A Comparative study of changes in NO_2 levels in Oxford due to electification

Supervisors: Antonin Knizek and Don Grainger
Candidate number: 1074052
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Abstract

In February 2025, the BBC released an article on Oxford being "at the forefront of electrification" after the launch of new electric buses [1]. This followed from a report showing that road-side nitrogen dioxide emissions had dropped from 40% to 32% in Oxford from 2024 to 2025. The city council claims that "Air quality has improved in Oxford in recent years, with an 18% average reduction of annual mean NO_2 across the city between 2021 and 2023". This study has found that ground-based measurements show a decrease in NO_2 levels by 39.8% and the Tropospheric Monitoring Instrument (TROPOMI), aboard the Sentinel 5-P satellite, measurements by 14.9% over Oxford from 2018 to 2025.

1 Introduction

The Oxford Source Apportionment study found NO_2 to be the pollutant of most concern in Oxford. For this pollutant, the city has been designated to be an Air Quality Management Area (AQMA) since 2010 [2], which sets the requirement to form an Air Quality Action Plan within 12-18 months to tackle the pollution levels. The legal limit set by the government is 40 $\mu g/m^3$ which Oxford obeys, while that set by WHO is 10 $\mu g/m^3$ which Oxford does not fulfil. The study also refers to the change in the level of particulate matter in Oxfordshire.

Nitrogen dioxide is emitted by high-temperature combustion processes like road transport and energy generation in urban areas. It is, for the most part, concentrated where it is emitted and has a lifetime of a few hours. The Air Quality Annual Status Report 2025 by the Oxford City Council claims that there has been a 12% reduction in NO_2 since 2021. These changes are attributed to the Zero Emission Bus Regional Area (ZEBRA) scheme which introduced 159 new electric buses in 2024 by the Council, leading to a 10% reduction in NO_2 levels in the year afterwards.

In a recent Oxford Mail report, it has been said that the shift in bus electrification has reduced noise pollution levels as well as air pollution. The Oxford Bus Company is to introduce a further 13 electric buses in 2026 [3].

This project aims to compare the different methods of measurement of NO_2, ground and satellite-based, to find the changes in its concentration over Oxford from the years 2018 to 2025. This is to contrast the efficacy of different methods of measurements and their comparison with the Council data to then account for future measurements with further reliability.

2 Theory

Nitrogen oxides impact atmospheric chemistry, air quality, and climate change. They are emitted into the atmosphere by both natural processes and human activity. Natural sources include lightning, microbial processes in soils, and naturally occurring wildfires. The dominant source of NO_x is fossil-fuel combustion from traffic, residential heating, cooking, and the industry and energy sectors. These sources are concentrated in cities and urban areas. In addition, biomass burning and the use of fertilizers are also significant sources of NO_x [4].

NO_x is defined by:

$$NO_x = NO + NO_2 \tag{1}$$

In the daytime, there is more NO_2 in the lower troposphere than in the upper troposphere, which is relatively dominated by NO. At nighttime, most of NO_2 does not photolyze, and thus, the atmosphere has a higher proportion of it.

NO_x are short lived in the atmosphere, with a lifetime of several hours in the boundary layer, the lowest part of the atmosphere directly affected by the Earth's surface upto a few kilometres, during daytime. This explains in part the high spatial and temporal variability observed for NO_2. Other factors leading to large concentration gradients in NO_2 are the heterogeneous distribution of sources and variations of meteorological parameters, such as wind speed, temperature, and illumination, which play key roles in determining the atmospheric lifetime and dilution of NO_2.

The average wind speed over the area considered is measured to be 3.82 m/s over the time period 2018 to 2025. With respect to TROPOMI, as it measures a column of air, this leads to horizontal and vertical mixing, measured using ERA5 (ECMWF reanalysis v5). Wind speed has an inverse relationship with NO_2 concentrations and as Oxford is located inland, leading to a moderate wind speed, it does not dominate its lifetime.

