Australasian Transport Research Forum 2012 Proceedings
26 September – 28 October 2010, Canberra, Australia
Publication website: http://www.patrec.org/atrf.aspx

Medium term effects of London's low emission zone

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Abstract

London's low emission zone (LEZ) was implemented in a staged process from February to July, 2008 in an attempt to reduce the emissions of air pollutants of direct harm to human health within London. Although a cordon-based congestion charge affecting nearly all vehicles had already been introduced in central London several years earlier, air pollution continued to be a problem both within central London and large parts of Greater London. As a result, the LEZ was introduced to target the worst polluters, specifically heavy vehicles, buses and vans by imposing minimum emissions standards on vehicles entering an area covering most of Greater London. Several years on it remained unclear how successful the LEZ has been in meeting its stated objectives and if any improvements to pollution levels are due to the LEZ or are the result of natural fleet turnover with similar effects found in the rest of the United Kingdom. This paper uses data from the DVLA and Transport for London to assess the impact of the LEZ to vehicle use and air pollution. Results show the rate of fleet turnover in London increased substantially when the LEZ was first introduced before returning to the national average in subsequent years. Early evidence for light commercial vehicles (LCVs) which became subject to the scheme in early 2012 shows a similar effect is likely. Despite an overall growth in freight vehicles operating in London, the number of pre-Euro III vehicles has dropped and this has been coupled with a switch from rigid vehicles to LCVs and (to a lesser extent) articulated vehicles. The concentration of PM_{10} within the LEZ has dropped by between 2.46 percent and 3.07 percent compared to just over one percent for areas near London but outside the LEZ.

1. Introduction

London's low emission zone (LEZ) was implemented in a staged process from February to July, 2008. The LEZ was introduced with the aim of reducing the emissions of air pollutants including particulate matter (PM) and nitrogen oxides (NO_X) from vehicles. These air pollutants are of direct harm to human health and with London having a population of approximately 7.8 million (Office for National Statistics (UK) 2011), the potential health benefits of reducing these emissions are substantial. A cordon-based congestion charge affecting nearly all vehicles had already been introduced into central London several years earlier. Although the congestion charge was primarily intended as a means of reducing congestion within the centre of London, it was intended to have supplementary benefits in reducing air pollution by exempting low-emission vehicles and reducing start-stop traffic at which most cars are at their most fuel-inefficient. However, air pollution has continued to be a problem both within central London and large parts of Greater London. To address air pollution specifically, rather than as a by-product of another policy, the LEZ was introduced to target the worst polluters, specifically heavy vehicles, buses, and more recently, vans. This was done by imposing minimum emissions standards on vehicles entering an area loosely bounded by the M25 motorway (Transport for London 2008). Several years on it remains unclear how successful the LEZ has been in meeting its stated objectives and if any improvements to pollution levels are due to the LEZ or are the result of natural fleet turnover with similar effects found in the rest of the United Kingdom. This paper assesses the impacts

of the LEZ on vehicle use within London and to what extent the changes (if any) can be attributed to the LEZ specifically.

2. Background and context

Low Emission Zones (LEZs) are one of a number of strategies to have been employed by governments to try to reduce (or at least limit) the emissions of air pollutants from road traffic within a specified spatial area. LEZs are areas where vehicles which do not meet a minimum standard for vehicle emissions are restricted from entering and are subject to large fines if they do enter. Although LEZs could potentially apply to all vehicles, they have generally applied to heavy vehicles due to their relatively large contribution to air pollution when compared to their representation in the vehicle fleet. First introduced in Sweden as part of an "environmental zone" which covers noise as well as emissions(Rapaport 2002), they have since been implemented in cities in a number of other countries including Germany, Italy, Japan and The Netherlands. Although there are currently no LEZs in Australia, one recent study on the potential effects of a hypothetical LEZ for Sydney suggested that the likely reductions in emissions of Particulate Matter less than ten microns in diameter (PM_{10}) from heavy vehicles could be around 10 percent (Greaves 2009). An LEZ is now also among the recommendations for reducing emissions in Sydney in a report written for the NSW Department of Planning (ARUP 2010). At present, the LEZ in London remains the UK's only active LEZ although they have been considered for a number of other metropolitan areas since London's was introduced.

2.1. Emissions standards for road vehicles and air quality standards

The European Union's (EU) emissions standards for road vehicles dictate the minimum emission standards required for all new commercial vehicles being sold in the EU. These emissions standards, commonly described as the "Euro" emissions standards have also been adopted by other countries and include a number of pollutants including PM_{10} and NO_X. A table summarising the minimum emission standards for heavy vehicles up to the current standard of Euro V is available in Table 1. An updated emission standard (Euro VI) is scheduled to go into effect in the EU in 2014. Australia adopted the Euro standards in 2006 when all new commercial vehicles were required to meet the Euro 3/III standard.

Table 1: European Emission Standards for Heavy Vehicles

Emission Standard	Year	PM_{10} (g/kWh)	NO_X (g/kWh)
Euro I	1992	0.61	8.0
Euro II	1996	0.25	7.0
Euro II (updated)	1998	0.15	7.0
Euro III	1999	0.02	2.0
Euro III (updated)	2000	0.10	5.0
Euro IV	2006	0.02	3.52
Euro V	2009	0.02	2.0
Euro VI[1]	2014	0.01	0.04

Source: Adapted from (Transport for London 2008), (European Commission 2009)

The EU has also introduced air quality standards that set a limit to the concentration of various pollutants to try to limit their negative impacts on human health. These standards require the concentration of PM_{10} to be below an average of 50µg/m^3 in a 24 hour period or 40µg/m^3 over one year. The equivalent standards for NO_X are 200µg/m^3 in a one period or 40µg/m^3 over one year (European Environment Agency 2011).

[1] Emission limits and date of introduction may change.

2.2. Implementation of London's LEZ

In the early 2000s, London's air quality was considered to be amongst the worst for European cities with emissions of PM_{10} and NO_X being particularly problematic and failing to meet both European and UK standards for air quality in urban areas (Transport for London 2008). With this in mind, a number of government agencies from both Greater London and the national government undertook a study on the use of an LEZ for parts or all of Greater London. This initial study was used to form the basis for further analysis conducted by Transport for London from 2005 to 2007. After these studies were completed, the LEZ was announced in May 2007 for most of Greater London[2] with a staged implementation beginning in early 2008 affecting heavy freight-carrying vehicles as well as larger buses.

These vehicles were required to meet a minimum of the Euro III standard starting in February 2008 for vehicles with a gross vehicle weight (GVW) of more than 12 tonnes. This was followed by freight vehicles with a GVW of more than 3.5 tonnes as well as buses with a GVW of more than five tonnes in July 2008 (Transport for London 2008). Although new heavy vehicles have been required to meet the updated Euro III standard since 2000, a considerable number of older vehicles continued to be used. As a result, the LEZ was used to create an additional incentive for organisations to replace their existing vehicles with newer and less polluting vehicles. The initial plan required large vans and minibuses to meet the same minimum standards starting in 2010, but this phase was later delayed until early 2012.

