14 Cost Effective Actions to Cut Central London Air Pollution

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Par Hill Research Ltd, Science, Environment & Policy Research

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Executive Summary

Great strides have been made in cutting Central London air pollution in the last 60 years and London's air is now the cleanest it has been since the 1800s. But significant local pollution remains and leads to the early deaths of hundreds of Londoners each year as well as breaches of UK and EU law, so continuing action is warranted. Having dealt with the smoke stacks and filthy vehicle motors of the past more difficult, potentially expensive and novel actions are now needed. To meet this need some 400 documents were examined across 94 possible actions drawing from examples on three continents and compared for their costs and benefits. Fourteen actions were found that are expected to be cost effective in London, with Benefit-to-Cost Ratios in the range 22 to 2.

Some cost effective actions can be delivered immediately, although they are small in total air pollution impacts. They are also highly visible symbols of councils commitment to improve air quality. They are:

- business engagement programmes, such as CityAir;
- expansion of car clubs, which raise revenue, reduce car use and pollution;
- ecodriving training for taxi drivers, saving money and pollution;
- iuse of competitively priced zero emission services where they exist;
- idling enforcement at large taxi ranks to get driver to switch off engines;
- if an exceedence is forecast, advertising to discourage polluting vehicles across London and CMA application on the most polluted roads.

These actions would reduce emissions in Central London by about 2%pa, and in-day by 7%-9% for advertising and 14% using CMA. Larger reductions can be achieved using the following actions, which would save £248Mpa and reduce air pollution impacts by 4,768t.pa of NOx and 81t.pa of PM.

Vertical roof exhausts on buses are low cost and have been demonstrated to cut emissions impacts by about 90% in the USA and Australia and should be implemented in London. Many Euro IV bus engines can be cheaply reprogrammed to have Euro V emissions. By doing so, a sufficient fleet of Euro V buses can be assembled for all Central London routes to be delivered using only Euro V buses or better. Diesel Particle Filters can eliminate 99% of PM exhaust from Euro III taxis at low cost and these should be required. All three of these measures can be implemented cost effectively using an LEZ.

The GLA's proposal to require new buildings to be air quality neutral is essential to reducing building pollution. Often CSH or BREEAM Level 4 compliance delivers this, or for more intensive developments Passivhaus compliance. Old gas boilers should be replaced by ultra-low NOx boilers when replaced instead of Class 4 or 5, reducing emissions by 40%-60% more at no extra cost. Energy efficiency should be accelerated and uptake of Warm Front and other schemes should be encouraged by councils. In all cases wood fuels should be avoided.

Cycling is very cost-effective, saving typical commuters £740pa. TfL research shows that 61% of Central London journeys can easily be cycled. Financial and air pollution evidence strongly supports cycling becoming the top priority road transport mode in Central London, with target modal share of 10%-15% being achievable. To deliver this, London's seven cycle networks need to be harmonised, integrated and re-signed. Cycle lanes should eventually be converted to tracks when pilot schemes to trial low costs designs for cycle tracks are complete. Cycle hire is the most cost-effective way to increase cycling, and should be expanded across Inner London once funding permits.

Extensive vegetation can substantially reduce air pollution in its immediate vicinity. Evidence suggests lower cost planting methods exist than those currently used and these should be investigated. Evidence suggests that a Crossrail station at Kensal Rise is likely to reduce local air pollution.

Dedication

The best ideas contained herein stemmed from conversations with my friend and colleague Gwyn Jones MSc (1969-2011), a formidable scientist, a proud Welshman and a great believer in action on air pollution rather than words. Some of his proudest moments off the rugby pitch were when he helped such action to happen in his adopted home of Oxford.