In 2024, the annual mean average was found to be 13.1 $\mu g/m^3$ while the annual roadside average was 20.7 $\mu g/m^3$ so we can see that the greater contribution comes from vehicular combustion [5]. It is also greater at these sites than urban background sites which denotes that local transport sources like buses have played a significant role. Road transport contributes to about 30% of NO_x pollutants, while some of the other contributors are fuel combustion in energy industries, industrial combustion and non-road transport.

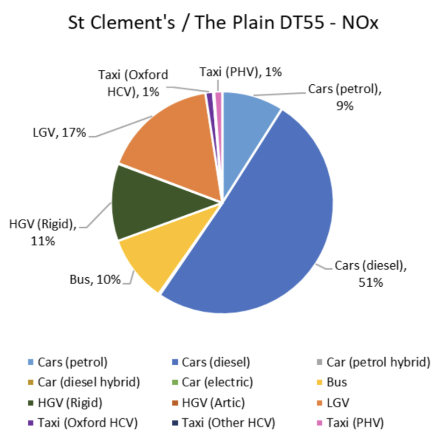


Figure 1: Pie chart representation of source apportionment for all road transport emissions on St Clement's / The Plain for the 2022 ZEBRA model

As seen in the figure above, a greater proportion of the NO_x pollution in road transport comes from cars, and 10% from buses.

3 Method

By plotting the results on Google Earth Engine to analyze both: TROPOMI and ground-based data, comparative results are obtained.

3.1 TROPOMI

TROPOMI (As seen in Figure 2) aboard the European Sentinel-5 Precursor satellite tracks and monitors climate and air quality globally. It provides data for detecting changes in the global atmosphere and is intended to support environmental science and policy-making. It takes 14 orbits around the Earth and has a single data point for Oxford each day at 1330 hours. Using Level 3 data, processed to be gridded onto the map with respect to latitude and longitude, the NO_2 levels over Oxford city centre have been plotted with a linearly fitted line. As an imaging spectrometer, TROPOMI measures the solar radiation that is backscattered by the Earth and the atmosphere. By differentiating between the wavelengths of this radiation and their absorption spectrum, it derives the concentration of various gases. Its spatial resolution is 3.5×5.5 km^2 [6]. Offline data has been used so as to obtain accurate, processed results per pixel of measurement, as opposed to Real Time data, which we would expect to give more immediate, unprocessed results.

Figure 2: Copernicus Sentinel 5-P [6]

Figure 3: Diffusion tubes (DEFRA UK Air)

The data was adjusted for distortion by clouds by considering intensity in areas less than 70% covered by clouds, using Google Earth Engine tools for Level 3 data. The instrument measures the radiance in a column of the troposphere, which is then processed to separate constituents and rendered in the units of moles per metre squared corresponding to specific locations on the grid.

