Introduction

This report compares two contrasting EU Low Emission Zones (LEZ) one in London and another in Berlin followed by Clean Air Zone (CAZ) proposal for York. European Union implemented 6th Environmental Action Program to achieve protection of human health and social well-being by mitigating harmful effects of air pollution on human health and within this context 200 LEZ's were operational in EU in 2015 (Cruz and Montenon, 2016). LEZ is defined as "area that can only be entered by specified vehicles meeting certain emissions criteria or standards, e.g. certain Euro standards" (TFL, 2003). Brief comparison of LEZ's are shown in table-1.

| LEZ Comparison | London LEZ | Berlin LEZ |
|---|---|---|
| **Implementation** | 04-Feb-08 | 02-Feb-08 |
| **Size (sq km)** | 1500 | 88 |
| **Duration** | 24 hours a day, every day of the year including weekend and public holidays | 24 hours a day, every day of the year including weekend and public holidays |
| **Target Vehicle Fleet** | All HGV/LGV including foreign vehicles with few exemptions (disabled passenger vehicles, Historic/Military vehicles and cranes) | All vehicles including foreign with few exemptions (Disabled passenger vehicles and special purpose vehicles) |
| **Enforcement** | ANPR (Automatic Number Plate Recognition) camera network | Manual enforcement |

*Table-1 Brief comparison of London and Berlin LEZ (TFL, 2019a;UrbanAccessRegulations, 2019)*

## London LEZ

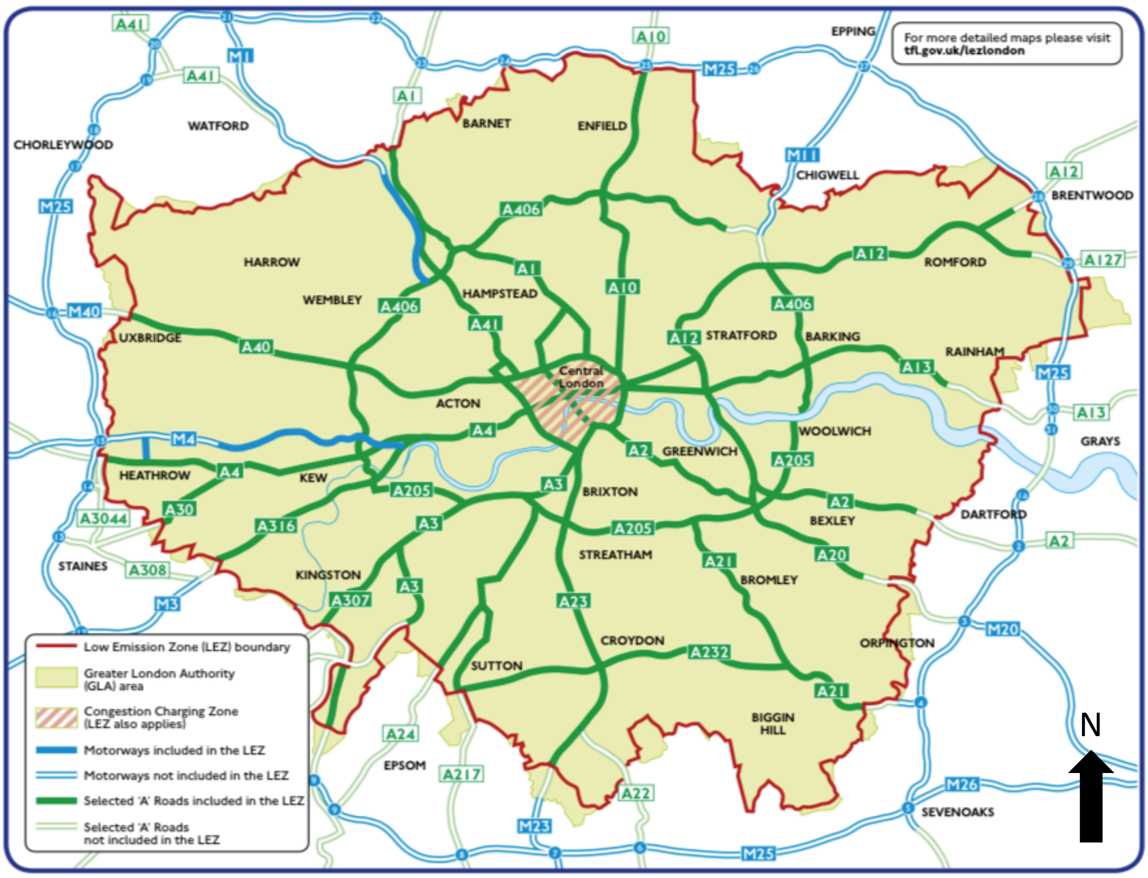



*Fig-1 London LEZ* (TFL, 2012)

Implementation and Enforcement:

To comply with exceedances and annual limits of EU Air Quality directives targeting urban areas by restricting entry of high polluting vehicles to address road side concentration of pollutants (eg: $NO_2$) which tend to be higher at center of the road and reduces as distance increases LEZ was introduced (TFL, 2003). Within the LEZ lies the congestion charging zone (CCZ) which was implemented in 2003 and its impacts are assumed to be at steady state when LEZ was enforced (TFL, 2003).