I. Kilbane-Dawe, June 2012

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INTRODUCTION

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THE STRATEGIC APPROACH
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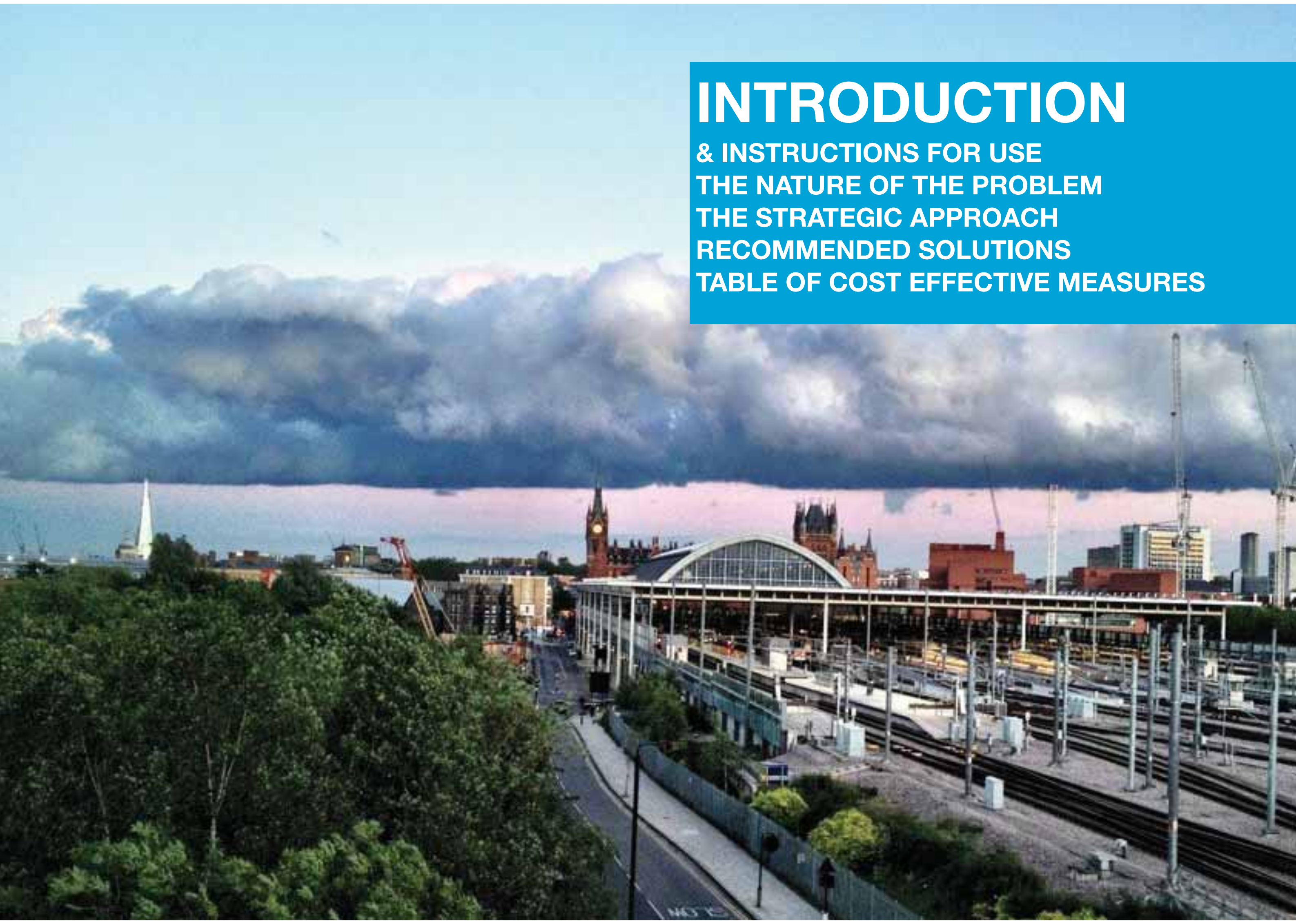


Introduction

Concerns about London's air pollution have existed for hundreds of years - the earliest known air pollution regulation in London was a ban on coal fires by Edward I in the 1300s. The Great Smog of 1952 killed 5,000 Londoners and prompted decades of strong action, reinforced by scientific evidence on the effects of pollution on cancer, heart disease, acid rain and so on. The result is that London's air pollution - while still higher than is recommended or legally permitted in many areas - is certainly the cleanest its been in 100 years, and more likely the cleanest its been since the beginning of the industrial revolution.

