UNIVERSITY OF CAMBRIDGE

Quantitative Environmental Sciences

Traffic and Air Pollution

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Traffic is a leading source of air pollution that has led to an increase in respiratory health concerns. This modified POSTnote will look at the trends in air pollution following the COVID-19 pandemic. It also looks at how the London Low Emission Zones affected local air quality and considers whether similar mitigation measures are necessary in Cambridge.

Overview

- One of the main sources of air pollution in urban areas is traffic and increases in congestion can be seen in many cities across the country.
- Traffic mitigation measures are being tested to see if they can reduce the number of vehicles on the road.
- In light of the 22nd of September 2021 revision of World Health Organisation guidelines, the United Kingdom has committed to reducing the annual mean concentration of $PM_{2.5}$ to 5 µg/m^3. [5]
- Air pollution directly links to multiple health issues including cancer and many respiratory illnesses.[6]
- New low-cost technology can be used to monitor the UK's progress in achieving its goals and to identify whether further intervention is needed.

Euro Emission standards for cars, g/km. [2]

Tier	Carbon Monoxide	NO_x	Particulate matter (PM)
III	0.66	0.5	0.05
IV	0.5	0.25	0.025
VI	0.5	0.08	0.0045

London Low Emission Zone (LEZ)

Implemented in 2008 by Transport for London (TfL), the LEZ covers most of Greater London. Targeted at heavy goods vehicles, the zone initially only applied to lorries over 12 tons, but was later expanded to include minibuses, ambulances, buses and coaches over a wider range of weights. These vehicles had to adhere to Euro III standards or pay a £100 charge per day they entered the zone. In 2012 the standards were raised to Euro IV, and in 2021 this was raised further to Euro VI. Alongside the raised standards, the charge for not adhering to the older Euro IV standard was increased to £300 in 2021. The zone is monitored through automatic number plate reading cameras and checked against the DVLA database.[3]

World Health Organisation (WHO) Mean Annual Pollutant Limits, µg/m³. [4]

Pollutant	NO_x	PM_{10}	$PM_{2.5}$
Limit	40	20	5

London Ultra Low Emission zone (ULEZ)

A £10 toxicity charge was implemented in Central London following poor air quality in early 2017. It was converted into the ULEZ in April 2019, one year ahead of schedule. Initially limited to the daytime congestion charge region, it was expanded in October 2021 to cover all Inner London within the North and South Circular roads.

Petrol and diesel vehicles had to adhere to Euro IV and VI standards respectively, or else pay £12.50 for each day the vehicle was used within the zone. Motorbikes must adhere to Euro III, while heavy goods vehicles are exempt as they are charged under the LEZ regulations. A month after introduction, the number of compliant vehicles increased from 87% to 92% and after 6 months, this reached 95%. The zone is due to be expanded across Greater London in August 2023. This is expected to remove an additional 20,000-40,000 high emission, non-compliant vehicles from London's roads.[7]

Cambridge Sustainable Travel Zone (CSTZ)

The proposed CSTZ would consist of a £5 daily charge for any vehicle travelling within the boundaries of the zone between 7am and 7pm on a weekday.[8] The proposed boundaries cover the majority of the area between the M11, A14, Cambridge Airport and Addenbrookes Hospital. Coaches and HGVs may have to pay more, and no exemptions or discounts will be in place for low emission vehicles.

Categories of atmospheric pollutants

- Particulate Matter (PM_{10} and $PM_{2.5}$)
- Gaseous (Carbon Monoxide, NO_x, SO_2, Ozone)
- Heavy Metals – generated by burning e-waste.
- Volatile (Non-Methane) Organic Compounds also known as VOCs – these include all short-lived organic compounds that are found in the atmosphere.

