Investigating the effect of the ULEZ on NOx concentrations in Central London

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BRIEFS. Exploring whether government restrictions on the use of vehicles that emit high concentrations of air pollutants such as nitrogen oxides has dramatically improved the air quality in Central London.

ABSTRACT. The Ultra Low Emission Zone (ULEZ) was introduced in Central London in April 2019 and expanded to include all London boroughs in August 2023, with the intention of reducing nitrogen dioxide and particulate matter emissions from road transport in Greater London. Nitrogen oxides (NOx) are primary pollutants emitted as byproducts during the combustion of fuel in vehicle engines. This study aims to assess how effective ULEZ has been at reducing concentrations of nitrogen oxides as nitrogen dioxides (NOx) in the air, using public NOx concentration data from the U.K.'s Air Quality Archive at the London Marylebone Road site comparing the years directly before and after the ULEZ scheme was initially introduced in London. Mean diurnal and seasonal variation in NOx concentration between April 2019 and April 2020, after the implementation of the ULEZ scheme, was approximately 25% lower than between April 2018 and April 2019, before the ULEZ.

INTRODUCTION.

Air pollution, including nitrogen oxides (NOx), contributes to the premature death of around 4.2 million people annually [1,2]. Nitrogen impurities react with oxygen through the Zeldovich mechanism (Equations 1 and 2), which describes the oxidation of atmospheric nitrogen due to the high temperature and pressure within the combustion engine.

$$O + N_2 \rightarrow NO + N \quad (1)$$

$$N + O_2 \rightarrow NO + N \quad (2)$$

NOx's are interchanged rapidly in sunlight which turns a low NOx atmosphere that reduces surface ozone, into one that produces surface ozone, therefore increasing the greenhouse gas concentration in the troposphere, and leading to further global warming. The Air Quality Standards Regulations 2010 [3] states that the annual mean concentration of NO_2 must not exceed 40μg/m^3, and that there should be fewer than 18 exceedances of the hourly mean limit value (concentrations greater than 200μg/m^3) within a single year. We aimed to test whether the introduction of the Ultra Low Emission Zone (ULEZ) scheme helped to reduce the concentration of nitrogen oxides, specifically as nitrogen dioxide in the atmosphere, thus helping with efforts to comply with the government requirements.

MATERIALS AND METHODS.

The concentration of these nitrogen oxide gases were measured by determining the light produced when reacting NO with ozone to convert it into NO_2 (Equations 3 and 4). When NO reacts with ozone, NO_2 is produced which releases a photon of light to become stable; NO_2 is a brown coloured gas whilst NO is colourless. The NOx mixture would now be made up of only NO_2, which can be converted back to NO by passing the mixture over a heated catalytic converter. Due to the amount of NO_2 present in the original mixture, there is an increase in light observed, so the concentrations of NO and NO_2 can be determined by spectroscopy.

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (3)$$

$$NO_2 + \text{heat} + \text{catalyst} \rightarrow NO + O \quad (4)$$

The Air Quality Archive in the UK used this method of spectroscopy to determine the concentrations of nitrogen oxides as nitrogen dioxide from many locations across the UK, including the City of Westminster London Marylebone Road site. Data from this site for the time periods ranging from 08/04/2018 to 08/04/2019 (before the ULEZ implemented), and from 09/04/2019 to 09/04/2020 (after ULEZ), was used because the ULEZ scheme was officially implemented on the 8 April 2019 across Central London. More recent data during the covid lockdown was excluded as this would have been anomalous. Using the Microsoft Excel software programme, the hourly mean NOx concentrations was analysed on a month-by-month basis across the selected time periods.

Seasonal trends.

The data was then sorted into 12 months by season (March 1st to May 31st for spring, June 1st to August 31st for summer, September 1st to November 30th for autumn/fall and December 1st to February 28th for winter) for each of the two time periods (before and after ULEZ). Seasonal mean variation of hourly NOx concentrations for the four seasons was calculated.

The data was also analysed by splitting it into four groups (BST-season and GMT-season, before and after ULEZ implementation) based on the UK time changes between British Summer Time (BST) and Greenwich Mean Time (GMT). This enabled graphs to be produced of the mean variation in hourly NOx concentrations over these two 6-monthly periods, before and after the ULEZ was implemented.

RESULTS.