Cleaning London's air further means gradually eliminating the remaining intense sources of pollution - like taxis, buses and old gas boilers - in a cost effective way, that doesn't ask the impossible of the individuals and organisations who have invested in them. It also means ensuring that new sources of air pollution - such as biomass heating fuel - are nipped in the bud before damage is done.

This report identifies fourteen such actions, based not on the work of the author, but that of the hundreds of experts who wrote the 400 studies on which it is based. It is the product of the contribution of many transport, buildings and environment experts, in councils, the GLA, TfL, Defra, in private firms and from other cities, who freely gave their expertise during meetings to discuss practical ideas and options for air pollution reduction.

How To Use This Document

The document can be used both to inform a general audience on air quality and what to do about it (Executive Summary and Chapter 1), to help design detailed plans on major measures to reduce air pollution over time or in-day using the Frameworks in Chapters 2 and 3, or to quickly assemble a set of cost-effective measures that are very visible and capable of delivering small but effective pollution and cost reductions, as described in Chapter 4.

The document contains a wealth of supporting evidence, with over 70 of the referenced documents included in an accompanying database. For each action, both high impact, acute episode and quick win, a short summary with key data is provided at the beginning, including socio-economic and cost-benefit analysis summary figure that can be used to support discussion and policy development. These data are also presented as a summary table (page 12) which can be ranked by BCR, cost etc in order that measures can be understood and ordered according to the local priorities of the Authority in question.

In addition to the References Database, a Document Compendium is available which includes about 400 documents, files and databases which have been used or referred to during the study, in unsorted format.

The Nature Of Central London’s Air Pollution Problem

London is the greatest city in the World and Central London is her beating heart. A major engine of World growth and employment, Central London has two million residents and employs two million people of whom 95% commute in [TfL, 2010a]. It generates GDP of £120Bn [Eurostat, 2009], more than Kuwait, Qatar and 140 other countries. Travelling in by bus, train, car, and taxi each day we cause 9 tonnes of toxic nitrogen dioxide (NO2) and 560kg of toxic particulate air pollution (PM) to be emitted [LAEI, 2008], as well as thousands of tonnes of CO2. Heating our homes and workplaces releases 3,000t of NO2, 30t of PM, and megatonnes of CO2 each year [ibid]. More air pollution comes from aircraft, rail and road services for business and leisure travellers, and yet more is blown in from upwind power stations and shipping. London’s buildings and airports and the ships and power stations upwind create a background miasma of elevated PM and NO2, while the crowded roads and dense buildings of the Centre create hotspots (Exhibit 1), which often merge to cover large areas exposing millions.

People have worked on cleaning up London’s air since the 1840s when smoke from London’s lime kilns was first regulated. Power stations have been closed or cleaned up, coal burning banned, vehicle engines redesigned, millions of catalytic convertors and filters fitted to vehicle exhausts and novel regulations like the congestion charge and LEZ implemented. As a consequence air quality has improved enormously, but despite the numerous actions already taken, Central London still has air pollution levels that harm the health of commuters and residents alike, whether compared with UK, EU or World Health Organisation standards [LAQN, 2012]. Pollution levels consistently breach UK and EU legal limits and medical evidence suggests that several hundred Londoner’s die younger each year due to locally emitted air pollution [Miller, 2010], similar to the number of those killed on London’s roads each year.