Owners of vehicles not compliant with the minimum standards who nonetheless choose to enter the LEZ are required to pay a charge for each day they are in the LEZ. Currently the charge is £100 (approximately $155) for large vans or £200 (approximately $310) for heavy vehicles. If these charges are not paid by midnight on the day the vehicle was in the LEZ, penalty fines of £500 and £1000 for large vans and heavy vehicles respectively are incurred (Transport for London 2012). Operators can also choose to fit and have certified an approved filter although this process takes three months to complete and has to be repeated annually.

[2] The LEZ covers all roads in Greater London, Heathrow and parts of the M1 and M4. However, the M25 is not included even where it passes through the Greater London Authority boundary.

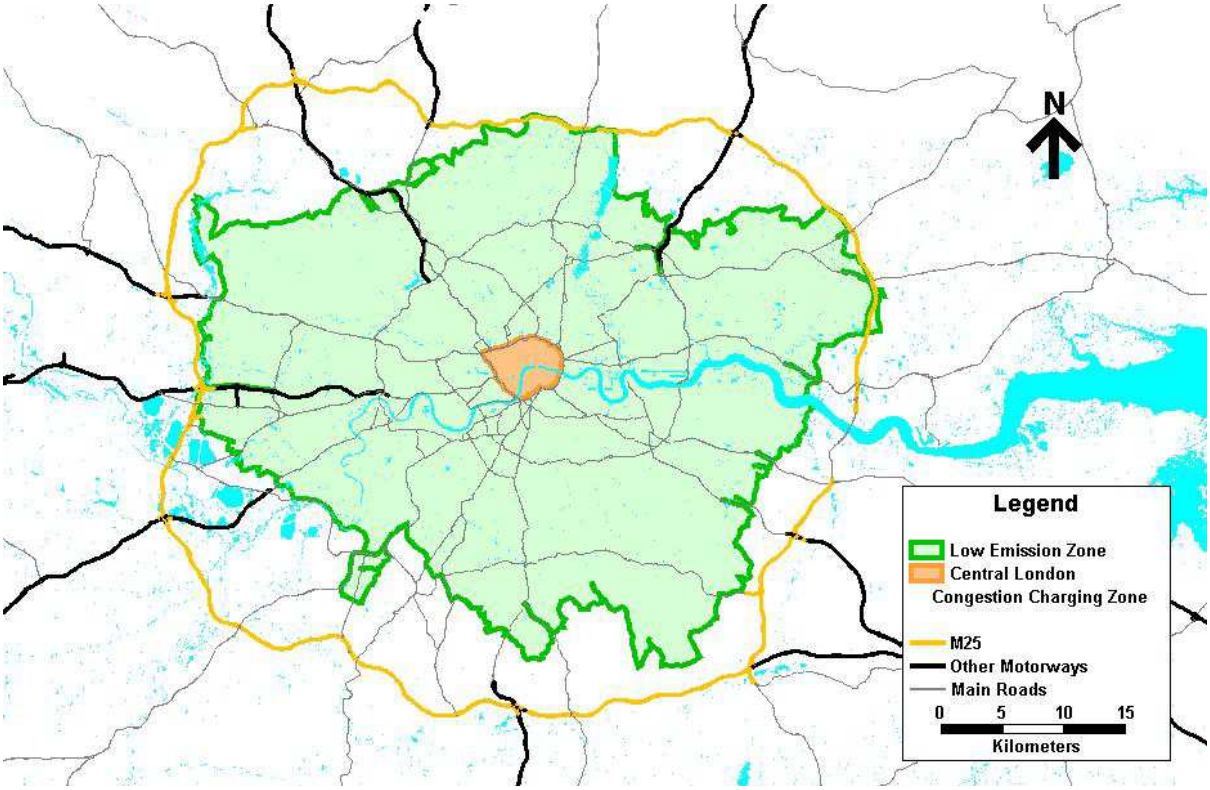

Figure 1: Map of London

2.3. Evidence for the effectiveness of an LEZ in London

A 2005 study on the likely behavioural responses to the introduction of an LEZ in London covering an area similar to the one that was ultimately used, found that the majority of responses would likely be either the purchase of new vehicles to meet the required standards or (for larger companies) a redistribution of non-compliant vehicles to outside the boundaries of the LEZ (Browne et al. 2005). A small proportion of respondents indicated that they would enter the LEZ regardless of the possible fine, while a similar number indicated they would switch to smaller vehicles which were not subject to the LEZ. This suggests that the largest effect of the LEZ should be on an increase in fleet turnover as company's update their fleets to meet the minimum standards. However, a switch to smaller vehicles also appears to be a possibility because the standards for heavy vehicles are tighter than those for small vehicles.

Emissions modelling conducted for Transport for London predicted that the LEZ would lead to a two percent reduction in PM_{10} emissions and four percent reduction in NO_X emissions in 2008 (the first year in operation) (Kelly and Kelly 2009). An earlier study had predicted the change to concentrations of NO_X achieved by an LEZ in London would be similar to that of natural fleet turnover of two or three years (Carslaw & Beevers 2002). Analysis undertaken on the environmental zone in Stockholm suggested emissions of particulates were half of what would have been without the zone. However, the effect on NO_X was considerably smaller (Rapaport 2002). The only reports publically released by Transport for London in July, 2008 showed that approximately 90 percent of heavy vehicles and buses entering the LEZ complied with the minimum standards by the time it was introduced. This compares with approximately 72 percent and 45 percent respectively for all vehicles in the UK at the same time (Transport for London 2008). This suggests that in the short-term the LEZ was successful in prompting firms to switch to cleaner vehicles. However, it is not clear if heavy vehicles within London continue to be cleaner than those in the rest of the country.

Recently, the minimum standards for the LEZ have increased to Euro IV for heavy vehicles and buses. At the same time, a minimum standard of Euro 3[3] (the equivalent standard for light vehicles) for large vans will be introduced. This presents an opportunity to assess the LEZ's longer term effects.

3. Data and methodology

This paper uses data provided by the Driver and Vehicle Licensing Agency (DVLA) on the vehicles registered in the UK by class and registered address. Data on the London LEZ was provided by Transport for London following a freedom of information (FOI) request. The dataset includes the number of vehicles operating within the LEZ for a period from January 2009 to October 2011 and information on the number of penalty charge notices (PCN) issued since 2009. This is supplemented by data on levels of a number of pollutants including PM_{10} and nitrogen monoxide and nitrogen dioxide (jointly NO_X) as well as meteorological readings at monitoring sites around Greater London for a period from 2001 to December 2011, accessed using a service run by King's College London (Carslaw and Ropkins 2012).