The data for the first year after the ULEZ plan was executed follows a similar diurnal and annual trend to the data for the year before the ULEZ scheme was implemented, but at reduced concentrations. Between April 2018 and April 2019 (before ULEZ), NOx concentration diurnally stayed within the 100 – 400 μg/m^3 range. Between April 2019 and April 2020 (after ULEZ), the range of NOx concentrations decreased to between 50 – 350 μg/m^3. In both time periods, generally the mean GMT-season variation of NOx concentrations in higher than the mean BST-season variation of NOx concentrations (Figures 1a and 1b).

Figures 2a and 2b show that generally there is a smaller standard deviation between the seasonal mean diurnal variation before ULEZ (2018-2019) compared with after ULEZ (2019-2020). Both before and after the introduction of the ULEZ scheme, there were wide fluctuations in NOx concentration throughout a 24hr day (Figures 3a and 3b). The concentration of NOx increases between 04:00 and 18:00, reaching a maximum at approximately 12:00, then decreases, reaching a minimum level at approximately 02:00. This is because NO_2 is broken down in sunlight to produce NO, so the concentration of NOx increases during daylight hours and decreases during the night.

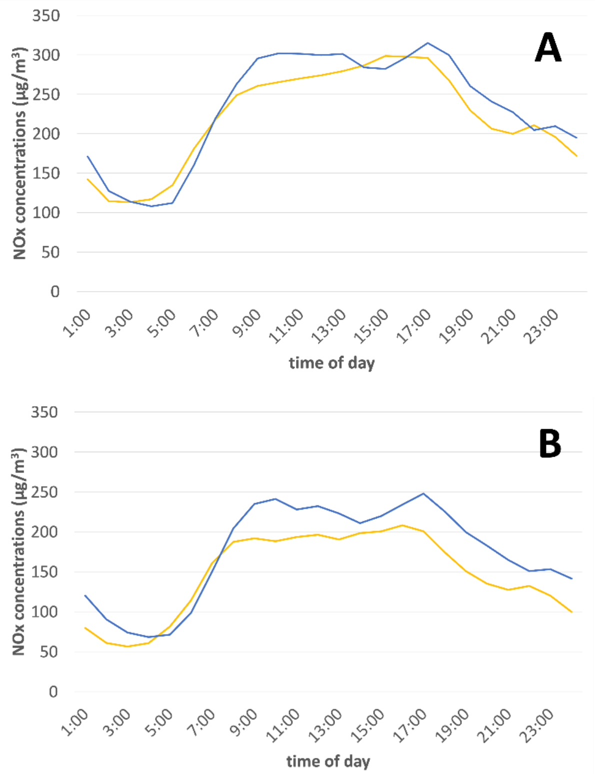

Figure 1. Mean variation of NOx concentration in London Marylebone Road before ULEZ (A) and after ULEZ (B) during the BST-season (yellow line) and GMT-season (blue line)

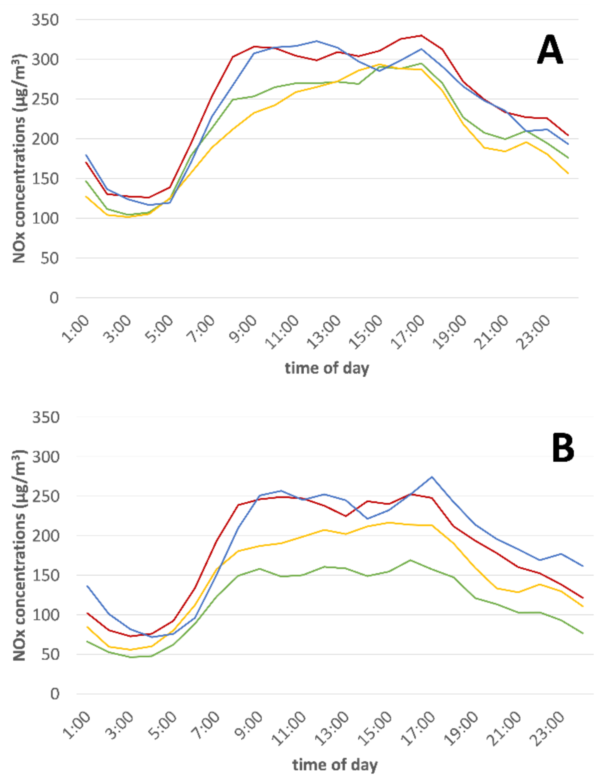

Figure 2. The diurnal mean variation of NOx concentration in London Marylebone Road before ULEZ (A) and after ULEZ (B) by season (spring – green line, summer – yellow line, autumn/fall – red line, winter – blue line)