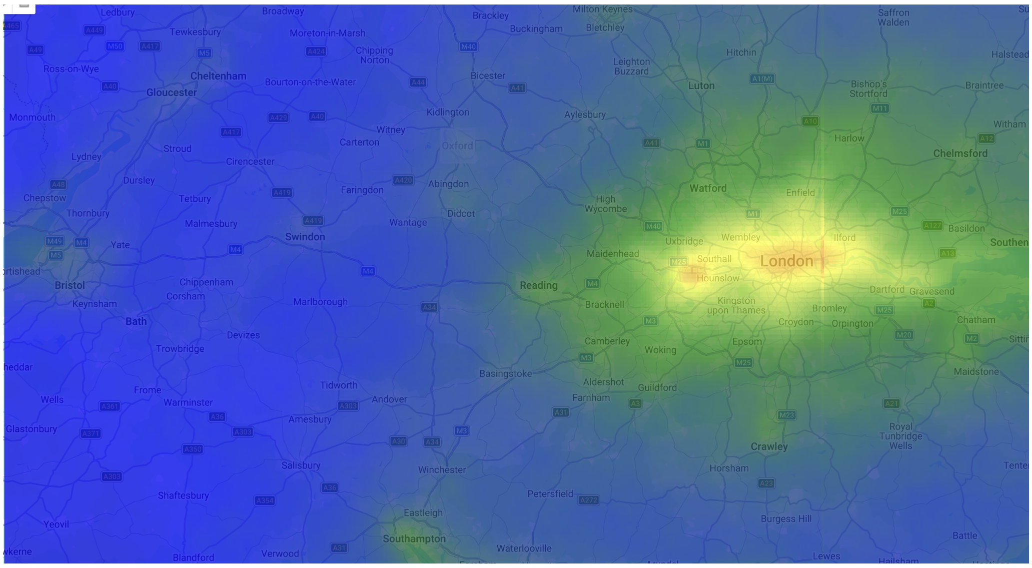
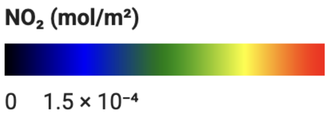


Figure 4: Heat Map of South England ranging from 0(black) to 150(red) µmol/m^2 of NO_2



The region around Heathrow airport and central London experience high levels of NO_2 pollution, taken as a cumulative average of the years from 2018 to 2025, as can be seen in the figure above. Compared to national averages, Oxford is a safe area.

3.2 Diffusion Tubes

Diffusion tubes (as seen in Figure 3) are installed in specific areas of Oxford to capture a volume of air, used as a method of pollution measurement by the City Council. These tubes are exposed for a month at a time before being changed and translating into annual means from processed data. NO_2 is collected on the walls of the tube which is subsequently recorded in micrograms per metre cubed.

OXON Air, which provides air quality monitoring services created by local councils, measures the following sites in Oxford for ground-based measurement for NO_2. Many of these are concentrated around city centre and busy roads.

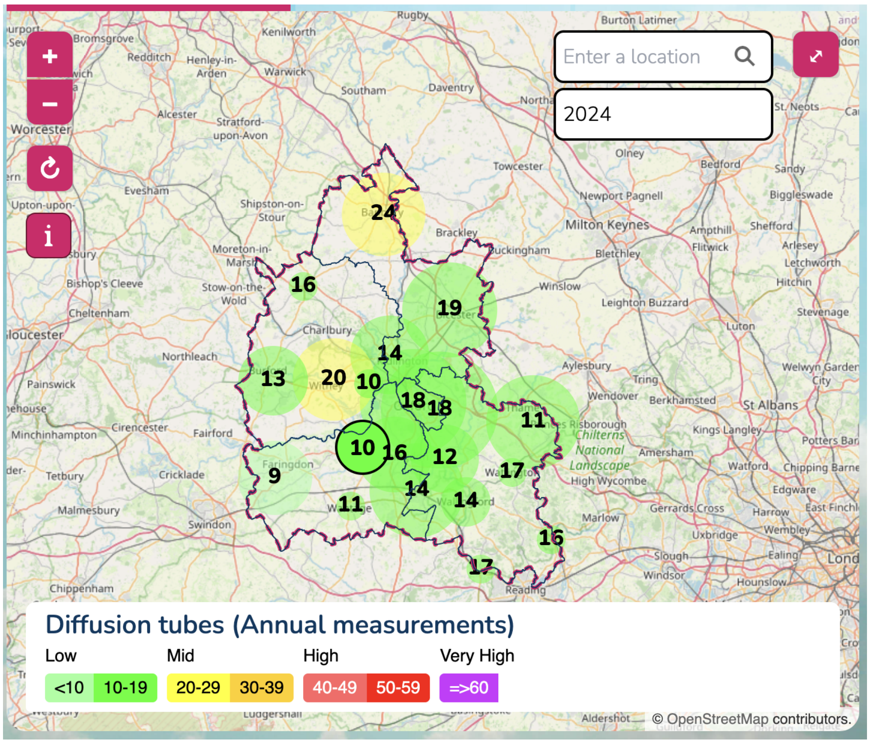


Figure 5: Locations of Diffusion Tubes

Figure 5 shows the locations of the various Diffusion Tubes around Oxfordshire and gives us an overview of the levels of pollution. The project uses the data from the areas under the management of Oxford City Council.