These data are used to first assess if there has been a change to the distribution of the age of the vehicle fleet registered in London compared both to the years before the implementation of the LEZ and to other areas of the UK. Although the DVLA vehicle registration data was provided for each postal area in the UK, this was thought to be too high a level of detail given that vehicles (particularly commercial vehicles) registered in one area will not necessarily be used there. For this reason, the vehicle registration and LEZ data has been aggregated to three broad spatial areas. Specifically, these are: postal areas which are either wholly or mostly located within the LEZ, postal areas located in counties surrounding Greater London (including Berkshire, Hertfordshire and Essex) and postal areas located in other regions of the UK.

Assessing the compliance of vehicles for the LEZ requires both the EU vehicle classification (see Table 2) and the year of manufacture/registration. However, the registration data provided by the DVLA did not include the EU vehicle classification of each vehicle since this is not currently held by the DVLA. Using additional data provided by the DVLA on the weight of the vehicle, the general type of vehicle and the number of seats, rules used by Transport for London (2008) were used to assign an EU vehicle classification to each vehicle. This combined with the date of first registration was then used to assess if a particular vehicle was in compliance with the standards required by the LEZ in both 2008 (the initial phase) and the updated standards imposed in 2012. It should be noted that vehicles that have been retrofitted with emission control devices (catalytic converters for instance) are counted using their original classification as this data is also not available to the DVLA.

Table 2: EU Vehicle Classifications

Vehicle Class	Vehicle type equivalent (approximate)	Maximum Weight (tonnes)
N1 – Class I	LCV* – Small	1.305
N1 – Class II	LCV – Medium	1.76
N1 – Class III	LCV – Large	3.5
N2	HGV – Rigid	12
N3	HGV – Articulated[4]	>12

*Light Commercial Vehicle

[3] Roman numerals are used to refer to emission standards for heavy vehicles, standards for cars and light commercial vehicles use Arabic numerals.
[4] Very large rigid vehicles are also classified as N3.

Data on vehicle use within the LEZ was collected by Transport for London (TfL) using monitoring cameras located both at entries into the LEZ and at locations within the LEZ. Cameras within the LEZ are used because even vehicles which never leave the LEZ must be in compliance with the minimum standards. The same aggregation process used for the registration data was applied to the TfL dataset to allow for geographic differences to be examined.

Data from the London Air Quality Network were used for an analysis of the concentrations of PM_{10} and NO_X in and around London. These data were analysed using the OpenAir package for R (R Development Core Team 2012; Carslaw and Ropkins 2012; Carslaw and Ropkins 2012) with the analysis of the trends in air pollution conducted using the Theil-Sen method for regression and the analysis of the distribution of concentrations for NO_X and PM_{10} done using the pollution rose method built into the OpenAir package (Carslaw and Ropkins 2012). Theil-Sen is a linear regression method that has been widely used to study trends in air pollution (Tang et al. 2011; Carslaw & Ropkins 2012). The slope between all pairs of observations taken in the same month of different years are calculated. The median of these slopes is then used to estimate the trend over the required time period (Sen 1968). The estimated slope is then converted into a percentage change per year for each pollutant and location being studied.

4. Fleet turnover

The vehicle registration data shows that pre-Euro III vehicles accounted for 51.4 percent of rigid vehicles registered at the end of 2006 across all of the UK. This dropped to 46.2 percent at the end of 2007, just before the introduction of the LEZ. Interestingly, London and the surrounding counties had a higher than average proportion of pre Euro III rigid vehicles of 56.3 percent and 57.1 percent respectively. Although by 2011 London has the lowest proportion of pre Euro III vehicles registered at 22.2 percent compared to the national average of 30.6 percent, the vast majority of the difference occurs in 2008 where the proportion of pre Euro III vehicles in London drops from 47.4 percent to 31.9 percent. After 2008, the annual change is comparable to other regions. This suggests that the introduction of the LEZ resulted in an extra 20 percent of pre Euro III vehicles being replaced over and above the natural replacement rate in the year that the LEZ was introduced. Perhaps surprisingly, the replacement rate returns to its natural rate in subsequent years meaning that organisations are not simply bringing forward the purchase of new vehicles but are continuing to replace their remaining vehicles at the same rate as they would otherwise have done.

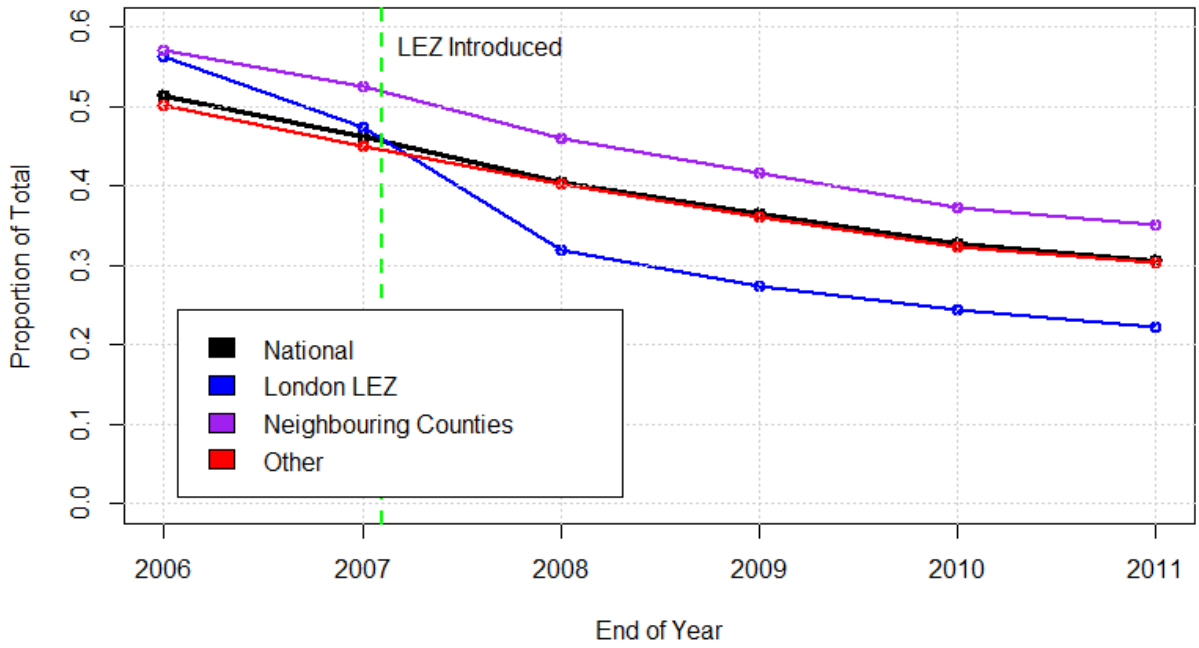

Figure 2: Proportion of registered rigid vehicles pre Euro III

A similar trend (but of smaller magnitude) was seen in articulated vehicles where London had a higher than average proportion of pre Euro III registered vehicles. However, in contrast to rigid vehicles where the change in the proportion of pre Euro III vehicles registered in London dropped to below the national average, for articulated vehicles this proportion dropped only to the national average. The smaller reduction in pre Euro III articulated vehicles registered in London relative to rigid vehicles is to be expected given the higher purchase costs of articulated vehicles and the lower proportion of pre Euro III articulated vehicles in 2006. The higher purchase costs means the fines for not meeting the minimum standards required by the LEZ are less likely to be higher than the costs of replacing the vehicle. Furthermore, the higher purchase costs also increases the incentive for companies (particularly larger companies) to reposition older articulated vehicles outside the LEZ.

