Trends in UK NOx and NO_2 Concentrations through the COVID-19 Pandemic: January 2022

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Experts in air quality
management & assessment

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1 Introduction

1.1 In January 2020, Air Quality Consultants Ltd (AQC) published the most recent of a series of reports on long-term trends to UK nitrogen oxides (NOx) and nitrogen dioxide (NO_2) concentrations[1]. This used statistical models to remove the predictable effects of meteorology on concentrations measured at several hundred chemiluminescence monitoring sites spread across the UK. It showed that, after weather effects were normalised ('deweathering'), a strong seasonal cycle remained, with higher concentrations during the winter than in summer, but that average NOx concentrations had fallen steadily each year from 2014 to 2019. The largest reductions were at the roadside, most likely driven by changes to the composition of the vehicle fleet.

1.2 In March 2020, AQC analysed changes to NOx and NO_2 concentrations caused by the COVID-19 pandemic[2]. This was subsequently updated in April[3], and November 2020[4] to use additional measurements which were then available. These analyses used the same statistical techniques as the earlier, multi-year, trend analysis, but focused on short-term changes observed during 2020. To isolate the effects of the pandemic, these analyses removed not only weather effects, but also routine temporal patterns, including seasonality. This showed strong reductions in NOx and NO_2 concentrations at sites across the UK, particularly at the roadside, with these reductions coinciding with the imposition of lockdowns in the UK.

1.3 At the time of writing, COVID-19 social and travel restrictions have been in place, in some parts of the UK and in some form, for almost two years. The approach which was used in March, April, and November 2020 to quantify their effect on air quality is no longer appropriate since, as was shown in the January 2020 analysis[1], NOx concentrations are likely to have changed appreciably over two years irrespective of the pandemic. Therefore normalising for non-weather temporal factors is inappropriate over such an extended period. Emissions models may be used to predict, and thus isolate, those changes which are unrelated to the pandemic, but the uncertainty associated with such models is too great to make such an analysis worthwhile. Instead, this current report takes a more holistic approach and presents measurements collected during the pandemic in the context of the longer-term air quality trends, and in comparison with concurrent traffic volumes. Understanding the extent to which recent NOx and NO_2 measurements are affected by mobility restrictions, and to what extent they are a broader response to long-term measures to improve air quality, will assist in devising strategies for future air quality management.

[1] Gellatly, R. and Marner, B. (2020) Nitrogen Oxides Trends in the UK 2013 to 2019, Available: https://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=af089039-6a2f-49b5-9533-fe31205f3134

[2] Gellatly, R., and Marner, B. (2020) The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality Available: https://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=3e564572-18ce-41be-99ae-96144e4dfef9

[3] Gellatly, R., Marner, B., Liska, T. and Laxen, D. (2020) The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality – 06 April Update, Available: http://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=1222ff30-3c9f-4189-b353-2f2ee50edab1

[4] Liska, T., Gellatly, G., Laxen, D., and Marner, B. (2020) The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality – November Update, Available: https://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=e12d94c1-c1f5-4e8e-8611-bf1b44a18064

1.4 The choice of start year for the analysis determines how many sites can be included. This is because sites must operate throughout the entire analysis period and also achieve sufficient data capture. To maximise data availability while providing sufficient long-term context, the current analysis runs from 1st January 2016 to 19th December 2021.

1.5 It should be noted that the raw data have not been carefully quality controlled and there may be some isolated instances of erroneous reported measurements. However, the large number of sites included, particularly at roadsides, means that the multi-site averages presented are likely to be representative.

2 Methodology

2.1 The methodology has been set out in previous reports[1,2,3]. This section serves as an update and is not exhaustive. Openair software[5] has been used to download all measured NOx and NO_2 data recorded between 1st Jan 2016 and 19th December 2021 from the UK Automatic Urban and Rural Network (AURN), Scottish Air Quality Network (SAQN), Welsh Air Quality Network (WAQN) and Air Quality England network. It should be noted that recent measurements are unratified and so still subject to change, however, since this analysis includes a large number of sites, any changes would be extremely unlikely to affect the overall findings. A small number of unratified measurements (<0.01% of dataset) have been removed by hand where they appeared to be plainly erroneous.

2.2 Duplicate sites (for example those that exist in more than one of the networks) have been removed, as have all sites which did not meet the data capture threshold of 90% (across the whole time period presented). The sites selected in this analysis therefore differ slightly from those selected in previous reports; the time period has been extended and so the ability of each site to meet the data capture thresholds has changed. The number of stations per site group is summarised in Table 1. Each monitoring station has been linked with the closest meteorological observation site which satisfied the same data capture criteria.