4 Results

4.1 TROPOMI

By plotting the daily mean of the levels of NO_2 in the Oxford area and aligning a line of best fit to it, the line is found to have a negative slope.

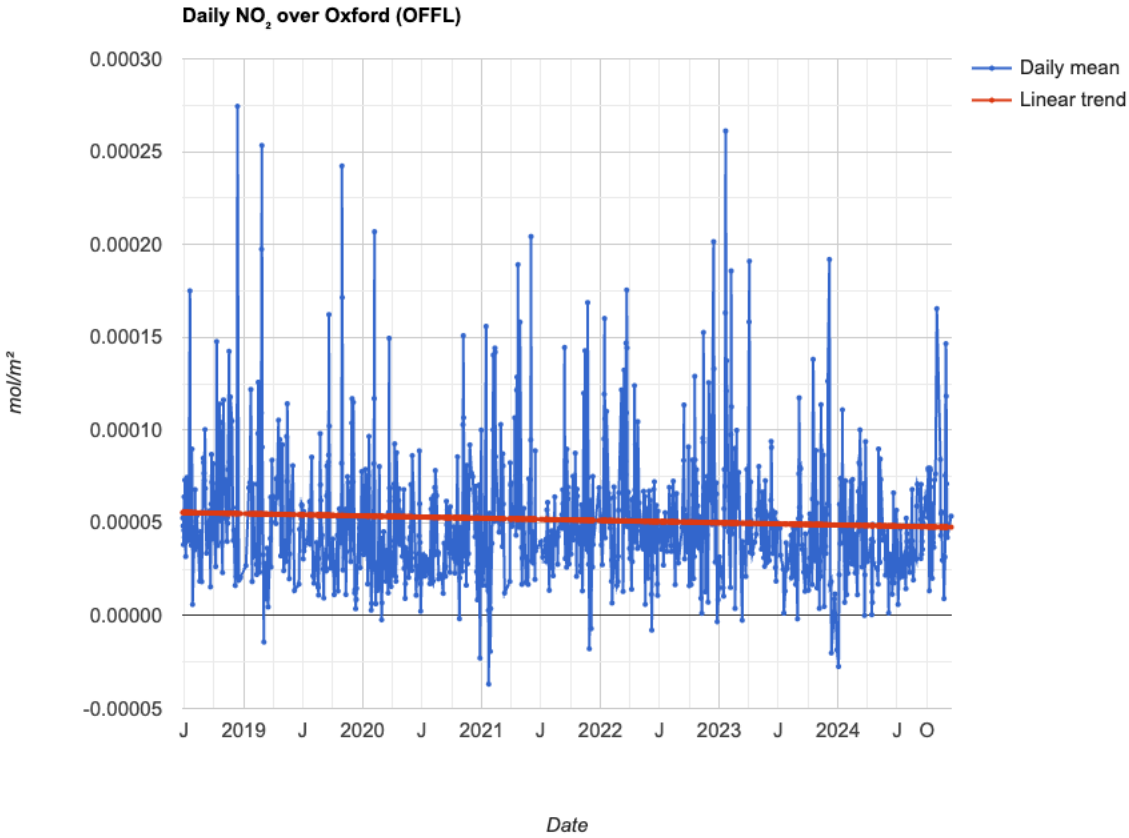


Figure 6: The change in NO_2 levels in Oxford from 2018 - 2025

This data represents measurements from an 8x8 km^2 sized square of Oxford on Google Earth Engine.