Particulate matter

Particulate matter (PM) is the category of atmospheric pollutant considered to be the most dangerous to health. The International Agency for Research on Cancer has declared PM as carcinogenic to humans, and it increases risk of cardiovascular and respiratory disease.[9,10] Within the category of particulate matter, three sub-categories exist: PM_{10}, $PM_{2.5}$ and $PM_{0.1}$, defined as particles that are less than 10, 2.5 and 0.1 microns in diameter respectively. These are colloquially referred to as coarse, fine and ultrafine particles. The finer particles are more hazardous to human health due to their ability to penetrate further into the lungs.[11,12] New evidence suggests $PM_{0.1}$ is even more dangerous, as it can cross into the bloodstream and travel throughout the entire human body. $PM_{2.5}$ was estimated to cost the UK health services £1.54 billion across 8 years, and causes 800,000 premature deaths per year.[9,10]

Gaseous Pollutants

The gaseous pollutant NO_x is a good indicator of traffic exhaust emissions. This is because 46% of NO_x emissions come from vehicles – predominantly from internal combustion engines.[13] NO_x predominantly affects the lungs, causing respirational diseases like emphysema and bronchitis, while also worsening pre-existing lung and heart conditions.[13] Other gaseous pollutants such as carbon monoxide and sulphur dioxide are more weakly correlated to traffic emissions and as such are less relevant here. Additionally, sharp declines in the practice of burning coal in households has resulted in sulphur dioxide levels falling, and hence they need not be considered further.[4]

Heavy Metals and VOCs

Heavy metals and VOCs are the least significant of the atmospheric pollutants, as their concentration in the atmosphere is much lower. Heavy metals mainly impact human health through bioaccumulation in food chains, caused by their deposition into soil.[14] Cadmium, lead and mercury are the three main heavy metal atmospheric pollutants. All three of these bioaccumulate into food, but mercury is the most dangerous of these three as it is a potent neurotoxin. Foetuses and very young children are most susceptible to mercury poisoning, normally occurring if mothers have a fish-heavy diet during pregnancy.[14] This is because atmospheric mercury is often dissolved into water and results in bioaccumulation in fish and other marine animals.

Volatile organic compounds (VOCs) similarly have concentrations much lower than that of particulate matter and gaseous pollutants. High exposure can result in breathlessness and wheezing, but not at the concentrations typically found in the atmosphere.[15]

Vehicular sources of particulate matter

There are multiple ways in which vehicles emit particulate matter - grouped into exhaust and non-exhaust emissions (NEEs). Exhaust emissions are limited to particles leaving through the exhaust, while non-exhaust emissions measure all other sources of particulate matter originating from the car. These non-exhaust emissions include tyre and road wear, brake pad degradation and particles from many other sources of friction between moving parts.[16]

The distinction between these two types of emissions is important because NEEs make up more than half the total vehicle particulate matter emissions and this is expected to rise as engines become more clean and efficient.[16] However, the Euro III-VI emission standards, on which the LEZ and ULEZ are based, are purely based on exhaust emissions.[17] This undermines the concept of emission standards, as most of the true emissions are being ignored.

Additionally, the Euro standards do not require the manufacturer to test the vehicle under everyday conditions. Instead, the manufacturer may improve aerodynamics by taping over the front grilles, disconnect the alternator to prevent the battery from charging or remove rear seats to lose weight.[18] This further reduces the accuracy of 'recorded' emissions, skewing them further from the true emissions of the vehicle under standard use conditions.

Data collection and site analysis

The data analysed in this POSTnote is taken from the Department for Environment, Food and Rural Affairs (DEFRA) Automatic Air Pollution Dataset. Specifically, the data is taken from the London Bloomsbury station monitoring inside Russel Square, which is within the boundaries of both the LEZ and ULEZ.

The site is located close to several busy two-lane roads which are subject to frequent congestion – the nearest of these is approximately 25 meters away from the monitoring station. DEFRA classes the environment type as 'Urban', meaning it is within a continuously built-up area (aside from city parks). It is also labelled as 'Background', meaning it is not significantly influenced by a single source or street, but rather the combination of all upwind sources. The other locations used in the spatial plot are traffic and background readings, where traffic readings are closer to the road and are more indicative of vehicle related emissions.