Table 1 Number of sites used within analysis summarised by site type

Site Group	Number of Sites
Roadside	135
Industrial	14
Urban	57
Rural	13

2.3 Meteorological effects have been removed by building statistical models to account for their influences on pollutant concentrations. Hourly measurements of wind speed, wind direction, temperature, and relative humidity have been paired with concurrent hourly measurements of NOx and NO_2 concentrations. A boosted regression tree (BRT) approach[6] has then been used to build statistical models of the input measured data that take account of the many complex interactions between variables, as well as non-linear relationships between the variables.

2.4 The statistical models have been built from the measured air quality and meteorology data between 2016 and 2021 (inclusive). These models have been used to predict concentrations during the entire time period in the absence of the identified meteorological influences. The predicted concentrations have been grouped by measurement site type and averaged to give monthly-mean concentrations.

5 Carslaw, D.C. and Ropkins, K. (2012) 'openair - An R package for air quality data analysis', Environmental Modelling & Software, vol. 27-28, pp. 52-61.

6 Carslaw, D.C. and P.J. Taylor (2009). Analysis of air pollution data at a mixed source location using boosted regression trees. Atmospheric Environment. Vol. 43, pp. 3563–3570.

2.5 Traffic-related pollutant concentrations typically exhibit strong diurnal, weekly and, to a lesser extent, annual profiles. In AQC's previous analyses of the effect of COVID-19 on concentrations during 2020, statistical models were used to remove the predicted effects of hour of day, day of week, and week of year. This was necessary in order to compare concentrations measured immediately before and immediately after the imposition of restrictions. In the current analysis, and consistent with the previous long-term trend analysis[1], only meteorological variables have been accounted for in the statistical analysis.

2.6 The UK Department for Transport (DfT) has published data on changes to traffic flows during the pandemic[7]. DfT summarises these from 275 Automatic Traffic Count (AQC) sites across Great Britain, indexed to flows in the first week of February 2020. Approximately 100 of the ATCs are on minor roads ('B' and 'C' class and unclassified), with the remainder being on 'A' roads and motorways. By contrast, most of the roadside air quality monitors used in this analysis are in urban areas. Analyses by DfT have shown the sensitivity of its benchmarking statistics to site selection[8] and the DfT's COVID traffic index will not perfectly represent the most common settings of the air quality monitors. The national traffic index is nevertheless helpful to the interpretation of concentration trends during the pandemic and is thus summarised in this report.

7 Department for Transport (2021) Domestic transport use by mode: Great Britain, since 1 March 2020. Available: https://www.gov.uk/government/statistics/transport-use-during-the-coronavirus-covid-19-pandemic

8 e.g. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916033/2019-minor-road-benchmarking-methodology-report.pdf

3 Results

Traffic Volumes

3.1 Figure 1 illustrates the DfT's index of changes to road vehicle activity between February 2020 and December 2021. As explained in Paragraph 2.6, these data summarise 275 sites across a range of UK road types and, while this average is unlikely to provide an ideal representation of the most common settings of the roadside air quality monitors (most likely being biased toward motorways and trunk roads when compared with the air quality network), it nevertheless provides helpful context.