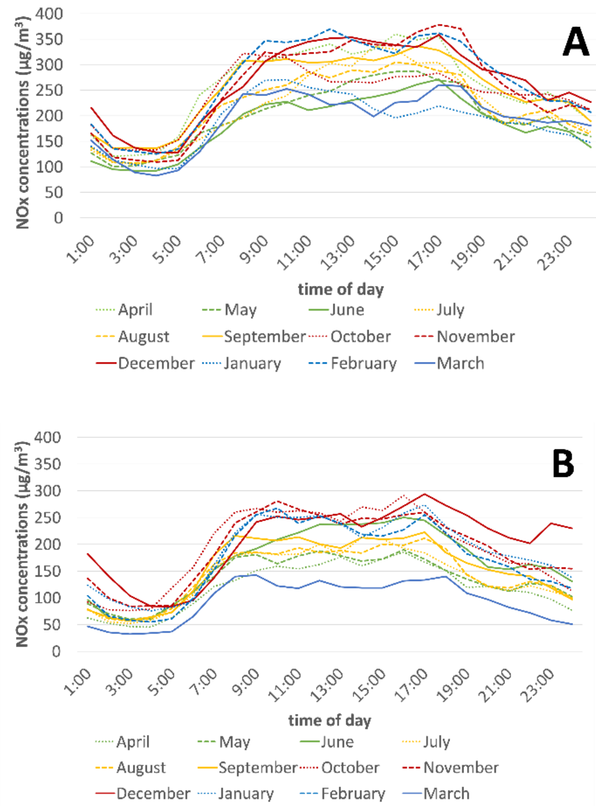

Figure 3. The mean diurnal variation of NOx concentration in London Marylebone Road, based on monthly hourly data before ULEZ (A) and after ULEZ (B)

DISCUSSION.

It was hypothesized that there would be a decrease in the mean NOx concentrations after the ULEZ was implemented as less people would drive high-polluting vehicles into Central London due to a reluctance to pay daily charges, especially disincentivising drivers of older vehicles with higher pollutant emissions [4]. Figures 1a, 2a and 3a show the NOx concentrations before the ULEZ are drastically higher than they are after ULEZ was implemented (Figures 1b, 2b and 3b). This suggests that the ULEZ has been successful in reducing the overall NOx concentrations over Central London.

In a diurnal cycle, there are two peaks in mean NOx concentration, occurring at roughly 9am and 5pm, which coincide with the periods of peak congestion. However, the minimum mean NOx concentration is only reached at 4am, meaning that concentration decreases at a slow rate, taking approximately 11 hours. This slow decrease suggests that overall, NOx follows an upward trend because pre-existing NOx is unable to be broken down quicker than the rate at which additional NOx is created.

Confounding variables that affect NOx concentration include wind speed [5,6] and humidity [7]. Lower wind speeds cause stagnation of air pollutants, resulting in decreased dispersion and an accumulation of NOx in the local environment [8]. Higher air humidity results in lower NOx emissions as the presence of water vapour in vehicle engines reduces the effective temperature during combustion [9]. There tends to be higher wind speeds and lower air humidity in the GMT months compared with BST months. However, in Figure 1, the NOx concentration of BST is lower than that of GMT. Other studies have also shown that higher NOx concentrations are associated with lower ambient temperature [10,11], which is also reflected in this study (data not shown). As shown in Figure 2, NOx emissions are higher in autumn/winter months compared with spring/summer. This could be linked to the colder temperatures causing more people to drive rather than walk, therefore more cars are on the road and NOx emissions increase. Overall, a combination of these factors may have resulted in the trends shown in the figures.

In conclusion, ULEZ has been effective in decreasing the air pollution in Central London. Furthermore, this could be helpful in reducing the health problems caused by pollutive chemicals among the Central London population in the long-term. Comparing peak values would provide more information about the impact of NOx on health, in accordance with the WHO 2021 Air Quality guidelines of less than 10 $\mu g/m^3$ of NO_2 [12] for an annual exposure period. However, our research findings indicate that ULEZ is helpful in reducing NOx emissions in a small area but does not cover a large enough area to have a national impact. In the 2021 governmental annual air quality assessment, at a number of roadside urban locations, the UK was still non-compliant with the limit value placed on the annual mean NO_2 concentration [13]. To improve the effectiveness of the ULEZ in hitting the government targets, it would need to be a more widespread scheme nationally. Further research to investigate a wider date range and comparisons with additional urban traffic locations would improve the reliability of these findings. It would also be valuable to undertake a follow-up study in a few years to determine how effective the expanded ULEZ has been, in comparison with both the initial plan suggested by the British government, and the 2030 Target reduction from 2005 levels [14].

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