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REVIEW ARTICLE

London air quality: a real world experiment in progress

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Abstract

London currently has the highest nitrogen dioxide (NO_2) concentration recorded for any European city and for particulate matter (PM) it has some of the worst hot spots. Therefore overall, for these two pollutants, London is the worst in the UK and amongst the worst in Europe. Exposure to elevated concentrations of air pollutants such as PM and NO_2 has well-established heath effects and most countries now have strict guidelines for air quality. London's air quality problems are driven largely by traffic. This, along with the high density of people in an urban area results in air quality guidelines being exceeded on a regular basis and large numbers of people being affected. In an attempt to combat London's air quality problems the Mayor of London introduced a series of measures to decrease traffic emissions. These included both a restriction on the number of vehicles entering central London each day – the Congestions Charging Scheme (CCS), and the discouragement of the most polluting heavy goods vehicles from entering – the London Low Emission Zone (LEZ). Together, it is hoped that these measures will lead to an improvement in air quality and provide a direct health benefit to Londoners. Research underway is charting the progress of this real world experiment.

Keywords: *Traffic emissions, respiratory health, air quality, particulates, nitrogen dioxide*

Introduction

Air pollution has been a serious problem in London since the 16th century owing to the city's importance as a commercial and industrial centre. As a consequence, the city has long been referred to as 'the big smoke' and has given its name to the combination of urban smoke and natural fog, namely 'London smog'. Concern over the health effects of London's poor air quality also dates back over many centuries. In 1661 the diarist John Evelyn presented Charles II with a treatise on the problem, suggesting that smoke pollution would shorten the lives of Londoners (Evelyn 1661). Nearly two hundred years later, an article in *The Lancet* stated that 'The air of this great city is, as all know too well, polluted by a variety of noxious gases and vapours diffused or held in solution'. The article went on in quoting the then Registrar-General as saying 'there can be no doubt that the dirty dust suspended in the air that the people of London breathe, often excites diseases of the respiratory organs. The dirt of the streets is produced and ground down by innumerable horses, omnibuses and carriages, and then beat up into fine dust, which fills the mouth, and inevitably enters the air passages in large quantities.' (Anon 1856). London's dominance as an industrial city and major port steadily declined during the 20th century, giving way to commerce and public administration as its major activities. Consequently, emissions of smoke and sulphur dioxide (SO_2) from industrial activities declined. Indeed, the annual mean black smoke (BS) concentrations fell 80-fold over the period from 1921 to 2005. In 1952, the infamous wintertime smog episode, claimed an estimated 4000–12 000 premature deaths (Logan 1953, Bell & Davis 2001), had a major impact on public health policies, leading to the 1956 Clean Air Act, the major focus of which was the curtailing of domestic coal burning in London and other major population centres in the UK. The 1956 Act reinforced the declining black smoke trends that were already well in hand due to structural changes in London's economy. Over the last 50 years coal burning has continued to decline, being replaced by centrally generated electricity and the use of natural gas in commercial premises and domestic homes.

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Air pollution in London in more recent times

In December 1991 a severe wintertime air pollution episode occurred in London, characterized by unprecedented levels of benzene, carbon monoxide (CO), oxides of nitrogen (NO_x) and in particular, nitrogen dioxide (NO_2) – all components of petrol-engined motor vehicle exhaust. In response to this, new air quality monitoring sites were established in and around London and the equipment base of existing sites extended. Continuous monitoring of particles with an aerodynamic diameter of 10 μm or smaller (PM_{10}) began to replace the original BS measurements. In order to co-ordinate the air quality monitoring established by the London Boroughs and to ensure spatial and temporal comparability, in 1993 the Environmental Research Group (ERG) at King's College London created the London Air Quality Network (LAQN). The establishment of the LAQN has generated a much clearer picture of London's air quality and the steps required to ensure its improvement. For example, what has emerged during the 1990s and early 2000s is that airborne particulate and lead concentrations have declined steadily following the phase-out of lead in petrol, while CO, benzene and 1,3-butadiene have fallen dramatically (with annual reductions of 10–20%) owing to the mandatory implementation of three-way catalysts and evaporative canisters in petrol-engined vehicles. In turn, the reduction in volatile organic carbon (VOC) emissions has produced a decline in the peak intensity of photochemical episodes. In contrast, the annual percentage reductions in NO_x levels (again achieved through the implementation of three-way catalysts on petrol-engined motor vehicles) of approximately 3–5% are substantially less than those achieved for CO and VOCs. This is because of the substantial and growing contributions to NO_x emissions from diesel-engined motor vehicles which, until recently, have not been the subject of emission controls. The increasing use of diesel-engined vehicles also means that PM is still of major concern despite the enormous reduction in BS levels. Concentrations of $PM_{10,}$ in fact, declined during the 1990s but these trends have slowed down and during the 2000s, levels have remained constant. So despite the air quality gains achieved in previous decades, like many other large cities around the world, London continues to experience high levels of air pollution, owing to a combination of mobile sources and regional background.