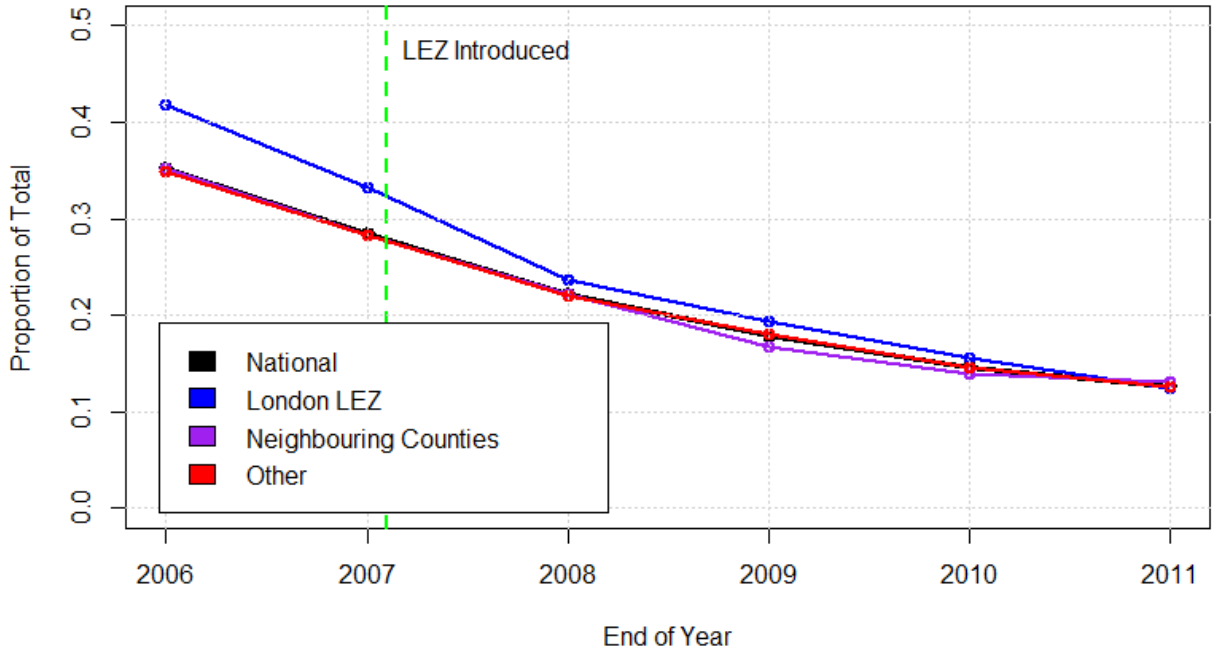

Figure 3: Proportion of registered articulated vehicles pre Euro III

4.1. Effect of changes to LEZ in 2012

In January 2012, the standards required by the LEZ were increased to Euro IV for Articulated Vehicles, Buses and Coaches. Although it is still too early for the changes in vehicle registration to be fully apparent, vehicle registrations in 2011 for both rigid and articulated vehicles show a similar trend as to when the LEZ was first introduced in early 2008. The proportion of registered vehicles not meeting the new minimum standards of the LEZ decreased by an extra four percentage points more than the national average for both rigid and articulated vehicles.

At the same time the minimum standards required for heavy vehicles operating within the LEZ were increased, vans became subject to the LEZ for the first time. Larger vans (with a gross weight of more than 1305kg) must now meet the Euro 3 standard for LCVs. The inclusion of larger vans is a significant change as just under 60 percent of all freight-carrying vehicles entering the LEZ are LCVs with a weight greater than 1305kg. Similar to the higher reduction in non-compliant rigid and articulated vehicles in London, the proportion of non-compliant LCVs in London also decreased by a larger amount than the national average. Providing further evidence that it is the requirements of the LEZ that is driving (at least in part) the greater reduction in non-compliant vehicles in London, there is no significant difference between the changes in the different areas until 2011 when registration of non-compliant LCV vehicles reduced by an extra three percent over the national average (see Figure 4).

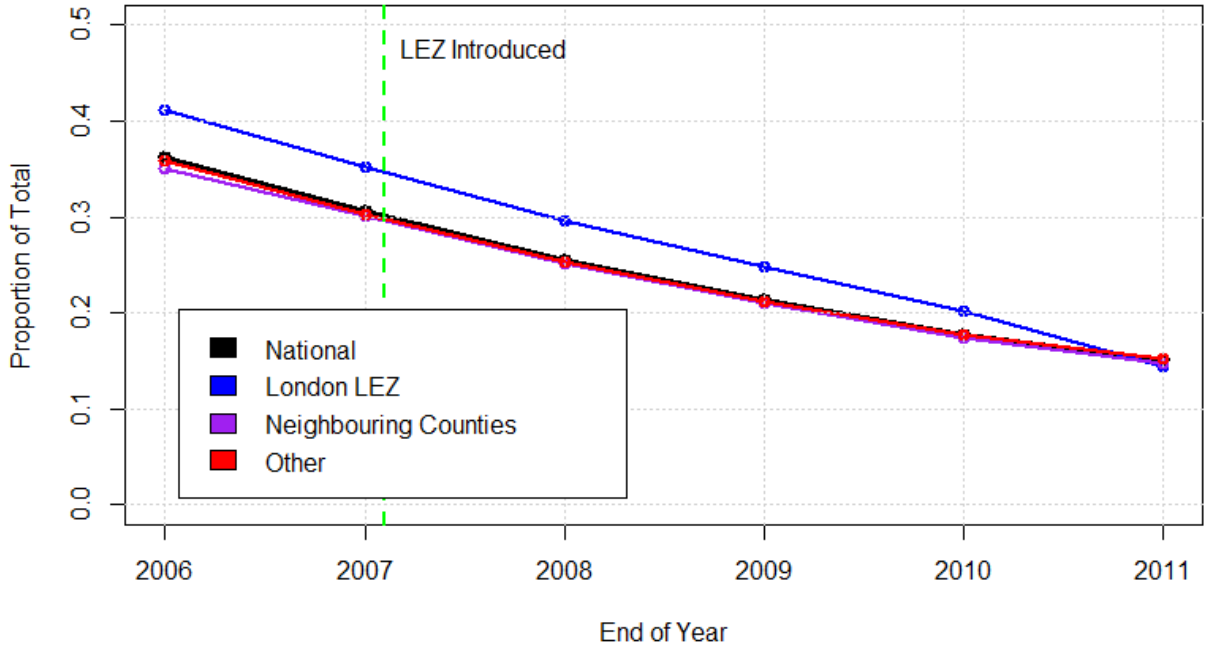

Figure 4: Registered LCVs not meeting LEZ requirements

This provides evidence that the LEZ is effective for increasing fleet turnover and that the change to the fleet is sustainable. Crucially, this shows that the emissions standards must continue to be updated as new vehicles become available as only non-compliant vehicles are replaced at faster than the natural replacement rate.