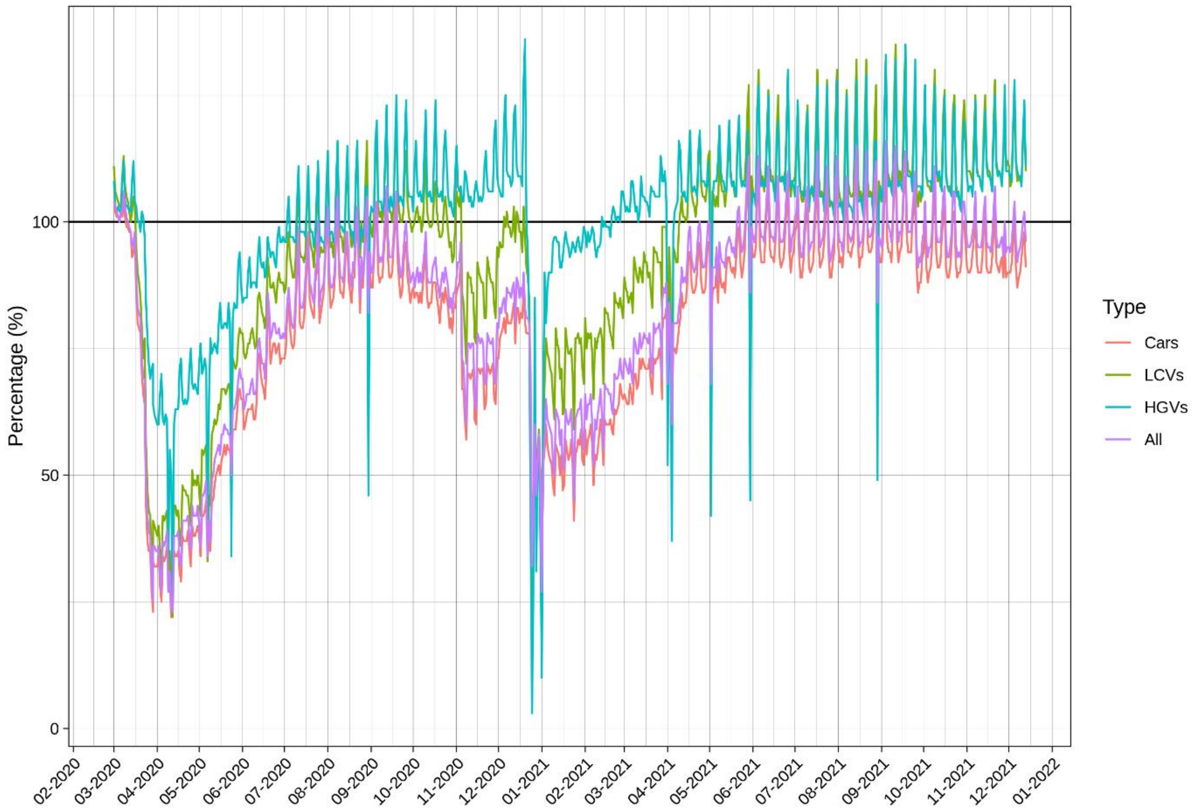

Figure 1 Motor vehicle flows expressed as a percentage of the equivalent day in the first week of February 2020[9]. Source: Department for Transport[7]

3.2 The impact of the first UK-wide lockdown in March 2020 is clear in Figure 1; car activity reduced by approximately 70%, while Heavy Goods Vehicle (HGV) activity reduced by a more modest 40%. By September 2020, vehicle flows in most categories had returned to close to those of February 2020, albeit that car volumes, and thus the overall total, remained slightly depressed.

9 No analysis is presented here regarding the suitability, or neutrality, of the February 2020 comparator used by DfT. Figure 1 simply summarises DfT's own analysis.

3.3 A second decline in traffic flows was evident in November 2020, which coincided with the second national lockdown[10]. The significant decrease in all vehicle classes in late December 2020 coincides with Christmas and New Year celebrations.

3.4 Since January 2021, traffic flows have increased steadily with all vehicle classes reaching or exceeding 100% of the measured flows in February 2020. Since June 2021, traffic volumes have remained relatively high, with flows of Light Commercial Vehicles (LCVs) and HGVs well above those in the first week of February[9].

NOx and NO_2 Concentrations

Roadside Sites

3.5 Figure 2 shows the average weather normalised NOx and NO_2 concentrations measured at 135 roadside monitors between 1st January 2016 and 19th December 2021. The pattern prior to 2020 has already been documented in AQC's January 2020 report[1,11]. Over this pre-2020 period there is a clear seasonal pattern, with peaks in the autumn/winter and troughs in the spring/summer. There is also a clear downward trend, with the multi-site average NO_2 concentration reducing from 45.8/31.1 µg/m^3 (max/min monthly mean) in 2016 to 37.3/27.0 µg/m^3 in 2019.

3.6 A sharp reduction in concentrations is clear during the first UK lockdown in March 2020. Concentrations during summer 2020 then remained substantially below those seen during previous years. Again, these two observations have been documented in some detail in previous AQC reports[2,3,4].

3.7 Concentrations during autumn/winter 2020 remained lower than those in previous years, but this should be recognised in the context of the long-term trend of steadily reducing roadside concentrations. As a visual aid, Figure 3 shows a simple linear extrapolation across the annual range in monthly mean NO_2 recorded prior to 2020. This provides context for the values measured in winter 2020, but it must be stressed that there is no strong reason to expect the approximately linear trend seen prior to 2020 to have continued since then without the pandemic[12]. Figure 3 nevertheless suggests that average roadside NO_2 concentrations during the winter of 2021 were only slightly lower than those which might reasonably have been expected without the pandemic. This is, to some degree, supported by the activity data in Figure 1, which shows generally lower volumes of cars, but generally higher volumes of HGVs than immediately prior to the pandemic.

10 Baker et al., (2021) Coronavirus: A history of English lockdown. Available: https://commonslibrary.parliament.uk/research-briefings/cbp-9068/

11 Data capture considerations mean that the precise set of monitors presented here is not identical to that used previously, resulting in small differences to the multi-site averages presented.