Evidence from CCZ implementation estimates LEZ implementation will cost around 6-10£ million to set up and operational cost of 5-7£ million/year (TFL, 2003). Vehicle population and type affected including foreign vehicles and subsequent changes since implementation are shown in table-2.

| Phase | LEZ entry conditions |
|---|---|
| Phase 1 : Feb 4, 2008 | Diesel vehicles with a permissible maximum weight of 12 tonnes must comply with Euro III PM. Exceptions : Buses and emergency vehicles |
| Phase 2 : July 1, 2008 | All vehicles with a permissible maximum weight of over 3.5 tonnes must comply with Euro III PM. |
| Phase 3 : Mar 1, 2012 | Goods vehicles with an unladen weight of over 1,205 kg and a permissible maximum weight of under 3.5 tonnes, ambulances and motor caravans with a permissible maximum weight of between 2.5 and 3.5 tonnes, as well as minibuses with more than 8 seats with a permissible maximum weight of under 5 tonnes must comply with Euro 3 PM. |
| Phase 4 : Mar 1, 2012 | HGVs of over 3.5 tonnes and buses and coaches of over 5 tonnes must comply with Euro IV PM. |

*Table-2 Implementation phases and entry condition revisions (Cruz and Montenon, 2016)*

ANPR enforcement network works on SIEMENS system as shown in fig-2. The camera network reads the vehicle number plate which is verified against the registration database to check if the vehicle meets the compliance standards, if not than penalized accordingly. Charging days run from midnight to midnight; vehicles parked in the zone but not driving are exempt (TFL, 2019a). Approximately 350 cameras are installed in LEZ located in areas with high traffic volumes, 650 cameras covering CCZ and additional mobile units randomly sample other routes within LEZ (Wang et al., 2017; Amundsen and Sundvor, 2018). Non-compliance to LEZ standards results in penalty ranging from 100£ to 200£ and failure to pay attracts additional penalty from 250£ to 1000£ (TFL, 2019c).

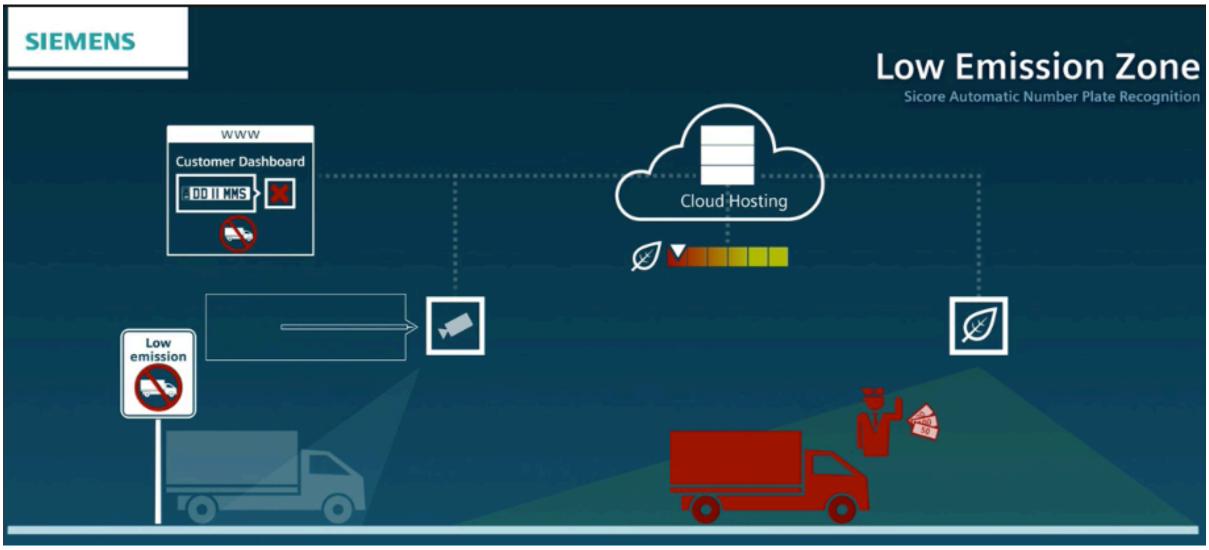


*Fig-2 ANPR enforcement mechanism (Seimens, 2019)*

Impacts:

Post implementation in 2008, pre EURO-III registered vehicles in London reduced from 47.4% to 31.9% (Ellison et al., 2013). Traffic flow in million vehicle kilometers travelled for all vehicles in London in 2007 was 24360 reducing in 2008 to 23878 and in 2017 at 22573 (TFL, 2019d), indicating there was no significant reduction due to implementation of LEZ. $CO_2$ emissions from road transport after weather correction in 2007 were 7.26 Mt$CO_2$ reducing in 2008 to 6.98 MT$CO_2$, whilst non weather correction $CO_2$ emissions in 2016 were 6.4 Mt$CO_2$e providing some abatement benefits (TFL, 2019b). From fig-3 it can be argued targeted freight delivery vehicles operating mix changed post implementation of LEZ with dominance of LCV and as a result $CO_2$ abatement is marginal.