5. Vehicle use within the LEZ

Although DVLA records show that the number of non-compliant vehicles registered within London dropped after the introduction of the LEZ, this does not necessarily lead to a

reduction in the number of non-compliant vehicles actually operating within London. Furthermore, looking only at vehicle registrations within London masks the (potentially) lower compliance rate of vehicles registered in other areas but operating within the LEZ.

Estimates of the number of freight vehicles driven in the area that was to become the LEZ during 2007 range from about 725,000 vehicles to about 860,000 of which approximately 20 percent were either N2 or N3 vehicles (Transport for London 2008). Although there was a change in the absolute number of vehicles driven within the LEZ during 2007, the pattern appears cyclical with the highest number of unique vehicles being seen in late spring and early autumn for all vehicle classes.

Initial analysis released by Transport for London (2008) soon after the introduction of the LEZ showed that the number of non-compliant (or pre Euro-III) vehicles entering London started to decrease from the middle of 2007. For articulated vehicles (European class N3), the proportion of non-compliant vehicles operating in what would become the LEZ dropped from approximately 24 percent to approximately 14 percent when it was first introduced. This dropped even further to approximately 3 percent soon after it was introduced. Similarly, the proportion of non-compliant rigid (N2) vehicles dropped from approximately 42 percent to approximately 28 percent during the same time period (Transport for London 2008). It should be noted that the highest drop in the non-compliance rate for articulated vehicles came after the introduction of the LEZ but that rigid vehicles only became subject to the scheme during Phase 2 in July 2008, a period not covered by the data in the report. These non-compliance rates show vehicles being used in London before the introduction of the LEZ were already less polluting than the national (and London-registered) fleet but provides evidence that the LEZ further encouraged the use of cleaner vehicles within London.

The disaggregate data used in the Transport for London report (and supplied to the authors) does not allow us to identify with certainty why cleaner vehicles were being used. However, possible explanations include the need to use smaller vehicles for deliveries in denser areas of London with narrow streets and heavy pedestrian traffic as well as the use of more fuel efficient vehicles due to relatively high levels of congestion in London (despite the congestion charge in central London).

5.1. Longer term changes

Despite the encouraging initial results of the LEZ, changes to vehicles operating within London in the longer term are arguably more important for sustaining any improvement in air quality. These changes (potentially) include a change to newer (and cleaner) vehicles and switching between vehicle classes (Browne et al. 2005).

The large area covered by London's LEZ means that industrial areas that are located near the M25 motorway are now covered by the LEZ. This has an important implication for the vehicles entering the LEZ as it means large articulated vehicles moving goods to or from London to other areas of the UK (or overseas) are subject to the restrictions imposed by the LEZ. This is apparent when the proportions of heavy vehicles entering the LEZ are examined with approximately 64 percent of heavy freight vehicles and 14 percent of all freight-carrying vehicles entering the LEZ in 2007 being articulated vehicles (class N3). Since articulated vehicles are (generally) more polluting than rigid vehicles and LCVs due to their larger size and weight, reducing the proportion of articulated vehicles operating within London would result in a reduction in emissions if this is not offset by smaller vehicles travelling considerably further distances. A switch from rigid vehicles to LCVs would likely have a similar, albeit smaller, effect.

Nationally, the number of registered freight vehicles has not gone up significantly since 2006 with the highest increase being from 2006 to 2007. Since 2007, the number of freight

vehicles has gone up by approximately 2.3 percent, a similar increase to that of the UK's population (Office for National Statistics (UK) 2011). However, this aggregate figure masks the changing distribution of freight vehicles as during the same time period the number of LCVs increased by approximately four percent while the number of rigid and articulated vehicles decreased (see Figure 5). Although the LEZ and economic slowdown and recession may have contributed to the reduction in rigid and articulated vehicles in recent years, the general trend has been apparent for a number of years with the increase in LCVs from 2006 to 2007 being higher than that of any later year.

In contrast to the relatively small changes of registered vehicles at the national level, the number of freight vehicles operating within the LEZ increased substantially between 2007 and 2011. Crucially, the only class for which there was a decrease in the number of vehicles were rigid vehicles for which the number of rigid vehicles operating within London decreased from 2007 to 2009. Although this initial reduction in rigid vehicles mirrors the changes in registered vehicles nationally, it is not consistent with the changes seen in London overall.