12 In practice, the rate of improvement may, without the pandemic, have accelerated owing to wider availability of the latest Euro 6 diesel cars and vans and the more rapid uptake of electric vehicles. It is not considered helpful to provide more precision than implied by Figure 3, since the underlying emissions projections are too uncertain in this context, and using past trends to predict precise future patterns is inappropriate.

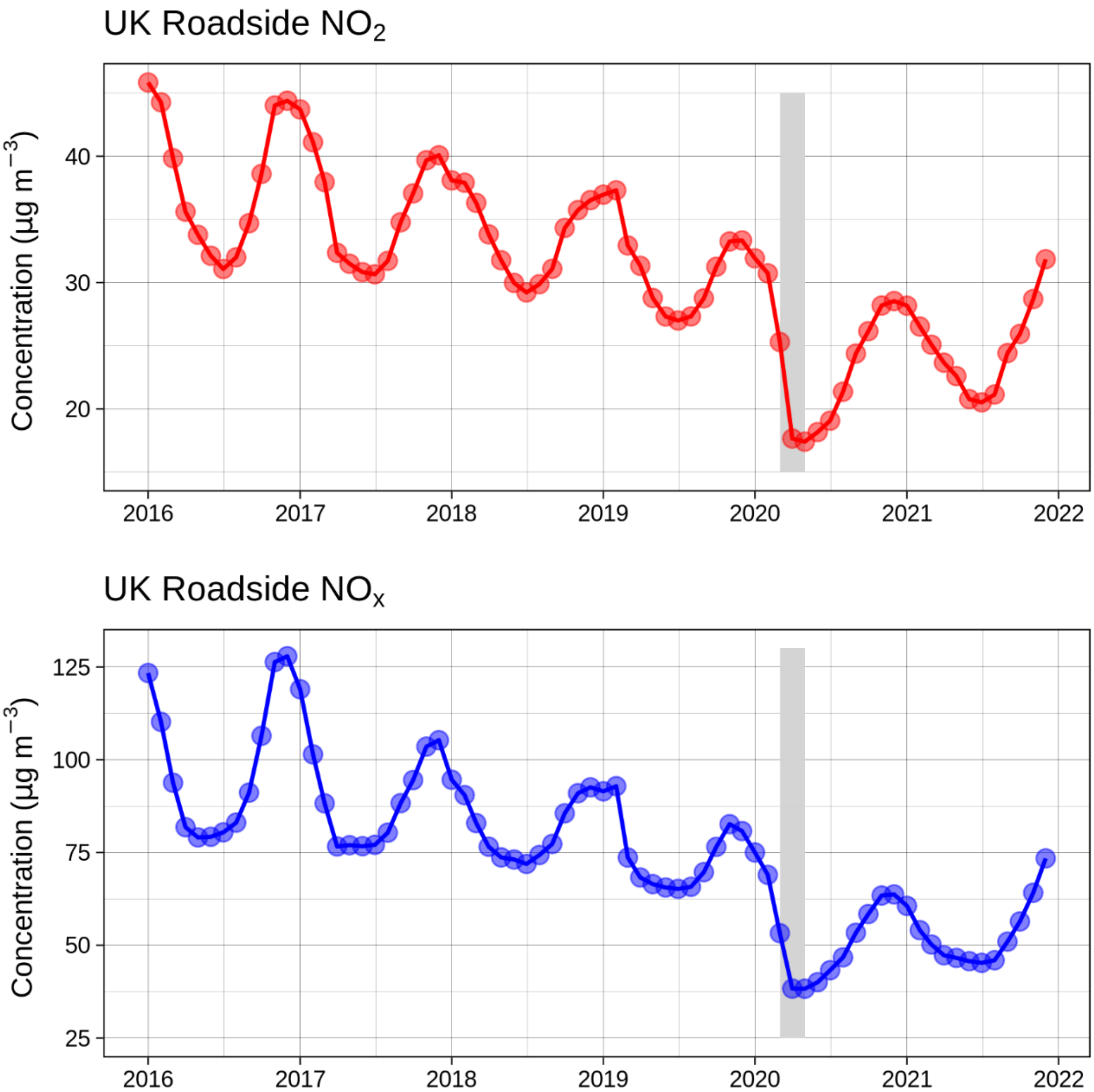

Figure 2 Average monthly mean BRT-adjusted NO_2 and NO_x concentrations measured between 1st January 2016 and 19th December 2021 at 135 roadside monitoring sites across the UK. Grey shading indicates the period March – May 2020 (inclusive) when the first UK-wide COVID-19 lockdown was enforced.