Air quality strategy

In view of widespread public concern about the health effects of air pollution, in 2002 the Mayor of London launched an Air Quality Strategy, entitled Cleaning London's Air. This strategy sets out policies and proposals to move towards the point where pollution no longer poses a significant risk to human health. The primary focus of the strategy is the reduction of pollution from road traffic as this is the main source of the pollutants of concern from within the city. In 2003, emissions from road transport contributed to approximately 40% of NO_x emissions and to 66% of PM_{10} emissions in the Inner London area. A reduction in London's road traffic emissions is being achieved in two ways: first, through a decrease in the number of vehicles on the road, and, second, through reduced emissions from individual vehicles (i.e. modernization of the fleet vehicle stock). To help achieve the first aim, the Mayor introduced a Congestion Charging Scheme (CCS) in central London on 17 February 2003 (GLA, 2002). One of the measures to tackle the second aim was a London-wide Low Emission Zone (LEZ), which was introduced on 4 February 2008.

The congestion charging scheme in London

The CCS in London is a vehicle-charging scheme, initially covering approximately 22 km^2 or 1.4% of the Greater London Area, and containing some of the most congested conditions in the capital (Transport for London (TfL) 2004). On 19 February 2007, the congestion charging zone (CCZ) was extended westwards and it now covers approximately 41.5 km^2 or 2.6% of the Greater London Area (Figure 1). The designated zone is clearly defined by signs and/or road markings at entrance and exit points. Vehicles crossing a cordon line to enter the CCZ between the weekday hours of 07:00–18:00, termed the congestion charging hours (CCH), pay a daily charge of what was originally £5 ($10), but in July 2005 this was increased to £8 ($16). The charge does not apply on Bank (National) holidays or the first three charging days that follow 26 December each year. Those exempt from the charge include disabled people or institutions for the disabled throughout the European Union that hold a Blue Badge, drivers of roadside recovery vehicles, accredited breakdown organizations, drivers of electrically propelled vehicles, vehicles with nine or more seats registered as a bus and motor tricycles 1 m or less in width and 2 m or less in length. In addition to these exemptions, discounts are available to residents living within the CCZ (90%) and drivers of alternative fuel vehicles (up to 100%). Assisted by revenue from the CCS, parallel improvements in the fleet of public transport vehicles and traffic management have been implemented to accommodate the shift in travel patterns following the introduction of the charging scheme as well as continued growth in demand.

The main objective of the CCS was to achieve a 15% reduction in traffic in central London and zero growth in inner London and each year, the principal traffic and