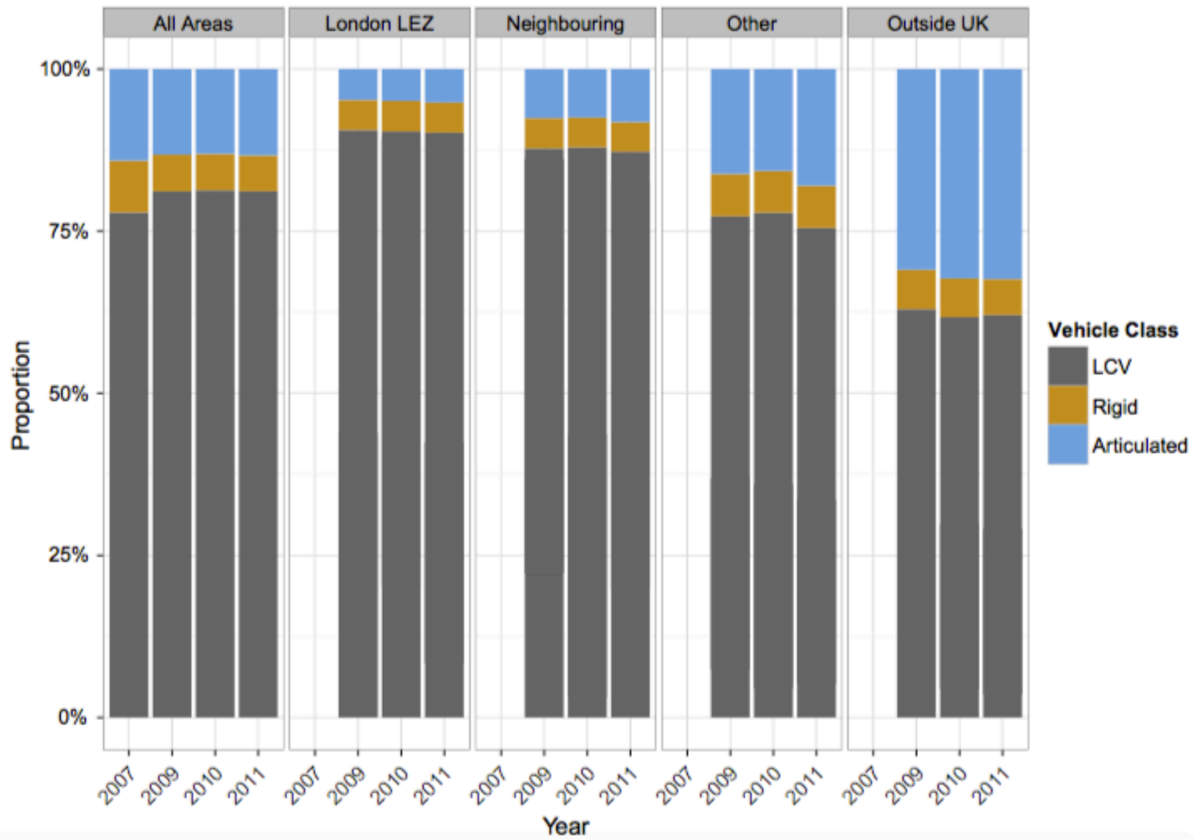



*Fig-3 Before/After LEZ implementation vehicle operating mix (Ellison et al., 2013)*

There have been several studies to understand impacts of LEZ, Modelled impacts from London ERG model and Cambridge Environmental Research Consultants (CERC) using ADMS urban model with same emission inventories, ERG model for baseline year 2007 predicted without LEZ 32.8% of 210 receptor points will exceed the $NO_2$ target while CERC model predicted higher percentage of receptors at 51.5% (TFL, 2003). With LEZ, $PM_{10}$ predicted reduction in annual mean concentration by ERG model at 1.17% whilst CERC predicting 0.77% and $NO_2$ decrease in annual mean predicted by ERG model was 0.6% while CERC model was 0.4% (TFL, 2003). Another modelling study by TFL in 2006 reported by Kelly and Kelly, (2009) stated LEZ implementation would result in 2% and 4% reduction in in $PM_{10}$ and $NO_x$ emissions respectively. This indicates uncertainty of results produced by different models/methods using same emission factors and results change with time.

Based on 2001-2011 trends for four sites (Enfield, Hackney and Sutton within LEZ and one in Sawbridge) for $PM_{10}$ and $NO_x$ from traffic showed post implementation $PM_{10}$ concentrations within LEZ reduced by 2.47% to 3.07% compared to 1% outside and $NO_x$ fell both inside and outside the zones and were not significantly different (Harrison et al., 2012; Ellison et al., 2013). Actual reduction for $NO_x$ being lower than estimated can be attributed to optimistic COPERT emission factors assuming reduced emissions with progressive EURO emission standards. But O'Driscoll et al., (2016) from Portable Emission Measurement System (PEMS) study showed average urban emission were 2.8 times and 1.8 times for $NO_2$ and $NO_x$ respectively than COPERT estimates. Similarly, Dimaratos et al., (2017) compared results of drive cycle on dyno to real world RDE compliant routes for 3 diesel vehicle with different aftertreatment technologies found $NO_x$ to be 5-16 times higher than EURO-VI limit.

Further, Carslaw and Rhys-Tyler, (2013) studied vehicle emissions using remote sensing for approximately 70000 vehicles model years ranging 1985-2012 in London found $NO_2/NO_x$ varying from ~12% to >50% for passenger diesel vehicles and urban buses with SCR systems having higher $NO_2/NO_X$ ratios indicate inefficiencies in optimization of combustion conditions and lack of sufficient exhaust temperature in low temperature urban driving for SCR system to perform to intent. Thus, emission factors used to estimate/forecast impacts were optimistic.