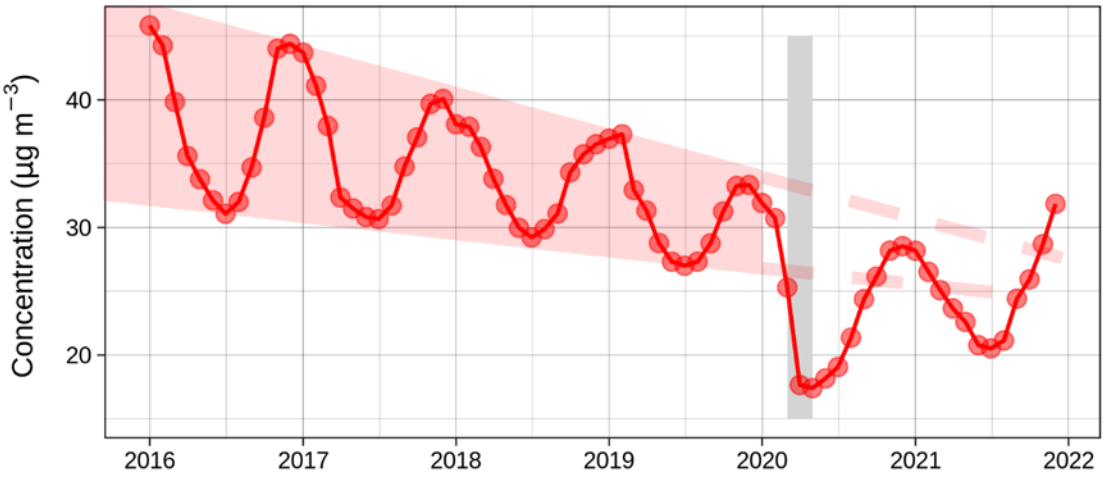

Figure 3 Visualisation of average monthly mean BRT-adjusted NO_2 concentrations at 135 roadside sites (from Figure 2) and approximate linear extrapolation of yearly range in pre-2020 monthly means (shaded area shows pre-2020 range, dashed lines show linear extrapolation).

3.8 It seems unlikely that the range (trough to peak) in monthly mean concentrations would, without the pandemic, have contracted by summer 2021 to the extent suggested by Figure 3. This highlights the limitation of this simple linear extrapolation. Nevertheless, comparing Figure 2 with Figure 1 suggests that traffic-related NOx and NO_2 concentrations during summer 2021 remained lower than would otherwise have been the case, albeit not to an appreciable degree.

3.9 The monthly mean values for December 2021 shown in Figure 2 and Figure 3 should be viewed with some caution since the monitoring period ended on the 19th December, and the remainder of December tends to be associated with less traffic activity, meaning that the complete deweathered monthly mean will likely be lower than that shown in these Figures. It is, nevertheless, clear that autumn/winter 2021 was characterised by a reversion to higher roadside concentrations. Again, this may be linked to the activity data in Figure 1. While average volumes of cars and HGVs in autumn 2021 were only marginally higher than those during the same period of 2020, Figure 1 suggests quite a large increase in LCVs when compared with 2020. The simple index provided by DfT is insufficient to analyse this in detail and further work is needed to understand if there has been a significant increase in LCV use and if this is linked to higher measured roadside concentrations.

Other Site Types

3.10 Deweathered measurements from the other site types are shown in Figure 4 to Figure 6. Patterns over time largely mirror those seen at roadside sites, albeit that, as noted in previous reports[2,3,4], the effects of reduced traffic volumes are less pronounced at urban, industrial, and rural sites. It should also be noted that there are fewer sites included in Figure 4 to Figure 6 than were available for Figure 2 for roadside sites and that, particularly in the case of the rural measurements, the smaller measured range makes the (rounded) source data less granular, reducing the ability of BRTs to remove weather effects. It is clear, however, that all site groupings are responding to the same overall patterns, albeit that non-roadside sites show a less immediate response to UK lockdowns.