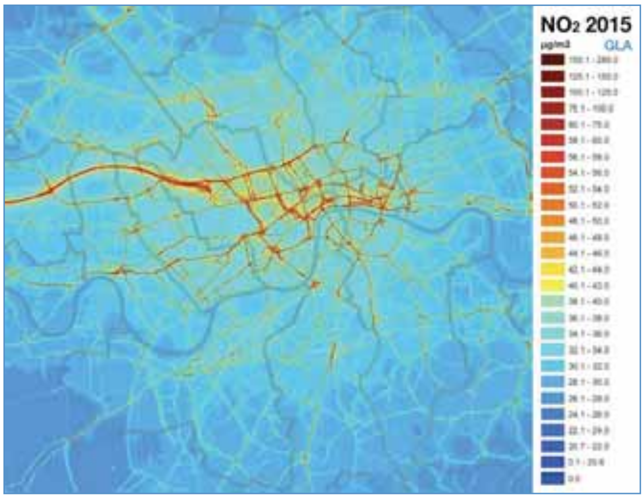


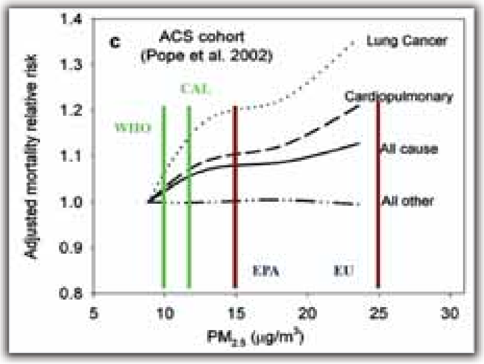
Exhibit 1: *Expected annual average concentration of toxic NO2 gas in Central London in 2015. Yellow, red and brown areas are above UK and EU legal limits. About 30% of NO2 is released from vehicle exhausts, hence the high levels around roads. The remaining 70% from buildings, aircraft, industrial processes and diesel trains contributes to a background miasma of air pollution. Map courtesy of the GLA.*

The extent to which people are affected by air pollution is very strongly influenced by their proximity to the pollution source, the pollutant type, and the state of their own health [Pope, 2002]. The old and the young are particularly vulnerable, as are those suffering from ill health. During moderate or high pollution episodes, vulnerable individuals can try to cope with the pollution by avoiding the most polluted areas when outdoors and ensuring they have a supply of their medication, particularly people with asthma or COPD [COMEAP, 2011]. Over the long term, breathing polluted air for years affects everyone and reduces lifespan through increased likelihood of developing cancer, heart failure, stroke, asthma, COPD and other serious illnesses (Exhibit 2). Diesel exhaust is a known carcinogen and exposure should be reduced [WHO, 2012].

Pollution levels fluctuate constantly in response to changes in pollution sources, wind, heat induced overturning of air and the chemical reactions that pollutants undergo as they react with each other, with rain and with sun. In a matter of minutes pollution can go from low levels to toxic levels [AQEG, 2004 & 2005] as winds drop, traffic builds up releasing exhaust fumes, the exhausts and wheels blow previously settled PM dust back into the air and sunshine drives chemical reactions that convert NO2 into both toxic ozone gas and chemicals that create additional PM pollution. These fluctuations are monitored at 48 sites across London on an hourly, daily and annual basis both to understand the processes that drive the pollution and to monitor compliance with UK and EU air pollution laws [LAQN, 2012]. The conditions that lead to moderate or high pollution episodes in London are well understood. Some are largely beyond our control, for example during atmospheric inversions, when the air over London develops a structure that traps any pollution that is released in the city, sometimes allowing it to build up for days at a time. Or when we experience light easterly winds and they carry pollution to London from the great urban and industrial centres of Europe, such as the Netherlands and the Ruhrgebiet.