**Berlin LEZ:**

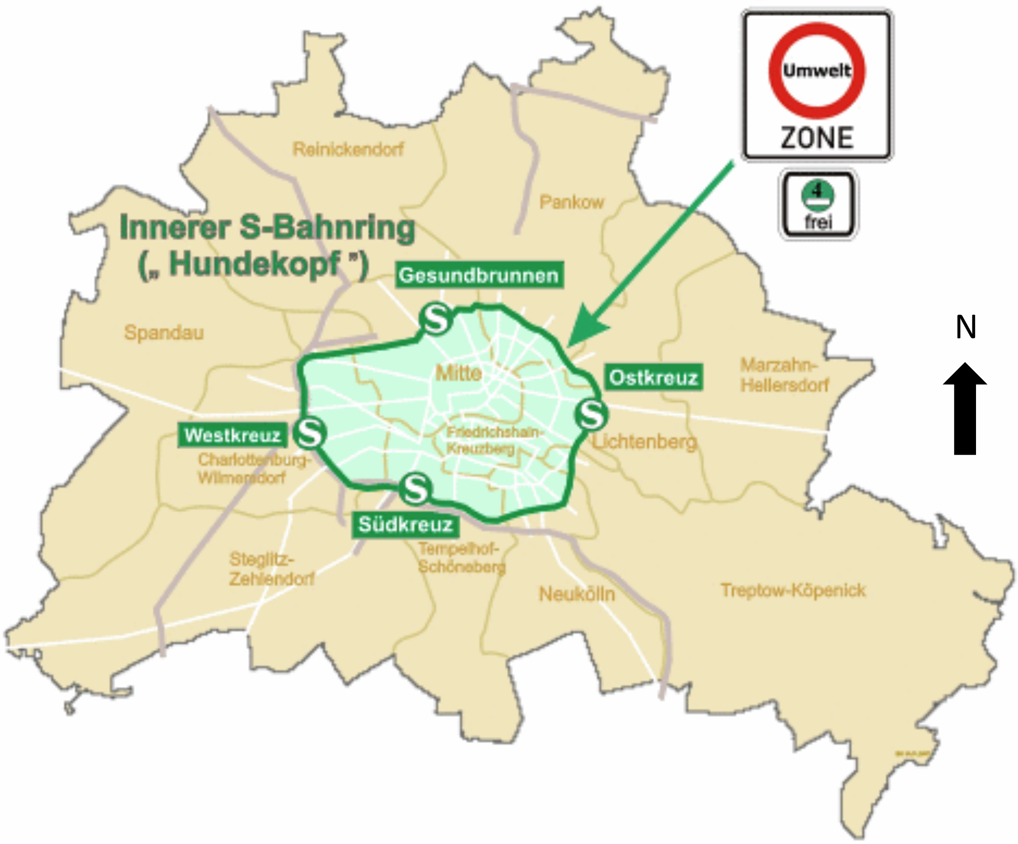



*Fig-4 Berlin LEZ* (UrbanAccessRegulations, 2019)

Implementation and Enforcement:

Like London, in city centre of Berlin limit values of $PM_{10}$ and $NO_2$ exceeded at many locations and 40% of $PM_{10}$ and 80% of $NO_2$ emissions were contributed by city-center and LEZ is operating under common framework for LEZ to mitigate effect of air pollution (KonSULT, 2016). Changes since implementation are shown in table-3.

| Phase | LEZ entry conditions |
|---|---|
| Phase 1 : Feb 2, 2008 | All vehicles must have a red sticker (Euro 2 or Euro 1 + retrofit for Diesel vehicles), a yellow sticker (Euro 3 or Euro 2+ retrofit for Diesel vehicles) or a green sticker (Euro 4 Diesel, Euro 3 Diesel+ retrofit or Euro 1 for petrol vehicles). |
| Phase 2 : Jan 1, 2010 | All German registered vehicles must display a green sticker, unless granted exemption. Foreign registered vehicles and coaches must display a yellow or green sticker. Vehicles with a yellow sticker are allowed to enter the zone if they have a retrofit system. |
| Phase 3 : Jan 1, 2012 | Vehicles from abroad and coaches must display a green sticker. |
| Phase 4 : Jan 1, 2015 | All vehicles must display a green sticker. Derogations will only be possible in exceptional conditions. |

*Table-3 Implementation phases and entry condition revisions (Cruz and Montenon, 2016)*

From London LEZ feasibility study cost of manual enforcement start-up costs were approximately 2.8£ million and operating costs of 3.9£ million respectively and Berlin LEZ being smaller in comparison this costs would be further lower than estimates making it quicker to implement and cheaper to enforce (TFL, 2003). Manual enforcement by traffic warden and police by identifying the windshield stickers as shown in fig-3 indicating emission level which are common across all German LEZ and attracts penalty of 80€ if found without or incorrect sticker, not very robust in comparison to London LEZ (Amundsen and Sundvor, 2018).

At the start of the scheme only vehicles without stickers were banned into the zone however with phase-2 only vehicles with green sticker are allowed (Amundsen and Sundvor, 2018). Compliance of 95-99% for private cars, 85-93% for trucks and vans and 90% of the vehicles satisfying the exhaust requirements of green stickers (Amundsen and Sundvor, 2018) which is lower for HGV's in comparison to London LEZ.


*Fig-3 Berlin LEZ sticker enforcement. (Amundsen and Sundvor, 2018)*

<u>Impacts:</u>

Number of vehicle ownership in Berlin decreased post implementation of LEZ followed by increase again but not crossing pre 2008 levels in 2016 however, number of motorcycles (which are exempt) have increased (Amundsen and Sundvor, 2018). From 36 traffic detectors motor traffic reduced by 4% inside the zone and by 6% outside the zone as shown in fig-4. Traffic flow has not changed considerably but provision of subsidy of 2500€ (Cyrys et al., 2014) speeded up vehicle fleet conversion to stricter emission standards.