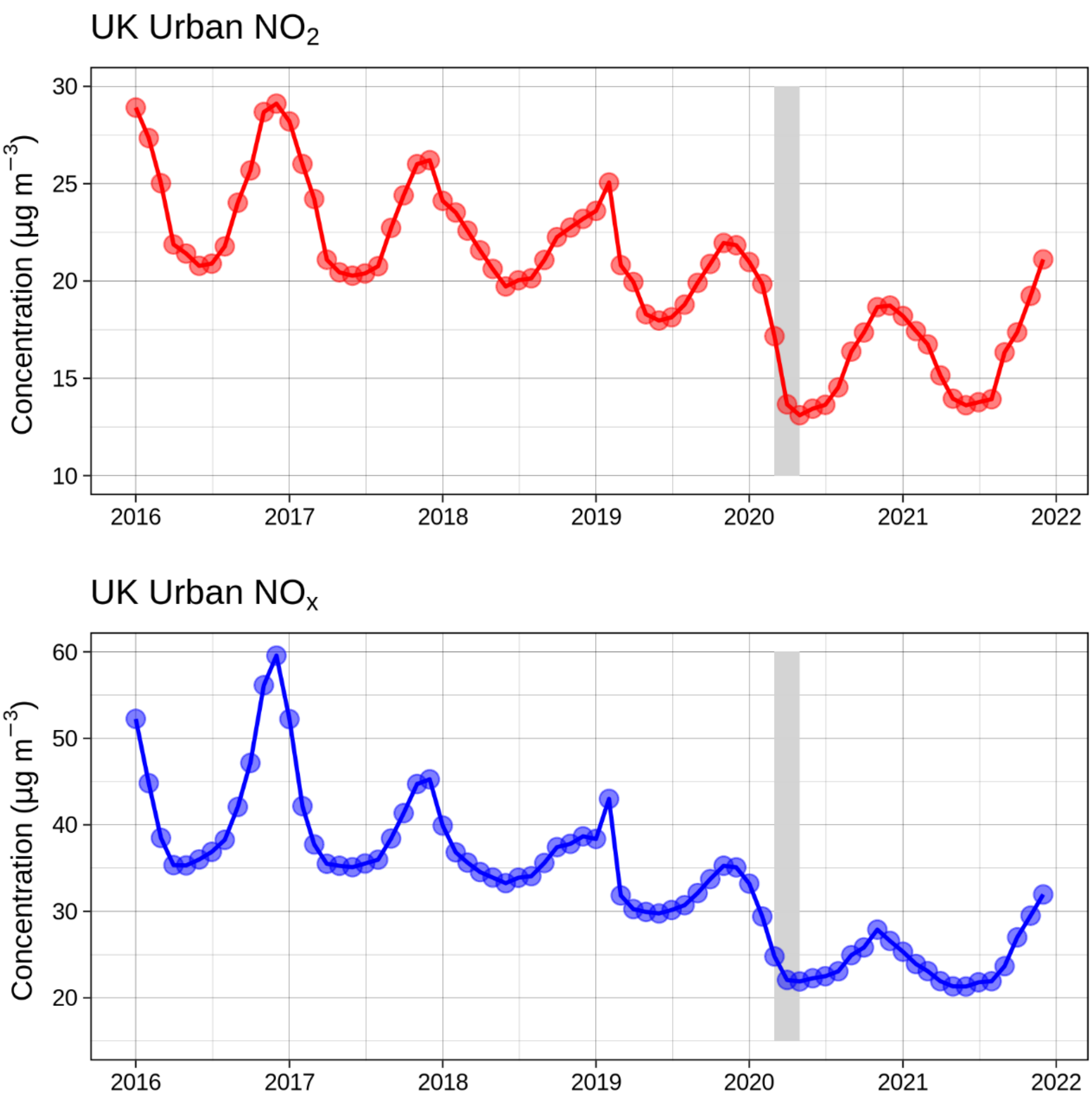

Figure 4 Average monthly mean BRT-adjusted NO_2 and NO_x concentrations measured between 1st January 2016 and 19th December 2021 at 57 urban monitoring sites across the UK. Grey shading indicates the period March – May 2020 (inclusive) when the first UK-wide COVID-19 lockdown was enforced.