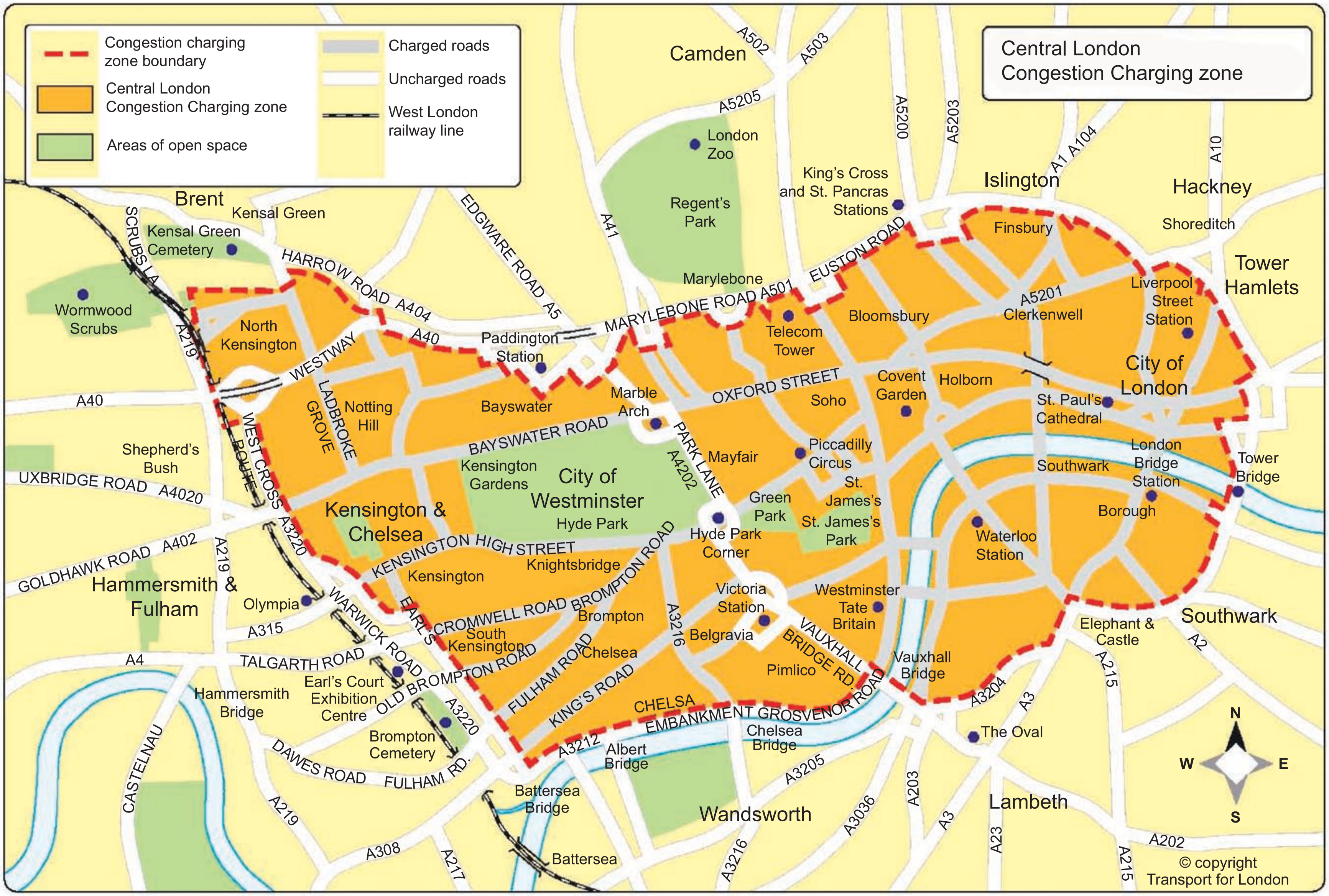

Figure 1. The extended central London congestion charging zone.

transport objectives have been met, mirroring the effectiveness of similar schemes in Singapore, Stockholm and Norway (Chin 1996, Tuan Seik 2000, Victoria Policy Transport Institute 2007). Changes to travel patterns (e.g. traffic entering the CCZ, congestion and speeds) arising from the scheme in 2003 occurred very quickly; however, changes in the period since, have tended to reflect wider traffic trends and possibly effects (from both the CCS and other transport schemes in London) that have developed more slowly.

How has it worked?

After 1 year of operation of charging, traffic (vehicles with four or more wheels) entering the charging zone during charging hours had reduced by 18%, whilst the most recent results from TfL illustrate that such a reduction continues to be maintained. In relation to pre-charging conditions in 2002, traffic entering the CCZ during 2006 was 21% lower (TfL 2007). In contrast to the within-zone findings, traffic on the inner ring road (the boundary of the CCZ along which no charge is applied) has remained similar to levels before the introduction of charging. As one would expect, the immediate (1 year following) effect of the CCS was to reduce the number of potentially chargeable vehicles (i.e. cars, minicabs, vans and lorries) entering the central London charging zone during charging hours, whilst non-chargeable vehicles such as licensed taxis, buses and two-wheelers all increased (TfL 2007). Comparing values for 2006 against those for 2003, further declines across most vehicle types were seen. The overall impact of the CCS on congestion (i.e. rate of travel) is a more complex one to interpret. During 2003 and 2004, levels of congestion in the charging zone were typically around 30% lower than those in 2002 (TfL 2004). However, since 2004, some increase in the level of decongestion inside the charging zone became apparent, such that the average congestion reduction, comparing 2005 with 2002, was 22% (TfL 2006a). Moreover, during 2006, despite the continued reduction in traffic outlined above, it is apparent that there was an increase in congestion, which correlates with an increase in road works plus a gradual longer-term trend of increased congestion across London. The reduced levels of traffic maintained in 2006 mean that, when compared with conditions without the scheme, congestion relief is still broadly in line with the 30% reduction achieved in the first year of operation. However, a direct comparison of 2006 congestion levels with the pre-charging baseline gives an average 8% reduction (TfL 2007).