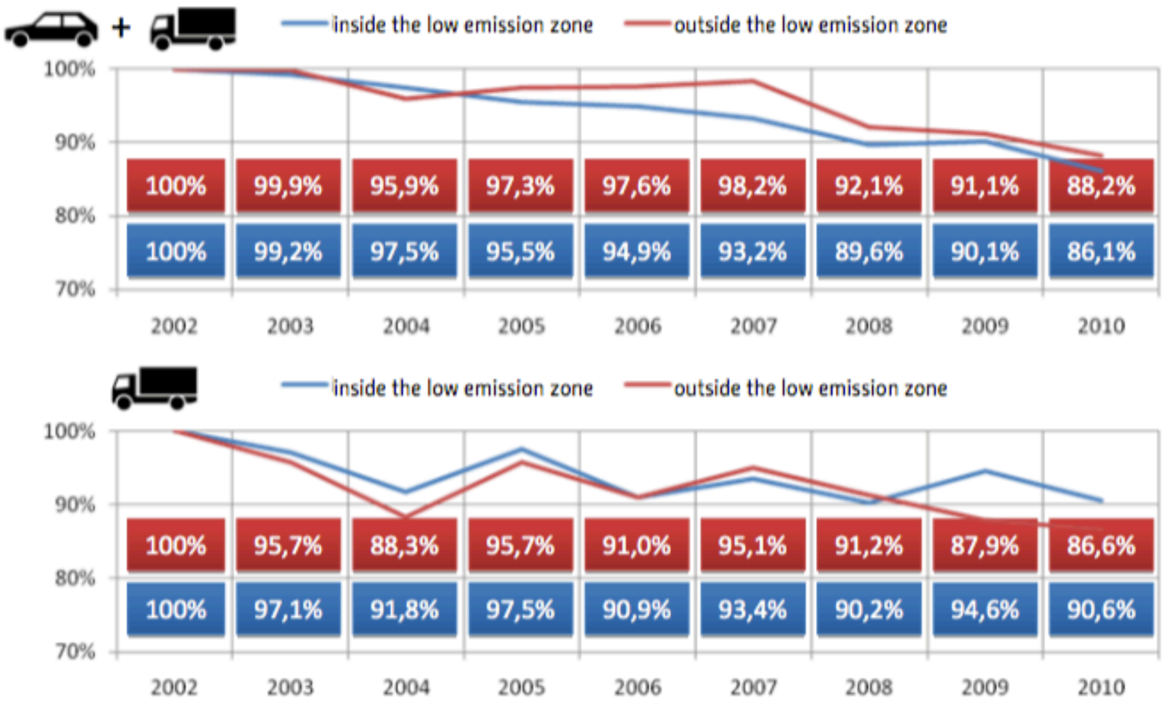
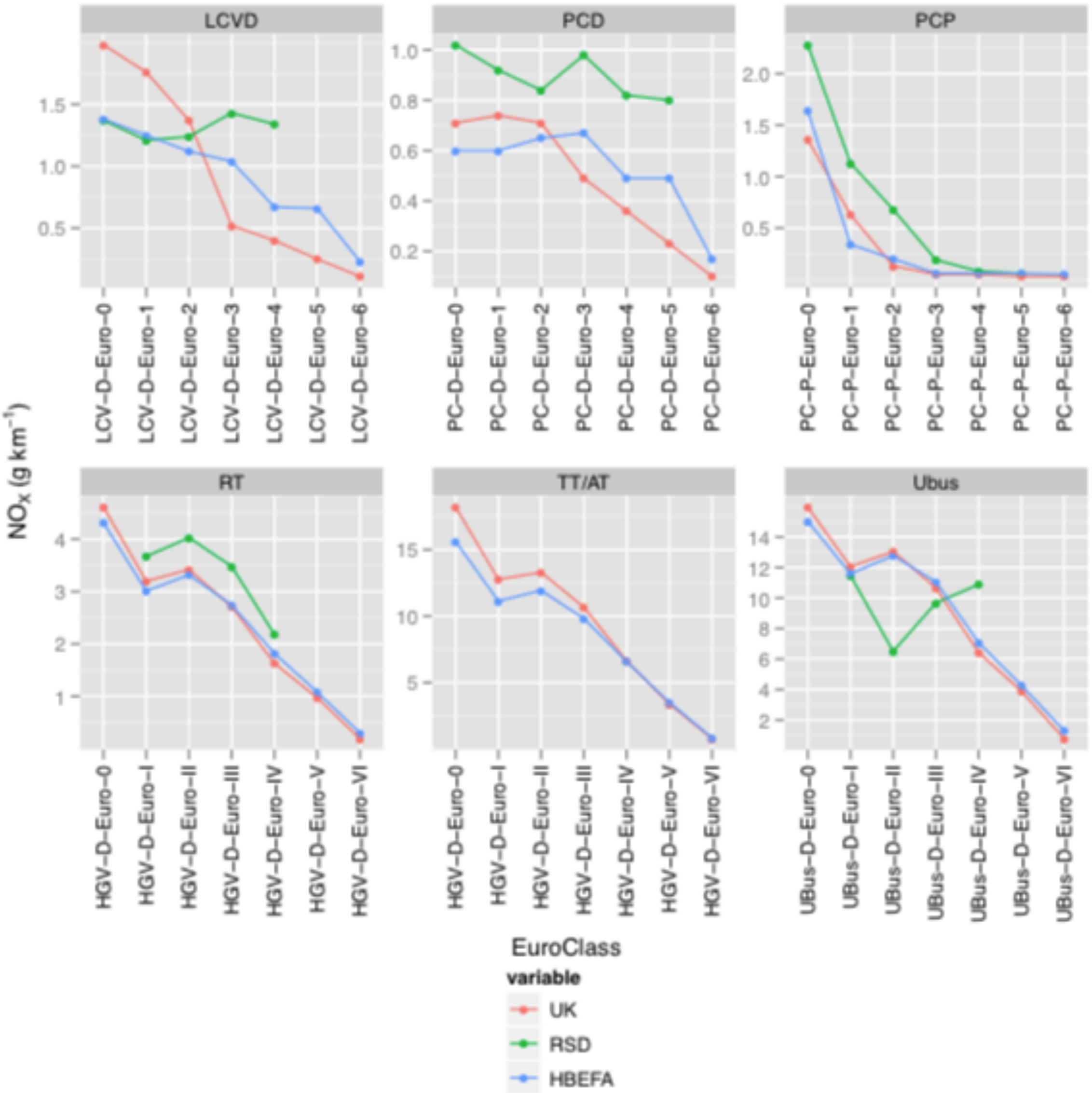



*Fig-4 Traffic change inside/outside zones after Berlin LEZ implementation* (Lutz, 2009)

System of models using IMMIS program were used to understand spatial distribution of dispersion models from street canyon scale (1x1 km$^2$) to urban background (4x4 km$^2$) to regional background (30x30 km$^2$) using HBEFA 3.1 (Handbook Emission Factors Road Transport) for Berlin Air quality plans (Lutz, 2014). With implementation of phase-2 reduction of 5-10% in $PM_{10}$ and 4% in $NO_2$ concentration was anticipated (Holman et al., 2015). However, it should be noted in HBEFA revision 3.3 from 3.2 emission factor for diesel passenger car urban g-$NO_x$/km was increased by 0.5 (Keller et al., 2017) and fig-5 showing gap in remote sensing emission comparison to emission factors further increases uncertainty of modelling results including reasons discussed for London LEZ.