Other conditions that cause moderate and high pollution episodes are directly under the control of Londoners and are a result of the choices we make, both individually, collectively and politically. Intense, dense traffic causes higher emissions of pollution during the rush hour when 200,000 of us take cars, buses or taxis into the centre for work or taking our children to school [TfL, 2010a]. In principle, these emissions could be avoided through better spatial planning and traffic management or different choices of traffic mode. During cold weather, in our efforts to keep warm and healthy we tend run our heating more. This too releases more pollution, but is exacerbated by the fact that many of us live in poorly insulated dwellings with old and inefficient gas boilers

Exhibit 2: *The Relative Risk of fine PM particles (PM2.5) shows how higher concentrations of PM cause higher levels of disease. Also shown are the WHO, California, US EPA and proposed EU limits on PM2.5 concentrations. Exhibit courtesy of B. Brunekreef, U. Utrecht.*



[Cambridge, 2009]. Better home insulation would save both money, air pollution and lives. The increasing prevalence of extensive, poorly considered glazing in buildings means that workplaces and homes make increasing use of air conditioning in hot weather, driving emissions from power stations. And the needs of developers to conform to carbon emissions targets using what they perceive to be the simplest approach available has increased the use of wood and other biomass burning for heat. This emits huge amounts of smoke and threatens to overturn 20 years of progress in air pollution reduction in London [AEA, 2007].

To avoid the long term pollution exposure that leads to cancer, heart disease and other major disorders, Londoners are faced with only two choices: to leave London for a cleaner place, or to act to reduce the pollution emissions that we generate, both individually and collectively. If we choose to act, we must choose carefully, as every action has costs as well as benefits. We consider how to carefully choose between potential actions on the next page.

Strategic Approach To Assessing Actions

Delivering the actions needed to address air pollution often involves overcoming complex social, economic, political and sometimes emotional and ideological hurdles. For example, although London's Black Taxis are the source of more than 50% of exhaust PM in Central London, their iconic design is widely cited as impeding renewal of the taxi fleet to cleaner vehicles, as it restricts political options in opening the market to alternative designs. To succeed in addressing such daunting challenges, dispassionate and clear evidence is required that looks at the whole cost of a potential action. The general strategic approach required - and the approach taken here - must be comprehensive, taking account of the costs and benefits to all those affected, and considering whether an action can realistically be delivered given the regulatory environment and the actions' economic and social consequences, and whether the action is worthwhile given the effort needed to deliver it versus the benefits it would bring. This is strategy the used in this work.

This work compared 94 potential actions that could be applied in Central London, using a holisitic, quantitative approach combining financial, environmental, regulatory, civic and socio-economic factors. An initial long-list of 94 potential actions was derived from interviews with more than 40 transport, sustainability, climate, planning, forestry, environment and air quality officials, NGOs and scientists in London, San Francisco, New South Wales and New York. Additional enquiries were made in Barcelona, Seville, Amsterdam, Copenhagen and Sweden. A desk based review of over 400 official reports, peer reviewed publications and databases allowed 44 of these to be eliminated or amalgamated, giving a short-list of 50 actions. These 50 were discussed in a round-table workshop with 10 experts on regulation of Central London's air quality for their regulatory and civic feasibility and reduced to a final list of 27 actions to be studied in detail. In four cases work is ongoing elsewhere and additional study would have been duplication. The remaining 23 were examined in detail and included actions in the transport, buildings, business operations and behaviours sectors. The methodology used was the holisitic co-benefits approach set out in DfT's highly regarded Transport Analysis Guidance (TAG) [DfT, 2005]. This expresses the overall benefits and costs of an action in terms of a monetary Benefits:Costs Ratio (BCR), derived from the Net Present Value in 2012 of quantitative estimates of;

- the cost reductions arising from the action, say from fuel savings;
- air quality benefits of the action as IGCB Damage Cost [Defa, 2009];
- the HMT Shadow Price of Carbon reduction from any carbon reductions;
- any other financial costs or benefits such as higher fares, income from PCNs, camera installation costs, increased cycling etc;

The HM Treasury Deflators were used as the discount factor. A qualitative assessments of noise impacts of the action was included, though some aspects of TAG were beyond the scope, including impacts on historic buildings and biodiversity. Under TAG, a BCR greater than about 2 is considered suggestive of a cost effective action, so actions with BCR of around two or more have been highlighted and divided into three major categories:

- large Impact Actions, that can cut emissions from a sector by 10%;
- episode Reduction Actions, that can cut emissions locally by 5%-10% in-day during a high air pollution episode;
- quick Win Actions, with a BCR >> 2, but a small impact.