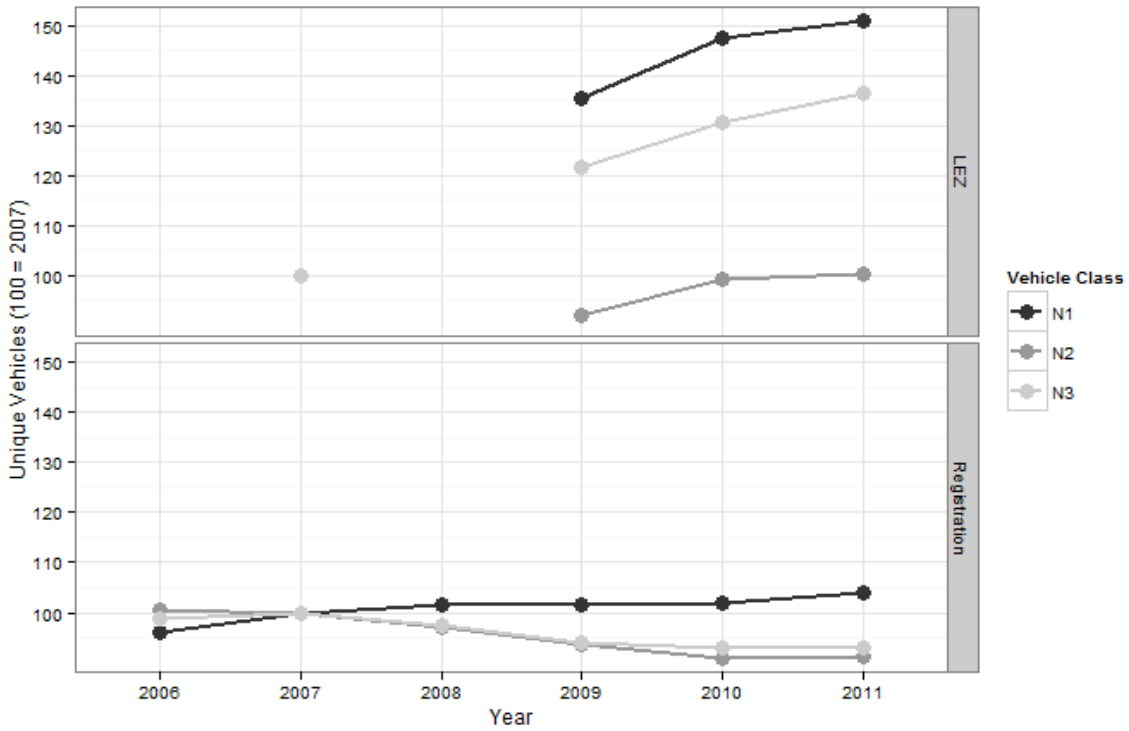

Figure 5: Change in number of vehicles by class

Comparing the proportions of vehicles operating within the LEZ from 2009-2011 to the base proportions in 2007 shows that there has been a shift in the vehicle classes used within London. However, the shift in vehicles has not been a straightforward switch to smaller vehicles. Instead, there appears to be a switch away from rigid vehicles towards LCVs and articulated vehicles (see

Table 3). Although some of the growth in LCVs could be attributed to the growth in package deliveries due to the expansion in internet shopping in recent years, the stability of the proportions (albeit not the absolute values) for the past three years suggests at least some of the switching is likely the result of the LEZ which until January 2012 did not include LCVs.

Table 3: Proportion of freight-carrying vehicles operating within the LEZ by class

	2007	2009	2010	2011
N1 (LCV)	77.9%	81.1%	81.3%	81.2%
N2 (Rigid)	8.0%	5.7%	5.6%	5.5%
N3 (Articulated)	14.1%	13.2%	13.1%	13.3%

Note: Data for 2008 not available

There is also a clear difference in the proportions of each class of vehicle depending on the registered address. Only a small proportion of freight-carrying vehicles entering the LEZ registered in London are rigid and articulated vehicles. The proportion of articulated vehicles in particular increases substantially the further the registered address is from London (see Figure 6). Although these differences are not likely due to the LEZ, they do show how the likely effects of the LEZ to organisations (and their responses) are likely to have differed depending on where they are based.

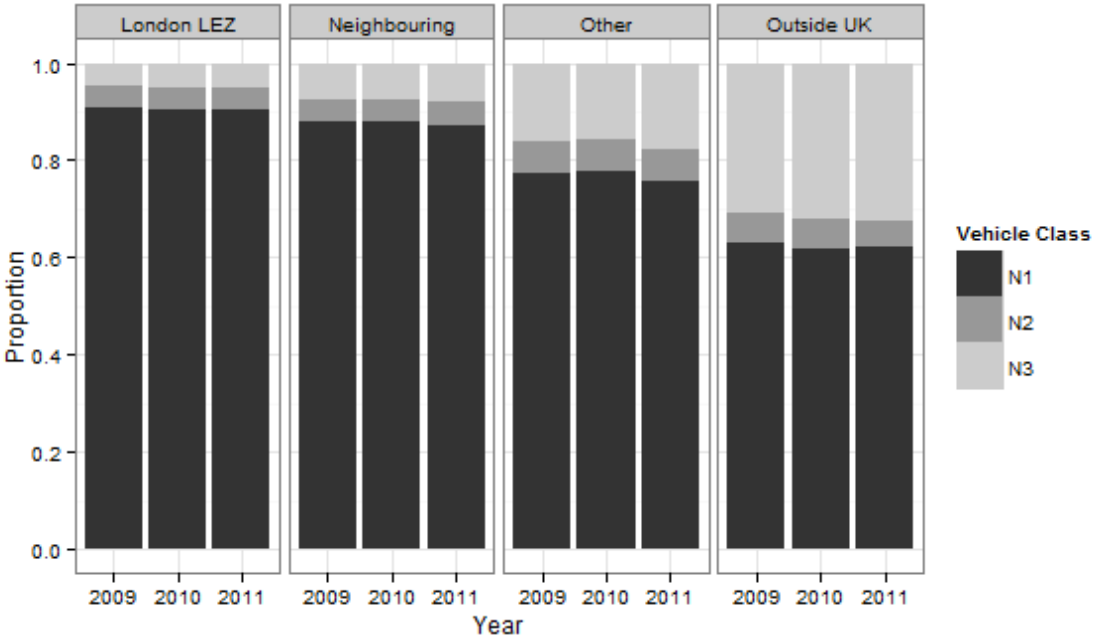

Figure 6: Proportions of freight-carrying vehicles in LEZ by area of registration

With articulated vehicles comprising a majority of the heavy vehicles operating within London, the LEZ's success is in large part dependent on reducing the emissions from articulated vehicles. Although initial results released by Transport for London showed non-compliance rates to be very low only a few weeks after it was introduced, more recent data shows the proportion of non-compliant articulated vehicles in the LEZ to be about the same as they were when the LEZ was first introduced. However, this still represents a halving of the number of pre-Euro III vehicles from the beginning of 2007 (see Figure 7).

The proportion of non-compliant rigid vehicles entering London in 2009 had dropped to approximately 22 percent, a six percentage point drop from just after the introduction of the LEZ. This is comparable to the change in non-compliant vehicle registrations over the same time period. Interestingly, the proportion of non-compliant vehicles entering London stabilises in 2010 before continuing to reduce in 2011 at a slightly higher rate than non-compliant vehicle registrations.

The geographic differences in the initial proportions of non-compliance and subsequent changes in vehicle registrations showed that the location of registration appears to have a substantial influence on how vehicle owners and operators use their vehicles. This is not surprising because those based in London are more likely to have vehicles operating within

London (and as such subject to the LEZ). However, somewhat surprisingly, the proportion of non-compliant vehicles entering the LEZ from 2009 to 2011 was higher for rigid vehicles registered in London than for any other area in the UK and similar to the proportion for foreign-registered vehicles. Furthermore, the change from 2009 to 2011 was broadly similar across all areas (see Figure 8). It should also be noted that the rate of non-compliance for London-registered rigid vehicles is higher than the proportion of non-compliant vehicles registered in London. This suggests that companies based in London are less able (or willing) to reorganise their vehicles so that non-compliant vehicles are used outside the LEZ.