RT= Rigid HGV's, LCVD= diesel LGVs, PCD= passenger car diesel, PCP= passenger car petrol

*Fig-5 Comparison between UK emission factors, HBEFA and Remote Sensing data (RSD)* (Carslaw et al., n.d.)

Post implementation Cyrys and Peters, (2009) compared $PM_{10}$ levels before and 4 months after implementation by applying multiplicative adjustment to reference station showing 5-12% reduction. Jiang et al., (2017) grouped stations inside the LEZ and outside the LEZ reductions for $NO_x$ , $NO_2$ and $PM_{10}$ are shown in fig-6, 7 and 8.

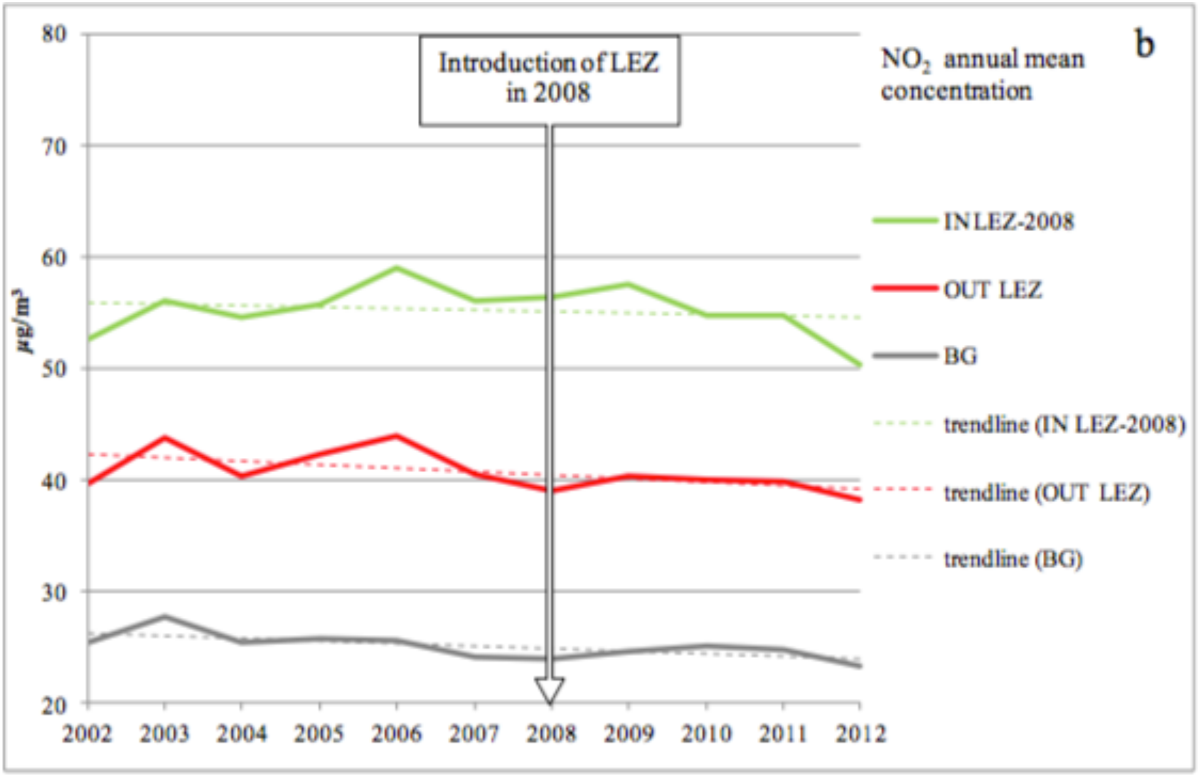



*Fig-6 Trends in $NO_2$ concentration before/after Berlin LEZ implementation (Jiang et al., 2017)*