Data Analysis

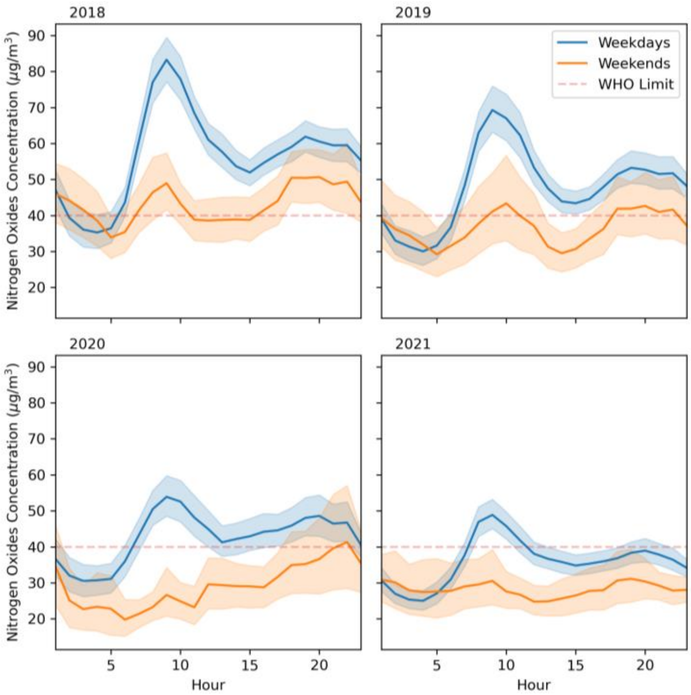


Figure 1: A plot of average NOx concentrations across the course of the day for weekends and weekdays. The shaded area represents the 95% confidence interval.

Figure 1 shows that there is a clear pattern of air quality across the course of the day. NO_x has a half-life of around 1 hour, and therefore is a good tracer to look at short term changes in concentration. NO_x concentrations are affected by the planetary boundary layer (PBL), which is the section of the atmosphere that is constantly mixed, the height of which varies throughout the day. Pollutant concentrations are normally lowest at around 4am, as the PBL is low and there are not many vehicles on the road to release emissions.[19] At 9am, during rush hour, while the PBL is still low, the number of vehicles on the road is high. This results in the highest NO_x concentrations, which drop as the PBL rises through the course of the day, increasing the volume through which the NO_x can mix, hence decreasing the concentration. A second peak is visible around 7pm, caused by the evening rush hour. The concentration then drops after sunset, as the residual layer of polluted air does not mix well with the new PBL that forms at sunset. Therefore, the concentration of pollutants remains low throughout the night until the number of vehicles increases in the morning.[19]

Although not plotted, similar trends are visible for all other major traffic related pollutants, especially $PM_{2.5}$ and PM_{10}. Weekends have noticeably lower values than weekdays, which is to be expected due to the lack of commuters contributing to the volume of traffic on those days.[20] The trend along the years shows that the air quality has been gradually improving. Notably, in the year prior to the ULEZ implementation the mean NO_x concentrations regularly reached 90 μg/m³, while values following the implementation rarely peaked above 60 μg/m³, a 33% decrease.

The weekday and weekend concentrations reduced significantly during the COVID-19 lockdown. The 2021 levels were confidently below the WHO limits for the entire day, due to a significant reduction in traffic volume as a result of the lockdowns.[20] The strong influence of traffic on NO_x concentrations seen in Figure 1 supports existing evidence of a strong relationship between the two, so a reduction in traffic volume will correlates with a decrease in NO_x concentration.