The actions are described in either a detailed Framework or short Factsheet, depending on their scale or benefits. Those not recommended are described last, and additional information on a Crossrail station is also included.

Recommended Actions

BUSINESS ENGAGEMENT PROGRAMMES (BCR > 22, £4M savings), in which large businesses with major centres in the area are engaged on a 1-2-1 basis and programmes that reduce air pollution and costs are enacted.

CAR CLUBS (BCR > 13, £8M revenues) should be expanded as quickly as possible using clean cars. They reduce use of cars and replace dirtier cars with cleaner. They also generate net revenue for councils.

ECODRIVING TRAINING (BCR 6, >£7M savings) programme rolled out to all taxi drivers will save them money, cut air pollution and improve road safety.

ZERO EMISSION LAST MILE DELIVERIES (BCR 4) can be delivered competitively by a number of companies in Central London, whether stationery firms, taxis, couriers or supermarkets. A Central London list of service providers should be drawn up and their use recommended in public and private procurement (such as in Business Engagement Programmes).

IDLING ENFORCEMENT (BCR 4) should be applied experimentally to taxi ranks with 200 taxis, such as Paddington Station. If good compliance is achieved it should be rolled out to smaller ranks. It is unlikely to be cost effective for buses, LGVs or HGVs, except for bus stands of 7 or more.

CAMPAIGN DAYS (BCR 1.7) to reduce in-day car and taxi use through public advertising should be planned for next Spring. **Spraying CMA dust suppressant** (BCR 1.7) is also effective in the worst polluted streets.

These seven won't substantially reduce air pollution. To do this, the following large impact measures are recommended, which can also save £248M.pa.

VERTICAL ROOF EXHAUSTS ON BUSES, A EURO V ONLY CENTRAL BUSES ZONE, and **RETROFIT OF ALL EURO III TAXIS WITH DPFs,** should be implemented and could be enforced through a sectorally agreed LEZ in the Centre, with the threat of an enforced TRO based LEZ. Pilot projects testing the effects of roof exhausts, Euro IV bus engine reprogramming and DPFs on Euro III taxis should be implemented immediately.

The GLA proposal requiring **NEW BUILDINGS TO BE AIR QUALITY NEUTRAL** is essential. This can be delivered cost-effectively by **REQUIRING CSH OR BREEAM LEVEL 4** in many cases, or the Passivhaus standards for more intensive developments. Ensuring old **BOILERS ARE REPLACED BY ULTRA-LOW NOX MODELS INSTEAD OF CLASS 4 OR 5** will reduce emissions by a further 40%-80%. Uptake of Warm Front, CERT, Green Deal etc should be encouraged by councils. Wood fuels must be avoided.

CYCLING (BCR > 2.5 and probably much higher) should be reclassified as the primary mode of road transport in Central London for money saving, health and air pollution reasons. A staged approach can initially emphasise high benefit, low cost actions such as **cycle to work schemes**, trials of **low-cost cycle track designs** and **co-ordination of cycle promotion, training campaigns and events across councils**. Later **improved and harmonised signage and way-finding across the current several hundred km of Central cycle lanes** would both advertise the infrastructure and improve journey times and safety. Once low-cost designs are proven, the **cycle lanes should be upgraded to tracks** everywhere that roads are wide enough. Finally, **accelerating expansion of the Cycle Hire scheme** is likely to substantially add to cycling numbers.

Symbols illustrating the action's key advantages

- 22 — High Benefits:Costs Ratio, BCR figure for 2012 shown
- 1.3 — Strong PM Reduction, Tonnes per annum
- Star — Councils Leading by example
- £4M — Cost savings or revenue generation, Millions of 2012 £
- 400 — Strong NOx Reduction, Shown in tonnes per annum

Recommended Actions

Table of Cost Effective Actions

All figures given are approximate, based on the evidence available. For full details of each action see the Full Guidance document.