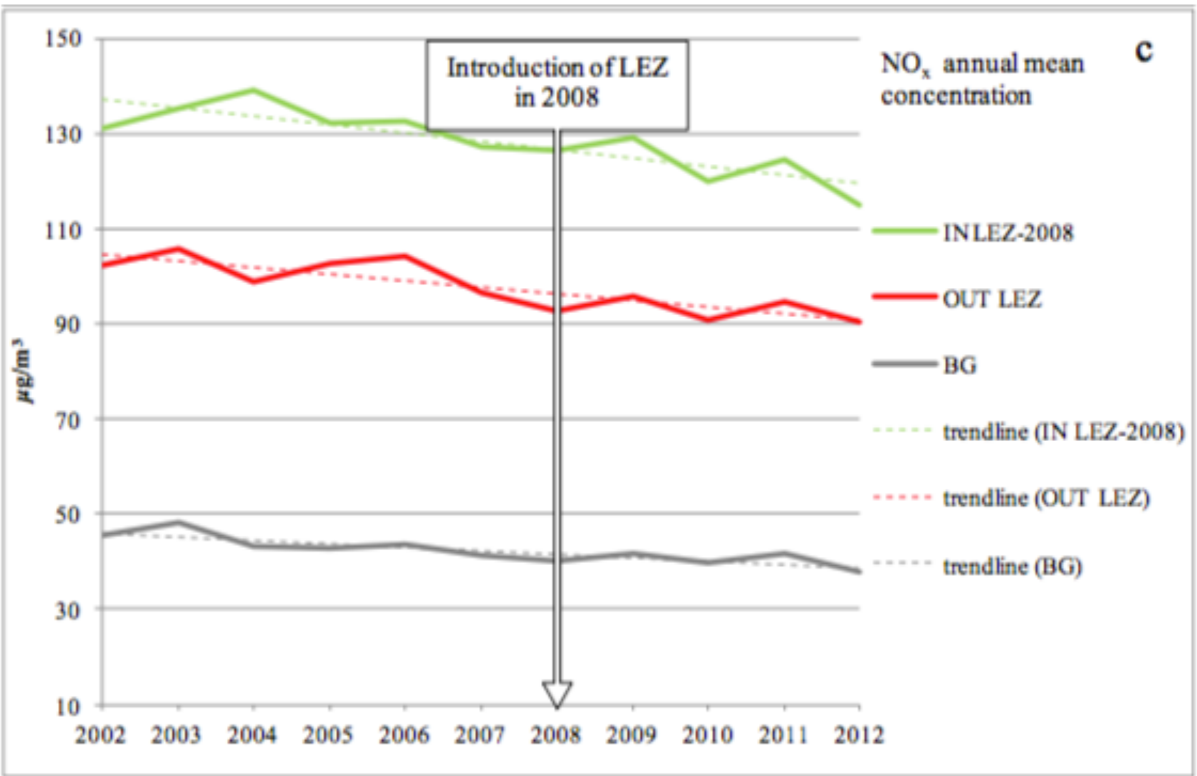



*Fig-7 Trends in $NO_X$ concentration before/after Berlin LEZ implementation (Jiang et al., 2017)*

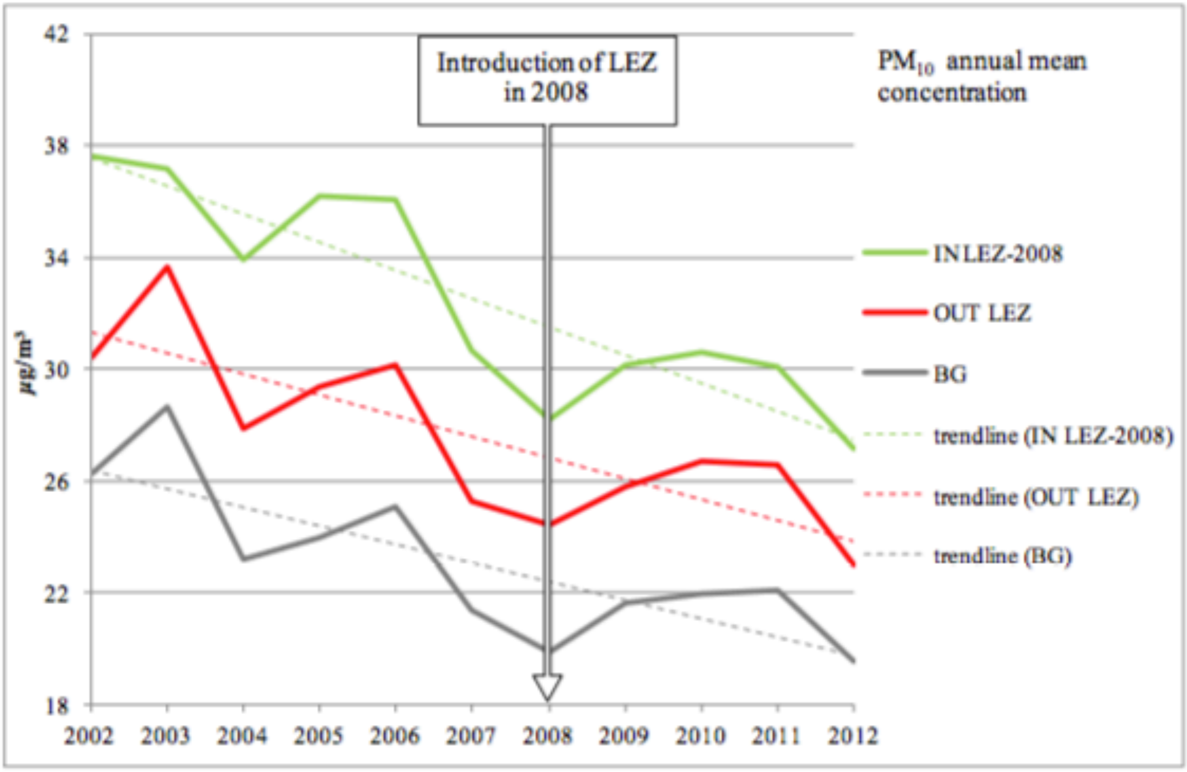



*Fig-8 Trends in $PM_{10}$ concentration before/after Berlin LEZ implementation (Jiang et al., 2017)*

<u>York CAZ Proposal</u>

York is an historic city in England, which is currently meeting the $PM_{10}$ standards as per DEFRA directives however exceeding $NO_2$ air quality objectives (Gillah and Bates, 2016). Extra vehicle movements being a tourist site attracting more than 7 million visitors/year, narrow canyonised streets along with congestion make it difficult to meet air-quality standards (Bates, 2019).

CAZ class-A should be declared for area within the inner ring road as shown in fig-9 operating 365 days a year. The vehicle mix affected as per DEFRA, (2017) guidelines will require all diesel buses, coach, taxi and private hire vehicles to meet EURO-VI for diesel and EURO-IV for petrol entering the zone. From fig-10 abatement from enforcing stricter emission standards for buses, vans, coaches and taxis including some demand suppression.

