach of the short-term NO_2 EU Limit Value. Although analysis of data from 2016 was compromised by an equipment fault; it is clear that the short-term peak concentrations from the CHP plant were corrected following a maintenance intervention in summer 2016. This highlights the need for adequate on-going testing and maintenance of urban combustion-based CHP units.

The emissions rate from the suburban gas-fired CHP plant cannot be determined from this study but it can be placed in context. A traffic counter some 200m from the monitoring site suggests a daily traffic flow of around 13,600 vehicles per day (AADT); 3.3 % buses (~ 450 per day) and 2.8 % HGV (380 per day) which passed the monitoring site at a similar distance to this CHP. However, these did not give rise to the same very high peak concentrations that the CHP produced.

It is clear from this analysis that combustion-based CHP plants can impact on local NO_2 concentrations. The impact clearly depends on the local situation, the size of the combustion-based CHP plant, its operation and the complexity of the air flows around the local buildings. The smaller plant in this study sustained a fault which was not detected by the operator and was not addressed in normal maintenance and servicing. This fault had been present for 21 months and was only detected due to the proximity of a nearby ambient air quality monitoring site. Modelling of possible receptor points affected by CHP emissions is also challenging. In the case of the small gas-fired CHP plant near site B, the exhaust vented from the top of the plant and there was no flue stack to aid dispersion of the exhaust plume. Also, this gas-fired CHP plant was also installed in an area with very complicated building terrain where the grounding of the plume would have been very unpredictable.

Despite a 42 m flue, the larger combustion-based CHP near Russell Square was most likely responsible for an increase of around 1.5 µg m^{-3} in the background annual mean NO_2 at 235 m distant. This was

around 3% of the annual mean concentration of 48 µg m^{-3} in 2015. The measured impacts of this combustion-based CHP plant might have been larger if the monitoring site was placed in the prevailing wind direction.

Environmental Protection UK and the Institute of Air Quality Management (EPUK & IAQM, 2017) provide criteria to judge the significance of air quality impacts as "negligible", "slight", "moderate" or "substantial". This scoring method is commonly used in the planning process and uses a matrix that considers the prevailing concentration and the additional pollution from the local source. Both locations would exceed the NO_2 Limit Value without the addition of the combustion-based CHP plants. The additional NO_2 concentrations from both of these CHP plants studied would be considered as "substantial", the highest criteria.

Neither of these CHP plants in this study require environmental permits or inspection by local authority or the Environment Agency. However, the Bloomsbury Heat and Power plant will be subject to the Medium Sized Combustion Plant EU Directive EU 2015/2193 by 2030. This study highlights the need to consider the air quality impacts of CHP in district energy schemes. A broader perspective could be obtained by analysing measurement data from other sites that are close to combustion-based CHP plants and setting up bespoke measurement programmes near representative combustion-based CHP plants.

The CHP at site B was around 450 kW_{th}. This is comparable to the engines used in the buses and trucks that passed close to the monitoring site. However individual buses and HGV did not give rise to the very large NO_2 concentrations that came from the CHP system. Buses and HGV are subject to emissions controls and annual emission inspections as part of their road worthiness. This is not the case for CHP plant.

6. References

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