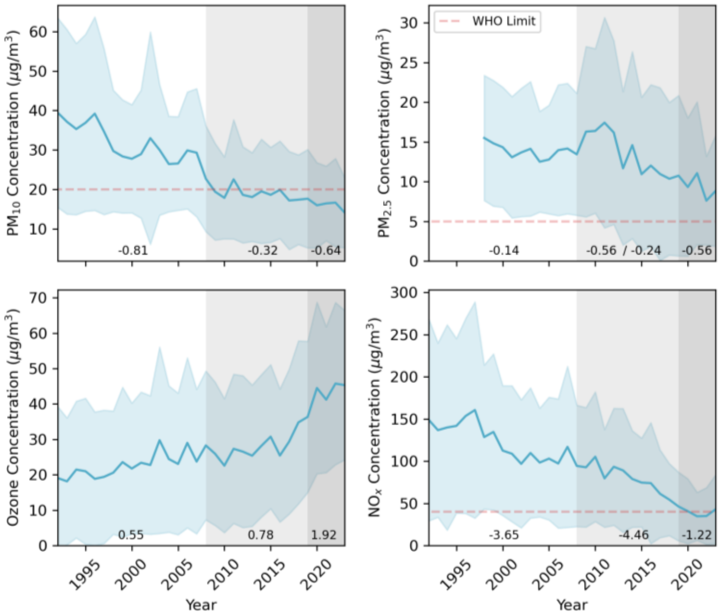
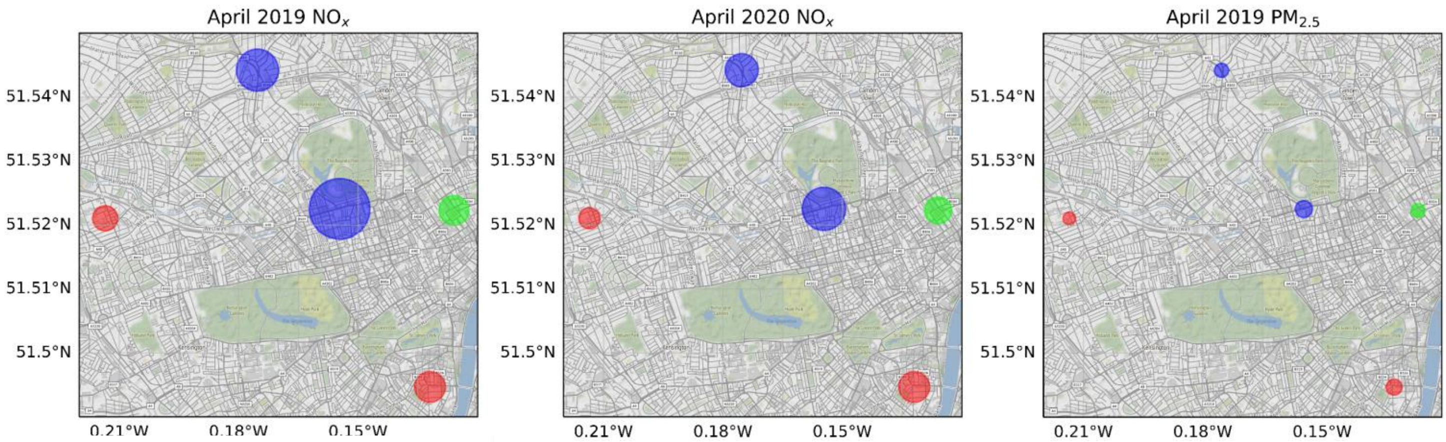


Figure 2: A plot showing the concentrations of PM_{10}, $PM_{2.5}$, NO_x and Ozone. Data for $PM_{2.5}$ from before 1998 is not available. Zones denoted by shading correspond to pre-LEZ, LEZ and ULEZ. Gradients calculated from linear regression are at the bottom of each zone. WHO limits are plotted (there is no annual ozone limit).

From Figure 2 we see that concentrations of PM_{10}, $PM_{2.5}$ and NO_x have been steadily decreasing since data has been available. NO_x has been decreasing faster, from -3.65 to -4.46 μg/m³/yr, after the LEZ introduction, although following the ULEZ introduction, this has plateaued to -1.22 μg/m³/yr. Both forms of particulate matter (PM_{10} and $PM_{2.5}$) have been steadily decreasing since tracking began. However, the rate of PM_{10} decrease slowed after the LEZ was implemented. This is likely because the Euro regulations on which the LEZ is based do not consider non-exhaust emissions, and therefore the LEZ will not significantly affect particulate matter concentrations.[17] Hence, low emission zones cannot be said to decrease the concentration of particulate matter.

The $PM_{2.5}$ trends seem to differ from PM_{10} trends, but further investigation revealed that the high $PM_{2.5}$ concentrations in 2011 and 2012 were caused by exceptional summer weather conditions – notably dust transported from the Sahara.[21] The smaller gradient stated accounts for this exception and reveals a trend closer to PM_{10}. Only a slight improvement compared to pre-LEZ levels can be seen, with a decrease of 0.1 $\mu g m^{-3} yr^{-1}$.