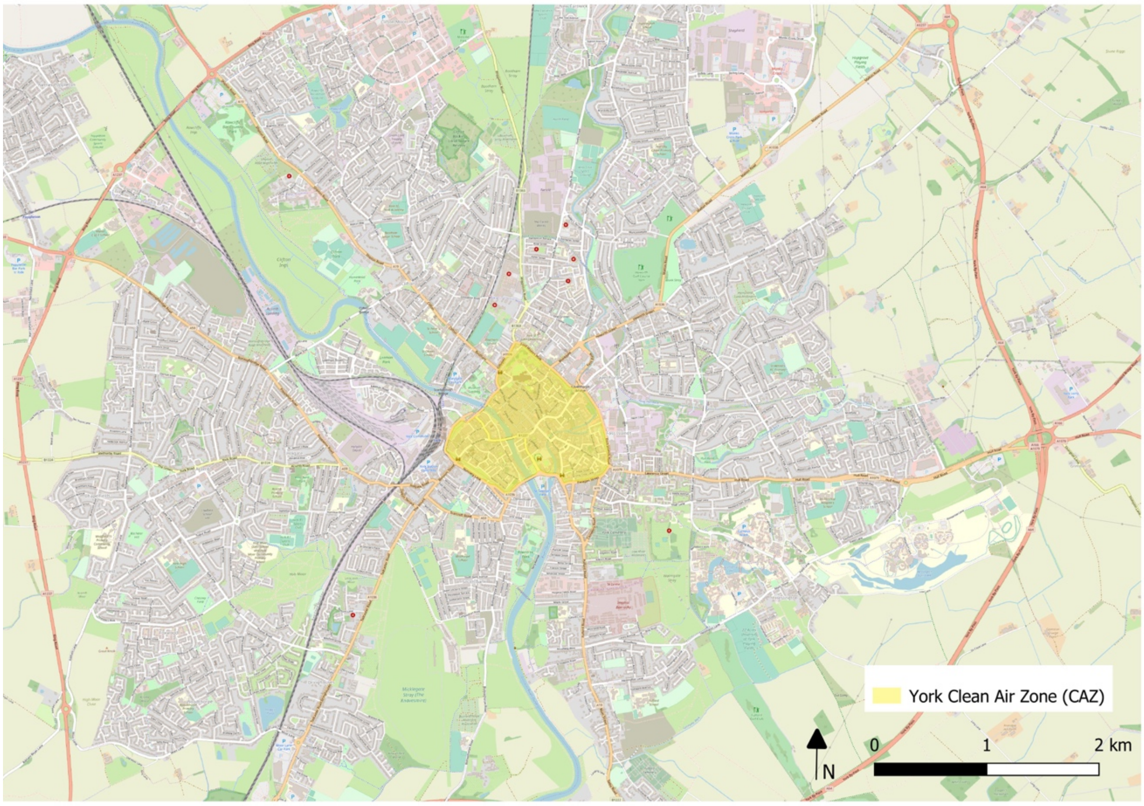



*Fig-9 York Clean Air Zone* (QGIS, 2019)

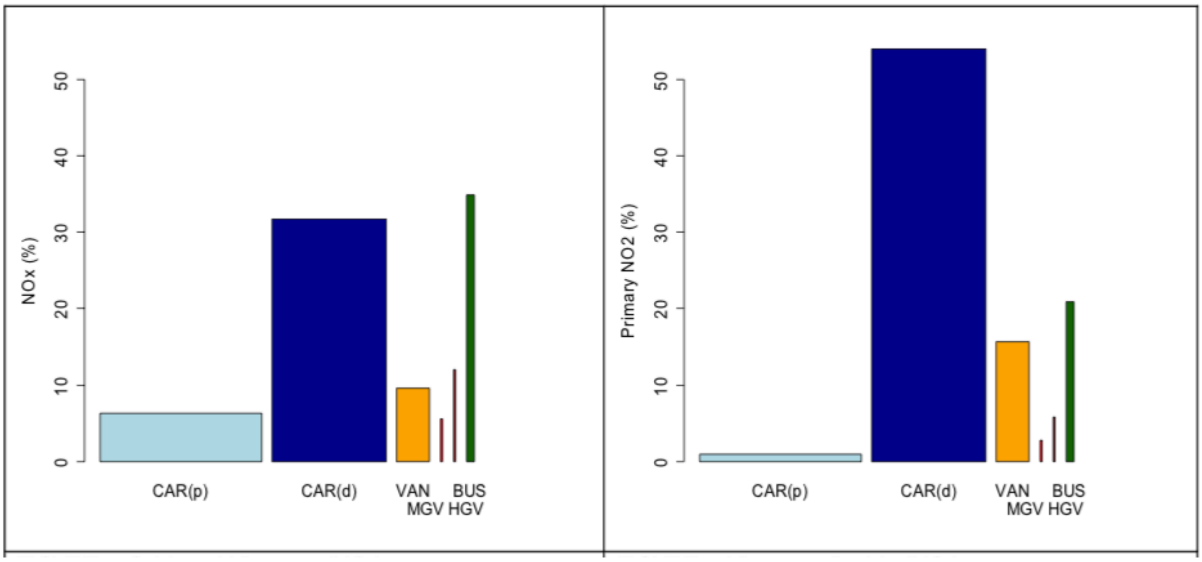



*Fig-10 Results form York remote sensing study by University of Leeds mentioned by* Bates, (2019)

Enforcement mechanism to be cost effective York can adopt labelling scheme similar to Berlin LEZ discussed above, use current/additional enforcement officers for compliance check. Initial implementation cost will require deploying stickers in York and surrounding regions, awareness campaigns and appropriate signages on streets. Ease of application/availability of stickers should be ensured with sufficient sunset period for business and residents (DEFRA, 2017).

Ethical Implications:

Air quality improvements from both LEZ's reduces exposure injustice to poor communities who are subjected to poor air quality and also emit the least pollution (Mitchell and Dorling, 2003). LEZ's exempting EURO-V/EURO-VI vehicles and encouraging purchase of progressive EURO standard vehicles or retrofitting to complying technologies not consistent with polluter pays principle instead of providing socially equitable mobility alternatives (Transport and Environment, 2018). LEZ/CAZ are economically vulnerable to vehicle rental and freight haulage business (specially small) as they might not be able to renew their fleet (Cruz and Montenon, 2016).

Conclusion:

LEZ/CAZ interventions help bring forward the benefits of improved air quality but it is important to note it only affects the traffic component of emissions, and pollutants like $PM_{10}$ often background dominates (Harrison et al., 2012). Also, modelling results and post implementation analysis with different statistical tests and different temporal data sets along with meteorological influences all together increases difficulty in examining effectiveness of LEZ (Amundsen and Sundvor, 2018).

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