Similar road pricing schemes are being considered for other UK cities and it is likely that traffic zonal payment schemes will become more common elsewhere in the world. Indeed, Milan introduced such a scheme on a test basis at the beginning of 2007 to address the city's severe air pollution and traffic problems, whilst New York came close to becoming the first major American city to introduce a traffic congestion charge in 2008. The CCS in London is therefore a likely forerunner in what may become a powerful and widely adopted approach to traffic demand management.

The CCS and air quality in London

There is considerable interest in determining whether or not the reduction in congestion and traffic achieved in London following the implementation of the CCS has had a positive impact on the air quality in London. If this was the case then such an outcome could be used to support decisions about road pricing schemes that are being considered in other cities around the world.

In principle the CCS, in reducing congestion and the numbers of vehicles crossing the cordon, should reduce emissions and improve air quality both inside and outside the CCZ. However, not only is this an unrealistically simple assumption, but in addition, the process of evaluating a step change in traffic management itself, will inevitably be met with a number of challenges. For this particular exercise, one would not expect the CCS to elicit more than a small effect on air quality within the zone, considering the charge has brought about a relatively moderate effect on traffic (approx 20% reduction in vehicles entering the CCZ) in a small (1.4% Greater London) area of London. This is particularly the case when one considers the host of other contributors to emissions both within London and from Regional background. For example, changes in association with the CCS in traffic flows and vehicle speeds have the potential to produce both increases and decreases in PM and NO_x emissions. In addition, improvements in public transport vehicles (and with this, an increase in the number and flows of diesel-powered buses and taxis entering the CCZ), the introduction of traffic management measures and the magnitude and location of road works are also likely to have air quality impacts. Furthermore, whether or not the CCS results in changes in air quality in London, depends on factors such as the magnitude of any changes in emissions, vehicle flows and/or speeds and the location of air quality monitoring sites. The HEI London Consortium is currently undertaking a programme of work to address these issues.

The London-wide low emission zone

The key driver for the introduction of the LEZ was the need to improve the health and quality of life of people who live and work in London through improving air quality (GLA 2002). In addition, the scheme is designed to move London closer to achieving national and EU air quality objectives for 2010. The LEZ is designed to tackle these objectives by restricting the entry of the oldest and most polluting vehicles across greater London, an area of 2644 km^2 (London Mayor 2007). The scheme operates 24 h a day, 365 days a year, using cameras to identify the registration numbers of vehicles and the Driver and Vehicle Licensing Agency (DVLA) database to identify a vehicle's emissions. The LEZ applies to diesel-engine heavy goods vehicles (HGVs), buses and coaches, larger vans and minibuses (Table 1). The LEZ initially (from 4 February 2008) targeted vehicles with disproportionately high emissions (lorries over 12 tonnes), obliging them to meet modern Euro emission standards which set limit values for exhaust emissions for new vehicles (see http://www.tfl.gov.uk/roadusers/lez/vehicles/2535.aspx). This first phase of the LEZ was followed by the inclusion of lighter HGVs, buses and coaches on 7 July 2008, and large vans and minibuses will be included from 3 October 2010. Specifically the LEZ will require heavy duty vehicles to meet the Euro III emission standard for PM_{10}, which will then change in 2012 to Euro IV. A standard for NO_x has not been included as part of the proposed scheme as there are currently too many unresolved issues about certification and testing of NO_x abatement equipment. With respect to cars, while it has been decided that the LEZ should concentrate on the most individually polluting vehicles at this time, the Mayor, in response to requests during the consultation period, has asked TfL (the Governmental authority managing the LEZ) to investigate the implications of including cars in the LEZ at a later date.

The stick and the carrot

In order to deter high-polluting vehicle use, and provide an incentive to operators to upgrade their vehicles, operators of targeted vehicles that do not meet the LEZ standards are required to pay a charge of £200 ($400;

Table 1. Details of vehicles to be included in the low emission zone (LEZ) and minimum emissions standards.