4.2 Diffusion Tubes

The average coefficient of variation for Diffusion Tubes is 5% and performed according to the LAQM TG22 (Local Air Quality Management Technical Guidance) [7].

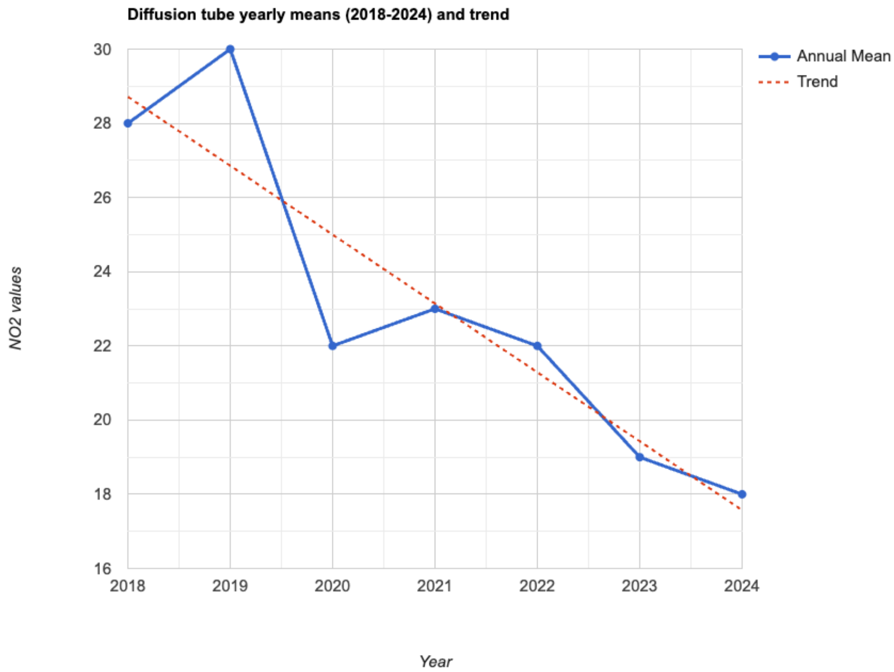


Figure 7: Ground based measurements

These measurements are plotted from the data sent by OXON Air with annual means calculated from the measurements of the monthly means of NO_2 levels. This covered 120 sites in Oxford.

4.3 Discussion

The change in NO_2 levels is seen to be 39.8% according to ground-based data and 14.9% according to TROPOMI, calculated by using the slope on the line of best fit for the data points.

The disparity in results from ground-based measurements and satellite data can be explained by the variation in the temporal and spatial resolutions of both measurement techniques. While TROPOMI captures a large area per pixel, its data point is limited to a unit measurement per day at the same hour. For diffusion tubes, as used by the council, the area is concentrated to the volume of a specific tube, but ranging in temporal resolution to average across all times, being exposed to their environment for a month before being changed.

TROPOMI measures the tropospheric column of NO_2, whereas diffusion tubes measure near-surface concentrations. Because NO_2 is short-lived and concentrated near emission sources, changes at the surface are not represented in a directly comparable manner to the column measurements. The retrieved column depends on the vertical distribution of NO_2, boundary-layer height, and assumptions within the retrieval algorithm, which can all vary in time.