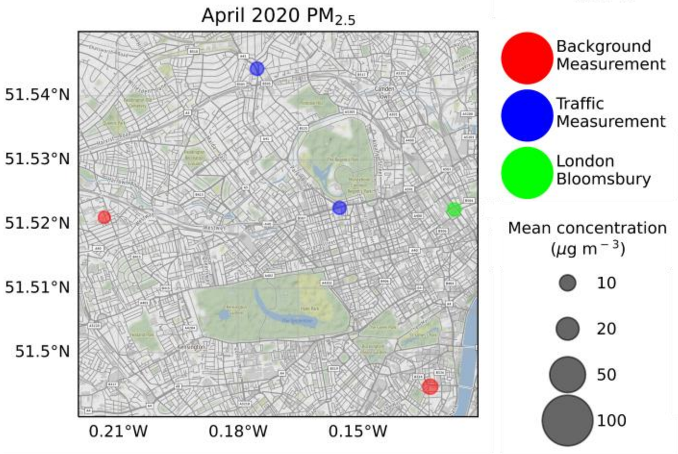


Figure 3: Spatial plots of London NO_x and $PM_{2.5}$ monitoring stations before and during the COVID-19 lockdown, with London Bloomsbury highlighted. Traffic measurements are taken from stations in close vicinity to large roads and are more indicative of vehicular emissions but are more susceptible to influence from a single source such as road works.

Ozone is an exception, as we see it steadily increasing. This is not because it is being emitted by anthropogenic sources, but because decreases in NO_x concentrations increase ozone formation shortly after.[22] Decreases in NO_x concentration in the last decade have therefore resulted in a sharp increase in the concentration of ozone. Ozone's stability in the early 21st century was because NO_x concentrations were also stable over the same time, but the higher fluctuations are due to seasonal variation. Increasing temperatures greatly increase the concentration of ozone, so a colder than average year will have lower ozone concentrations.

Figure 3 shows that concentrations of both NO_x and $PM_{2.5}$ decreased during the COVID-19 lockdown. Furthermore, roadside traffic measurements decreased further than background ones. This time period had very low traffic, and hence shows that reducing the number of vehicles on the road does improve air quality significantly.[20] This is in contrast to the LEZ implementation from Figure 2, where NO_x decreased significantly while $PM_{2.5}$ and PM_{10} did not. This indicates that while lockdowns and their associated traffic reductions are effective at reducing both pollutants, the introduction of LEZ's only serves to significantly reduce the concentration of NO_x. The time after the introduction of the ULEZ shows a decrease in particulate matter, although it is hard to be certain whether falling vehicle emissions are the cause as the concentration of NO_x has plateaued (which is proven to be linked to traffic). Furthermore, as it has only been four years since the implementation of the ULEZ (for one year of which the COVID-19 lockdown was in place), there is not enough data to be certain that these more recent trends are indicative of the ULEZ's efficacy.

Conclusion and Recommendations

Particulate matter is one of the most dangerous atmospheric pollutants, and low emission zones do not significantly reduce this because poor standards used to enforce these zones only consider exhaust emissions. The LEZ reduced NO_x concentrations, but the only intervention that improved particulate matter significantly was the COVID-19 lockdown.

As such, any new travel zones must focus on reducing the number of vehicles on the road, rather than focusing on the emissions of the vehicles. Any exemptions to these schemes, such as for low emission or electric vehicles, will hamper the attempts to improve air quality as these vehicles will continue to release particulate matter through the wear of tyres and brakes in the same way as high emission vehicles. Furthermore, caution must be associated with labelling these zones as "improving air quality". Whilst it is true that their implementation reduces NO_x concentration, significant hazard to public health still remains in the form of the more hazardous particulate matter particles, which the ULEZ does not reduce below WHO limits and UK pledges. Schemes such as the CSTZ will reduce this PM risk by reducing the absolute number of vehicles.

Additionally, vegetation and green spaces are particularly effective at reducing PM concentrations, so alternative schemes that increase the amount of green space in the city will further improve air quality if used alongside the CSTZ.[12] Similarly, funding should be provided to improve public transport options such as buses to minimise the number of vehicles on the road. Alternative options such as banning vehicles in the city center on weekends, or expanding park and ride schemes would also improve air quality.

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