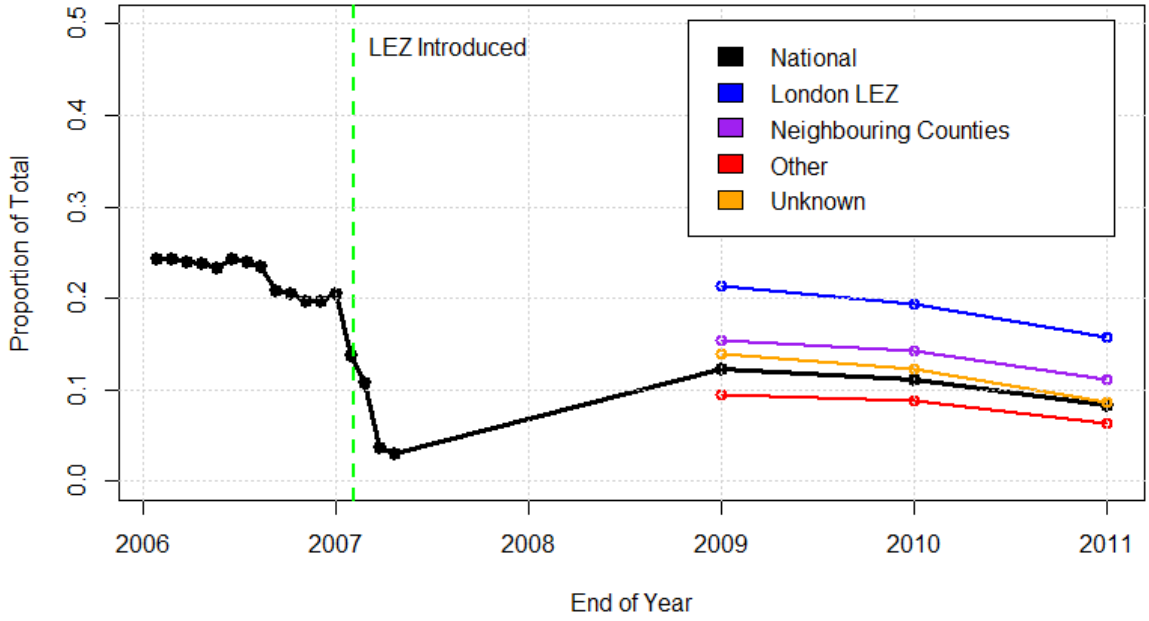

Figure 7: Proportion of non-compliant articulated vehicles in the LEZ

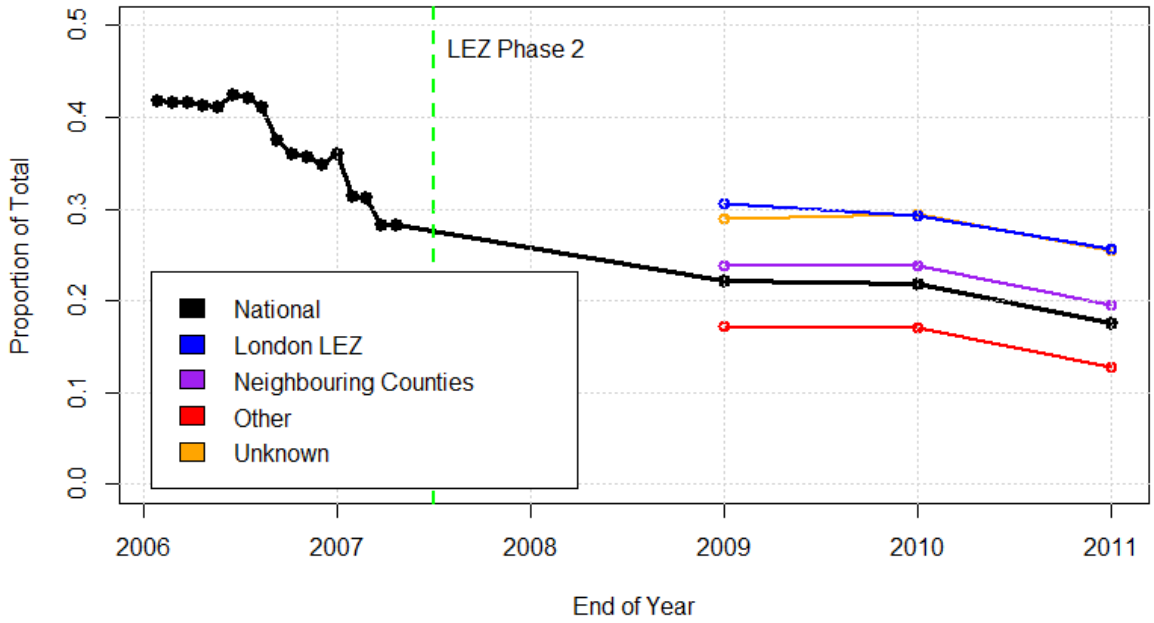

Figure 8: Proportion of non-compliant rigid vehicles in the LEZ

6. Effects on air quality

Assessing if London's air quality has improved since the LEZ was introduced is important to understand if the LEZ has succeeded in one of its stated (and arguably most important) objectives. Although a comprehensive evaluation of the changes, if any, to London's air

quality is outside the scope of this paper, an initial evaluation of the general trends in air quality are presented here. It must be emphasised that the results here are preliminary and intended to provide an indication of how London's air quality has improved since the LEZ was implemented.

Readings of PM_{10} and NO_X sourced from London's Air Quality Network run by King's College London[5] have been used to assess if London's air quality is improving compared to areas outside the LEZ. Using the Theil-Sen method, the trends in the concentration of PM_{10} and NO_X have been estimated. For this analysis, four locations have been chosen to provide an indication of how London's air quality has changed and if the LEZ has had any effect. Three of these locations are located within the LEZ (Sutton, Enfield and Hackney) and one is located approximately 25 kilometres north of the LEZ's boundary at Sawbridgeworth. Hackney is located just outside the boundary of London's congestion charging zone. It should be noted that all readings have been taken from roadside sensors along main roads in the locations and that this will give a somewhat higher results than would be seen if taken further away from the road.

Although there are significant seasonal variations in PM_{10} emissions, a clear (but relatively small) negative trend in the past ten years at all four locations. This trend ranges from an average annual reduction in PM_{10} emissions of between 2.46 percent and 3.07 percent for the three locations inside the LEZ to just over one percent for Sawbridgeworth, outside the LEZ. However, since the LEZ has been introduced, Sawbridgeworth has seen PM_{10} emissions increase by an average of 1.9 percent per year. In contrast, the three locations inside the LEZ have either seen relatively stable emissions of PM_{10} (ignoring seasonal variations) or have seen emissions decrease. Since the number of freight vehicles driven within the LEZ has increased substantially it would be expected that PM_{10} emissions would increase if fleet composition had not changed. This indicates that the LEZ may have had some effect in limiting PM_{10} emissions since it came into effect.

Further evidence of the effect of the LEZ is seen when comparing the frequency of readings in 10 ug/m^3 bands before and after the introduction of the LEZ. The change since the introduction of the LEZ can be seen in Figure 9 which shows there has been a substantial reduction in PM_{10} readings above 30µg/m^3. This has contributed to keeping PM_{10} emissions below the limit mandated by the EU air quality standard. The mean concentration of PM_{10} has decreased by an average of 13 percent within the LEZ since it was implemented. This compares favourably to a reduction of approximately 7 percent in Sawbridgeworth during the same time period.

[5] See http://www.londonair.org.uk for more information.