Vehicle type and definition	Date affected	Required emissions standards
Heavier lorries	February 2008 – Euro IIIJanuary 2012 – Euro IV	All Euro III vehicles meet the LEZ standard
Heavy diesel-engined vehicles exceeding 12 tonnes Gross Vehicle Weight, including goods vehicles, motor caravans, motorized horseboxes and other specialist vehicles		Vehicles first registered as new on or after 1 October 2001 are assumed to be Euro III, so will meet the LEZ emissions standards
Lighter lorries	July 2008 – Euro IIIJanuary 2012 – Euro IV	Vehicles not meeting the emissions standards could be made to do so by modifying them to meet the Euro III standard for particulate matter
Heavy diesel-engined vehicles between 3.5 and 12 tonnes Gross Vehicle Weight, including goods vehicles, motor caravans, motorized horseboxes and other specialist vehicles		Vehicles not meeting the emissions standards would need to pay a daily charge if used within the LEZ.From January 2012 the required emissions standards are raised to Euro IV. All Euro IV vehicles will meet the LEZ standard
Buses and coaches		
Diesel-engined passenger vehicles with >8 seats plus the driver's seat exceeding 5 tonnes Gross Vehicle Weight		Vehicles registered as new on or after 1 October 2006 are assumed to be Euro IV, so will meet the LEZ emission standards
		Vehicles not meeting the emissions standards could be made to do so by modifying them to meet the Euro IV standard for particulate matter
		Vehicles not meeting the emissions standards would need to pay a daily charge if used within the LEZ
Large vans	October 2010 – Euro III	All Euro III will vehicles meet the LEZ standard
Diesel-engined vehicles between 1.205 tonnes unladen and 3.5 tonnes Gross Vehicle Weight and motor caravans and ambulances between 2.5 tonnes and 3.5 tonnes Gross Vehicle Weight		Vehicles registered as new on or after 1 January 2002 are assumed to be Euro III, so will meet the LEZ emission standards
Minibuses		Vehicles not meeting the emissions standards could be made to do so by modifying them to meet the Euro III standard for particulate matter
Diesel-engined passenger vehicles with >8 seats plus the drivers' seat below 5 tonnes Gross vehicle weight		Vehicles not meeting the emissions standards would need to pay a daily charge if used within the LEZ

lorries, coaches and buses) or £100 ($200; vans and minibuses) for each day they are driven into the zone. Furthermore, should an operator of a non-compliant vehicle not pay the daily charge, then following the service of a penalty charge notice, penalty charges of £1000 ($2000; lorries and busses) or £500 ($1000; vans and minibuses) apply, reduced by 50% if paid within 14 days or increased by the same increment if not received within 28 days. Those exempt from the charge include UK and foreign military vehicles (not registered with the DVLA or European equivalent), pre-1973 historic vehicles, off-road vehicles (e.g. tractors and diggers) and circus vehicles. Of note, the majority of vehicles affected by the LEZ do not pay a charge, not because they are exempt, but because they meet the minimum emissions standards set by the order (see http://www.tfl.gov.uk/roadusers/lez/vehicles/2535.aspx).

LEZs elsewhere in the world

LEZs for freight vehicles have already been successfully implemented in Sweden since 1996 when Stockholm, Gothenburg and Malmo (extended to Lund in 2002) introduced 'Environmental Zones' in their city centres, to improve air quality and reduce noise (Watkiss et al. 2003). Tokyo has been a LEZ since October 2003 and again has been successful in reducing emissions of HGVs. More recently Berlin has developed plans to implement a LEZ in the central city area. Such schemes are also being considered by other UK (Oxford and Greenwich) and European cities (Suceava, France and Amsterdam, The Netherlands). The London LEZ is the largest such zone in the world and the first to use a charging mechanism rather than an outright ban.