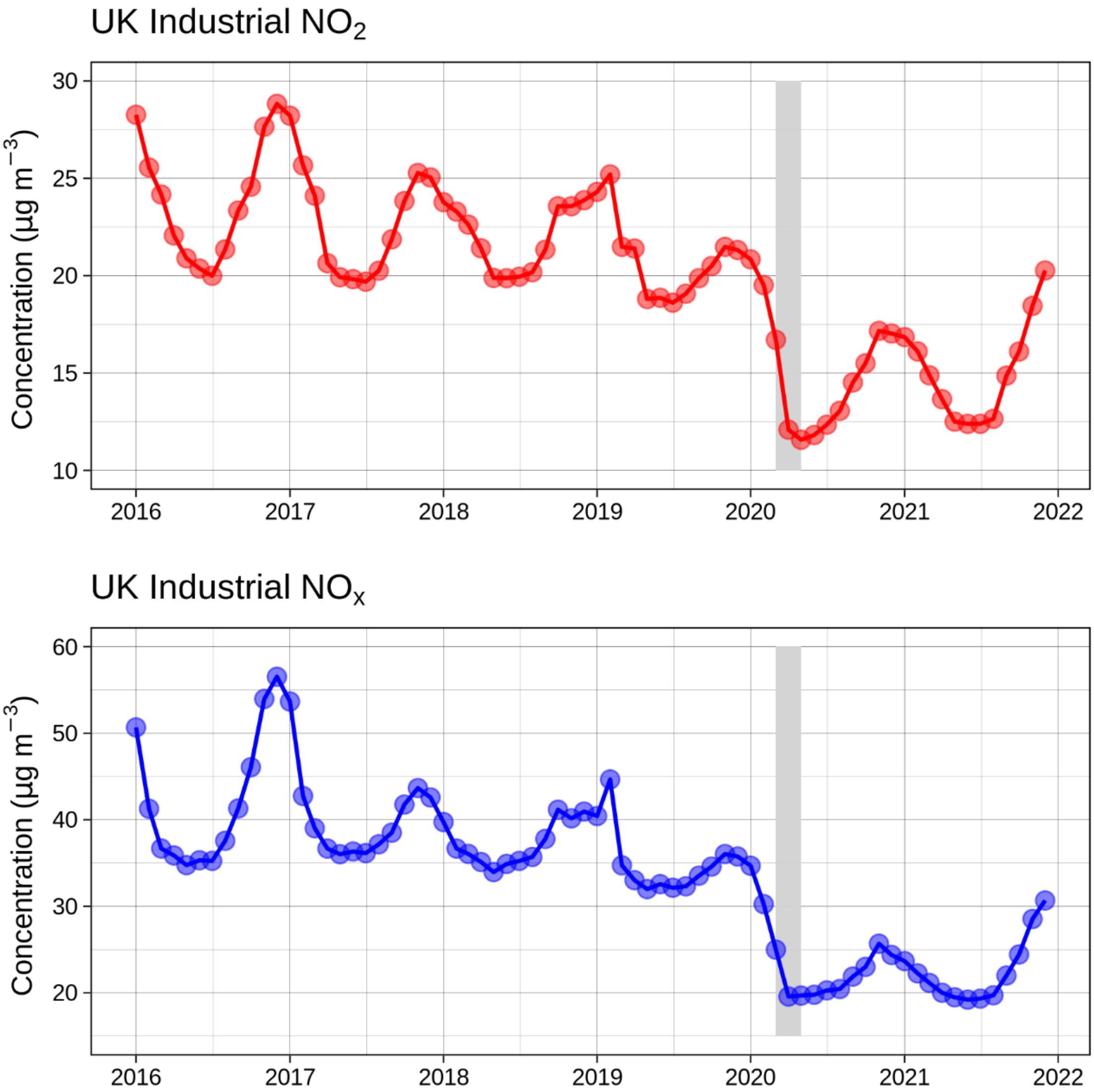

Figure 5 Average monthly mean BRT-adjusted NO_2 and NO_x concentrations measured between 1st January 2016 and 19th December 2021 at 14 industrial monitoring sites across the UK. Grey shading indicates the period March – May 2020 (inclusive) when the first UK-wide COVID-19 lockdown was enforced.