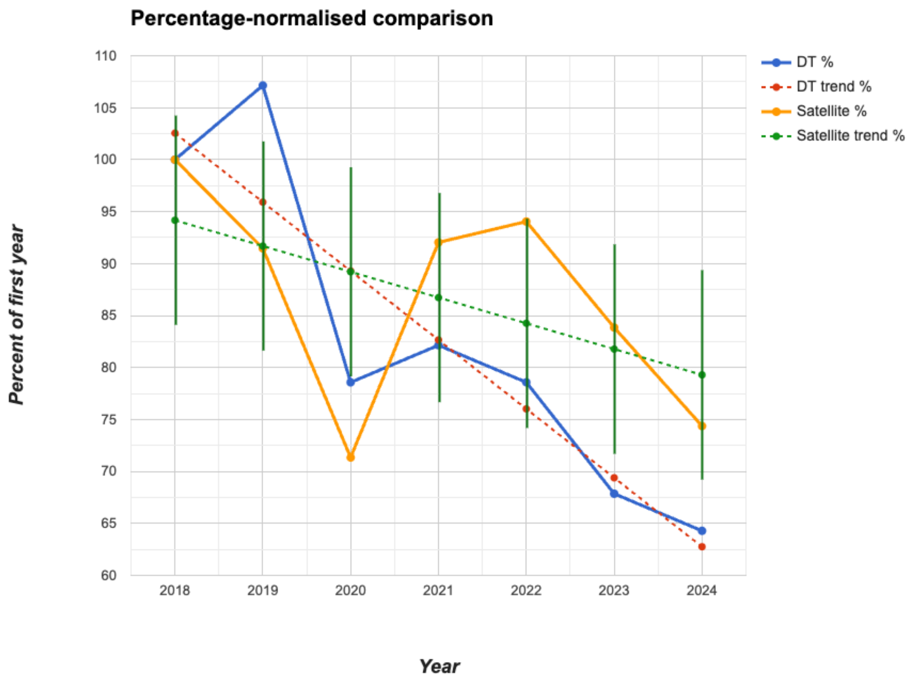


Figure 8: Comparison of ground-based and TROPOMI measurements

The figure above is a comparison of the normalised trends of ground and satellite data. The error on the TROPOMI data is calculated using the root mean square error. We notice large error bars for the satellite data due to its resolution and relative sensitivity to noise due to Oxford measurements being on the order of one pixel, while errors on the ground-based measurements are accounted for in the processing of OXON air data according to Council guidelines. The TROPOMI pixel represents an average over a large area, including cleaner surrounding regions, whereas diffusion tubes are often located at roadside or urban hotspot locations. This difference in spatial representativeness can lead to reduced apparent trends in the satellite data. In addition, TROPOMI provides a single measurement per day at 1330 hours GMT and only under relatively clear-sky conditions. This means it does not capture the full diurnal cycle of NO_2, particularly traffic-related peaks, and may introduce a sampling bias if cloud occurrence varies over time.

As we can see in Figure 8, there is a considerable dip in the year 2020, likely owing to Covid-19 and the lack of vehicular combustion in the dwindling of transport, and it has a strong influence on the regression model. When interconverting between the units, from micromoles per metre squared to micrograms per metre cubed for the two measurements, the raw values differ by a 100 order of magnitude, as these units are not directly comparable. This can be explained by the short lifetime of NO_2 and its concentration in the boundary layer which would render the right values if estimated to be a 100 metres.

5 Conclusion

The disparity in the results from ground-based measurements and satellite data is in part attributed to their optimisation in capturing, either, a vaster time or space respectively. The inherent differences in units of measurement allow an approximate comparison and the noise relative to one pixel of TROPOMI is relatively large.

Considering all of these factors, the effects of nitrogen dioxide pollution on people would be reliably explained by Diffusion Tubes located at densely populated areas and main roads that have experienced a change in transport systems, owing to electrification of buses amongst other factors. On the other hand, TROPOMI presents data on the general trends of the change in NO_2 levels of the troposphere, not accounting for diurnal variations.

6 References

[1] Kirsteen O'Sullivan. City 'at forefront' of electric buses initiative. BBC. (2025).
[2] Thomas Adams, Abigail Pepler, Jekabs Jursins, Anton Girard-Sequeira, Ella Wingard. Oxford Source Apportionment study. (2025).
[3] https://www.oxfordmail.co.uk/news/25969911.oxford-bus-company-adds-13-new-electric-buses-fleet/
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