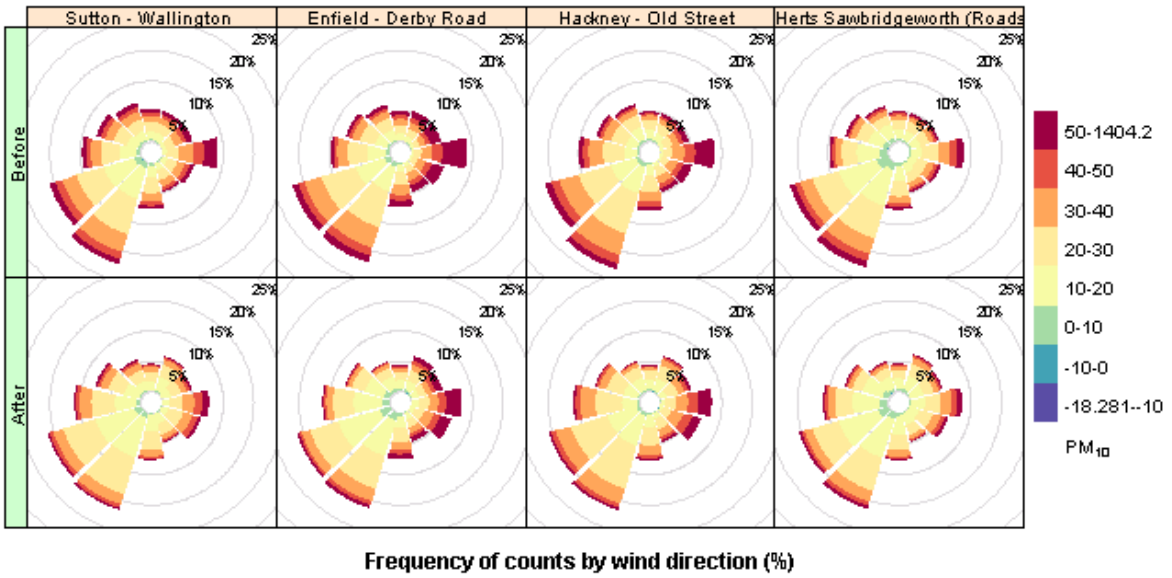

Figure 9: Changes in PM_{10} emissions before and after the start of the LEZ

The results for NO_X do not show a significant difference between Sawbridgeworth and the LEZ with emissions of NO_X reducing in all locations by between 0.5 and 1.5 percent per year between 2008 and 2011 (see Figure 10). The trends from 2001 to 2011 also do not appear to show a substantial difference between the changes in NO_X emissions inside and outside the LEZ since its introduction. Analysis of the frequency of readings shows similar results (see Figure 10).

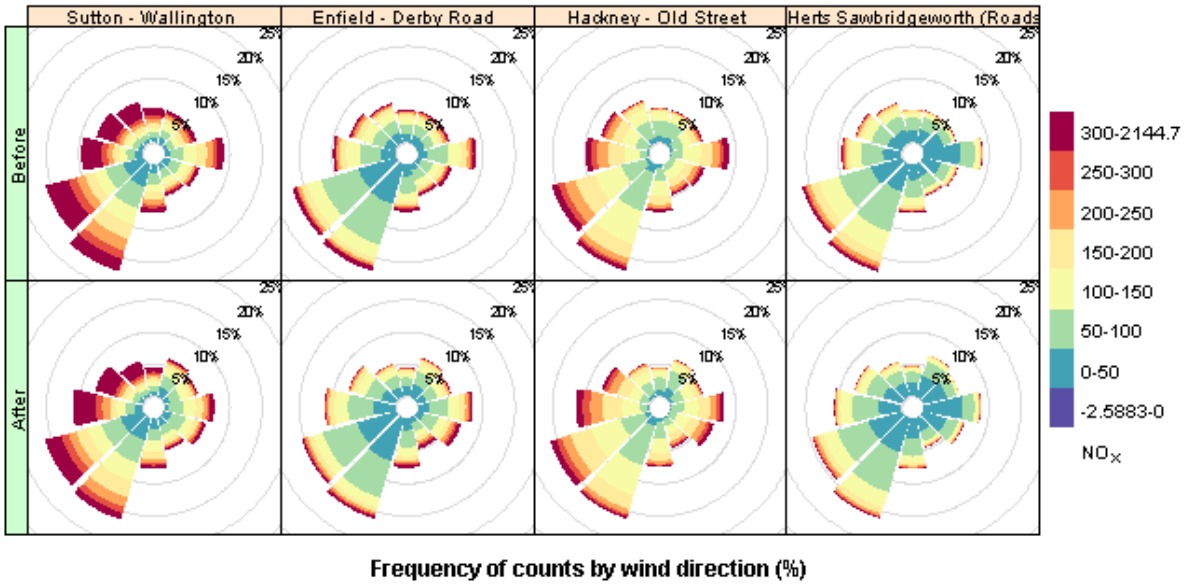

Figure 10: Changes in NO_X emissions before and after the start of the LEZ

Notwithstanding the limitations of this initial analysis of the changes in air quality in London since the introduction of the LEZ, it does suggest there has been an improvement in air quality despite an increase in the number of freight vehicles operating within the LEZ. Furthermore, it is of interest that the reductions in emissions of both PM10 and NOX have been greatest in Enfield where the air quality monitoring sensors are located closest to an industrial estate from the four locations used.

7. Conclusions and directions for future research

London's low emission zone has had a substantial effect on the composition of the vehicle fleet in London with its influence in increasing the replacement rate for older vehicles being sustained in the years since. It also appears to have had an effect on the replacement rate of LCVs at the end of 2011 in anticipation to the changes which came into effect in early 2012 although the full effects are not likely to be apparent until later this year. The LEZ also appears to have had an effect on vehicle use within London with LCVs comprising an even larger proportion of vehicles being used within London, mostly at the expense of rigid vehicles. This switch to smaller vehicles has been coupled with the proportion of pre-Euro III rigid and articulated vehicles operating within London continuing to decrease. These changes provide evidence of the main responses of owners and operators of heavy vehicles to the LEZ being a switch to newer vehicles, a change in the class of vehicles used and repositioning of vehicles to avoid using non-compliant vehicles in the LEZ.

London's air quality also appears to have improved with reductions in concentrations of PM_{10} and NO_X despite an increase in the number of heavy vehicles within the LEZ and greater reductions in PM_{10} emissions than elsewhere. In addition, there are indications that improvements in air quality have been greater near areas with a large proportion of heavy vehicle traffic. Both these findings indicate that the LEZ has at least played a part in improving air quality.

With the full effect of the changes to the LEZ in early 2012 not likely to be seen until the end of the year, an updated analysis including data from 2012 and future years would be needed. The updated analysis would allow for an investigation into how including large vans in the LEZ further changes which freight vehicles are used in London. In addition, an analysis of the charges paid by operators of non-compliant vehicles would give a better understanding of when operators choose to pay repeated charges for entering the LEZ instead of replacing the non-compliant vehicle.

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