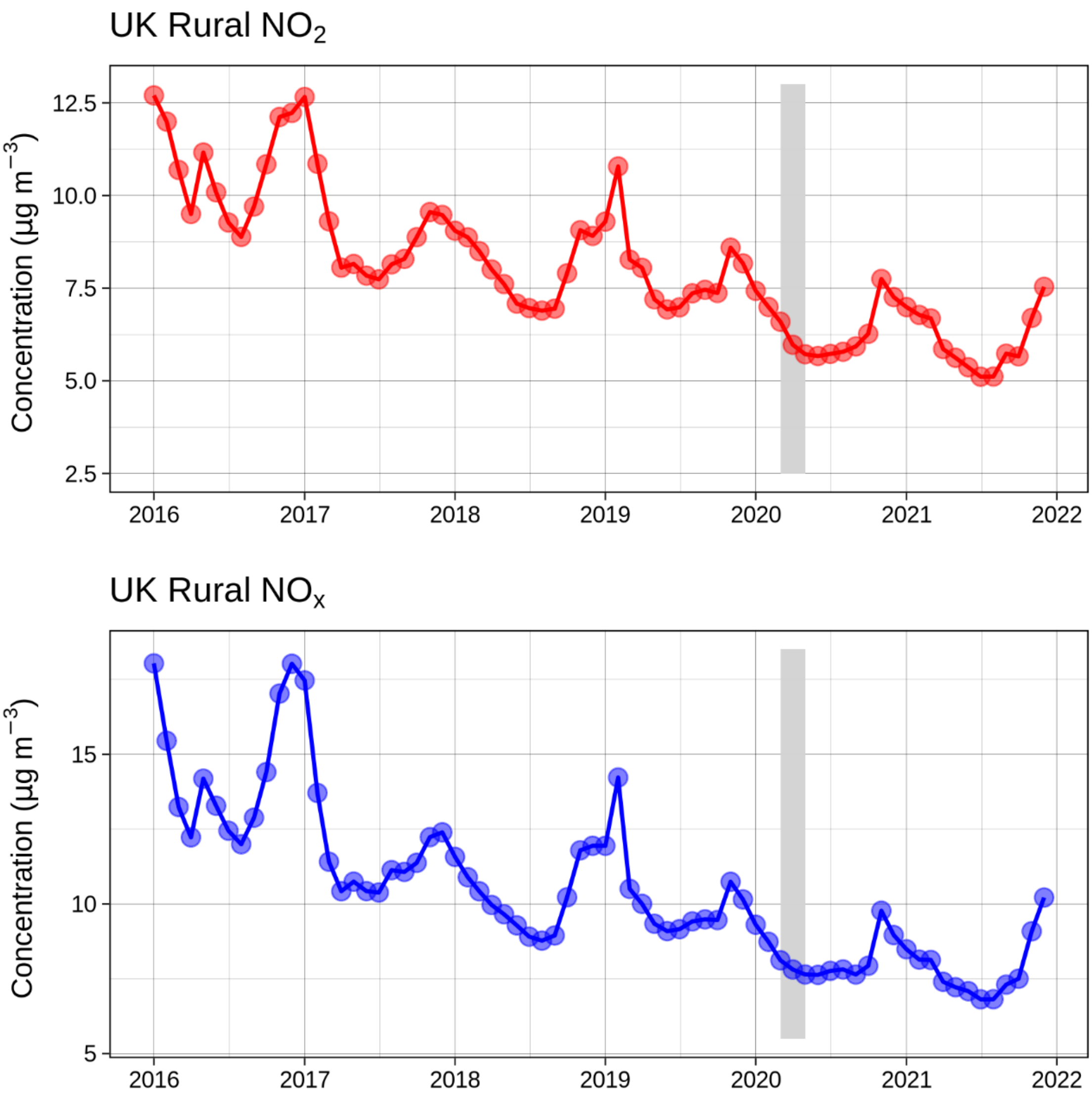

Figure 6 Average monthly mean BRT-adjusted NO_2 and NO_x concentrations measured between 1st January 2016 and 19th December 2021 at 13 rural monitoring sites across the UK. Grey shading indicates the period March – May 2020 (inclusive) when the first UK-wide COVID-19 lockdown was enforced.

4 Conclusions

4.1 Weather-normalised concentrations of NOx and NO_2, averaged across the main networked UK monitoring sites, showed a steady decline between January 2016 and February 2020 at all site types. In March 2020, disruptions caused by the COVID-19 pandemic further reduced concentrations, with the largest improvements at roadsides. Concentrations remained depressed throughout the summer of 2020, likely reflecting the effect of the pandemic on average traffic volumes. Since autumn 2020, there have been various periods when average traffic flows, as indexed by DfT, either matched or exceeded those seen prior to the pandemic, particularly for goods vehicles (both HDVs and LCVs). Despite this, roadside NOx and NO_2 concentrations have remained well below pre-pandemic levels. This is most likely because of longer-term changes to emissions, including turnover of the vehicle fleet, which have continued during the pandemic. Although the average NOx and NO_2 concentrations measured since autumn 2020 appear relatively low in a historic context, it nevertheless seems unlikely that these levels will be exceeded in the near future regardless of the resumption, or otherwise, of historic travel patterns.

4.2 These observations relate to weather-normalised concentrations averaged across a large number of monitoring sites. Previous studies have highlighted that a downward trend on average does not mean that there has been an improvement at every location[13].

4.3 The most recent period of monitoring (autumn/winter 2021) is associated with elevated NOx and NO_2 concentrations. It has also been noted that volumes of LCVs recorded by DfT have been higher over recent months than at any other time during the pandemic (or, based on the DfT's index, before it). It will be informative to revisit this analysis in subsequent months.

[13] Laxen, D., Gellatly, R., Richardson, T., and Marner B. Nitrogen Dioxide and Nitrogen Oxides Trends in the UK 2005 to 2018, Available: https://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=feb92332-26f7-4989-b86a-21e5732a5404