Potential health and environmental impacts of the LEZ

Poor air quality is known to have marked effects on certain, sensitive individuals (Table 2). It also seems that the young and the elderly are generally more sensitive to air pollution. In that the LEZ will be implemented across the whole of Greater London, an area in which more than 8 million people live and work, suggests the scheme has the potential to bring about a range of health benefits for London residents. In preparation for the scheme, a wide-ranging modelling program, to understand the likely impacts of various LEZ scenarios, has been undertaken by TfL in cooperation with ERG at King's College London (http://www.london-lez.org). Results from this work show that the LEZ could provide small improvements in London's air quality. For example, the LEZ is predicted to reduce the emission of PM_{10} in London by 64 tonnes (or 2.6%) in 2008 (TfL 2006b), and in turn, decrease the area of Greater London that exceeds the EU air quality limit values for PM_{10} of 40 μg m^{-3}. Furthermore by 2012 emissions of PM_{10} would be decreased by 6.6% and the area of London exceeding this annual mean PM_{10} objective would have reduced by 16.2% compared with the baseline – the situation without the LEZ (TfL 2006b). For the annual mean objective for NO_2 it is predicted that the LEZ will help progression towards meeting the UK objective and EU limit value of 40 μg m^{-3}.

Modelling suggests that in 2008, the LEZ will decrease emissions of NO_x by 1288 tonnes, or around 3.8% of the total tonnage emitted (Tfl 2006b). This would lead to the area exceeding the annual mean NO_2 objective for 2010 to decrease by 3.7% (TfL 2006b). In 2012, the LEZ would reduce NO_x emissions by 2475 tonnes, which would reduce the area exceeding the annual mean NO_2 objective by 15.6% (TfL 2006b). Given the overall decline in air pollution, the LEZ would effectively bring forward the attainment of air quality standards, by up to 3–4 years (TfL 2006b).

Studies to support the supposition that such a traffic intervention scheme could lead to improved health, include those indicating that living in the vicinity of roads carrying heavy duty traffic is associated with an increased prevalence of chronic respiratory symptoms (Brunekreef et al. 1997, Venn et al. 2001, Nicolai et al. 2003). Moreover, convincing evidence is available which suggests that children attending schools close to motorways with high

Table 2. Health impacts of air pollution. For most people, pollution levels in the UK are unlikely to cause any serious health effect; during particularly severe pollution episodes, eye irritation or coughing may be triggered. Certain sensitive individuals who are more susceptible to pollution may feel the effects more acutely, or at lower levels. These individuals include those who suffer from heart and lung disease, including asthma and bronchitis, especially young children and the elderly. Actual effects will, of course, vary from person to person, and individuals will learn from experience how they are affected by pollution. The Air Pollution Banding system is intended to make air quality information more meaningful. The table shows the four bands and their impact on the health of people who are sensitive to air pollution.

Pollution band (index)	Health impact
Low (1–3)	Effects are unlikely to be noticed, even by people who know they are sensitive to air pollution
Moderate (4–6)	Mild effects are unlikely to require action, but may be noticed by sensitive people
High (7–9)	Sensitive people may notice significant effects, and may have to take action to reduce or avoid them (for example, by reducing time spend outdoors). Asthmatics will find that their 'reliever' inhaler is likely to reverse the effects of pollution on their lungs
Very High (10)	The effects on sensitive people, described for 'high' levels of pollution, may worsen

truck traffic counts in the Netherlands experienced more respiratory symptoms than children attending schools near motorways with low truck traffic counts (Janssen 2003). Also of relevance are studies of the relationship between proximity to road pollution and the prevalence of lower respiratory symptoms (Studnicka et al. 1997, Shima et al. 2003), as well as associations between traffic-related pollution and upper respiratory problems (Brauer et al. 2006). A number of cohort studies have observed intra-urban variations in mortality associated with air pollution (Hoek et al. 2002, Finkelstein et al. 2004, Nafstad et al. 2004, Jerrett et al. 2005, Gehring et al. 2006), whilst three of these relate specifically to proximity to traffic (Hoek et al. 2002, Finkelstein et al. 2004, Gehring et al. 2006). In the city of Duisburg in Germany, an association between exposure to traffic and coronary atherosclerosis was recently reported (Hoffmann 2007). If real, this would provide a link with cardiovascular mortality, and may be reflected in greater morbidity from coronary heart disease (CHD).

It should be noted that despite the studies outlined above, the causality of associations between traffic-related air pollution and impacts on respiratory and cardiovascular health is still open to debate. To strengthen the causal argument, evidence that reductions in pollution, specifically in traffic-related pollutants, deliver quantifiable improvements in respiratory health is required. The LEZ and the CCS together provide the means by which air quality in London should gradually improve and, in doing so, provide a health benefit to Londoners.

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