Measure	Impact timescale from policy decision	Ratio of total Benefits / total costs	Benefits (NPV in 2012)	NOx reduction tpa	PM10 reduction tpa	CO2 reduction tpa	Noise improvement
Replacement of old boilers with Ultra-low NOx devices	Years-Decades	Infinite (as zero cost)	Not calculated	566.00	8.00	Not estimated	0
Business engagement (ongoing for 6 years)	Months	22.11	£4,630,096	0.07	0.01	34.92	+1
Car Clubs Expansion Programme	Months	13.58	£7,558,993	28.53	1.40	26,915.65	+1
Cycle to Work Schemes Expansion	Months	6.22	£4,567,538	3.54	0.33	2,171.49	+1
Ecodriving Training for Taxi Drivers	Months	5.75	£7,683,700	4.14	0.36	2,023.22	+1
ZEV Last Mile deliveries	Weeks-Months	5.05	£4,046	0.02	0.00	20.46	+3
Taxi Rank Idling Wardens	Months-Years	4.12	£546,572	0.96	0.35	1,490.54	0
Cycle infrastructure & Promotion using low cost cycle tracks	Years	2.49	£209,912,924	249.48	18.59	150,685.92	+3
Vertical Exhausts at roof level on buses	Months	2.46	£24,015,078	2,667.15	21.15	-	0
Euro V requirement for Central London buses & Euro IV engine reprogramming	Months	2.41	£2,123,339	204.71	1.34	-	0
Fitting DPFs on Taxis	Months-Years	2.01	£27,916,732	0.00	15.28	-	0
Campaign Days	Days	2	£2,500,000	15.00	2.40	20,000.00	+1
Totals (Average for BCR)		**6.2 Average BCR**	**£ 291,459,018**	**3,740 t.pa NOx**	**69 t.pa PM**	**203,342 t.pa CO2**	**+1=some, +2=significant, +3=substantial**

Table of Cost Effective Actions

LARGE IMPACT ACTIONS

LEZs: bus roof exhausts, bus reprogramming & taxi DPFs
CYCLING: pollution & fiscal benefits, cheap ways to increase it
BUILDINGS: energy efficiency, renewables & building standards

Large Impact Measures can reduce air pollution by 10% or more from a given source. The following frameworks detail three sets of Large Impact measures in Central London, providing expanded and relevant evidence for air quality specialists, outlining the required regulatory frameworks and include some suggestions for delivery.

Three Viable Low Emission Zone Options

Although London already has the World's largest LEZ setup by the GLA, London boroughs have the powers to apply a Central LEZ(s) on their own highways. Since an additional LEZ for HGVs would be duplication, and LGV and car LEZs are not thought to be cost effective in Central London [TfL, 2011b], three measures were considered that could be applied using LEZ powers to substantially reduce pollution from taxis and buses in Central London. All three were found to have the potential to reduce toxic pollution or its impacts by 20%-90% from taxis or buses, with Benefits to Costs Ratios of greater than 2 in all cases, but no fuel reduction, CO2 or noise benefits.

The approach tested for taxis requires Euro 3 taxis to have a DPF fitted to be allowed to operate in Central London. This is found to reduce PM emissions from taxis by 18t in Central London, or 43%. Two approaches were considered for buses: high level exhausts and Euro IV engine reprogramming. High level exhausts (as applied routinely in the US and Australia) were found to have the potential to reduce the impact of PM and NOx emissions by 50%-90%. Diesel engine reprogramming, as executed in Bristol for buses and Manchester for fire tenders, was estimated to reduce emissions of NOx and PM by about 13%. Of these three, the taxis DPF retrofit and high exhausts on buses deliver the most substantial improvements for the effort involved in deliver the measures.

The regulations and procedures to establish LEZs are described in detail, along with the potential pitfalls and opportunities for leverage. The simplest approach uses Sectoral Agreements reinforced by operating contracts. Another creates a legally enforceable LEZ through a Traffic Regulation Order (TRO).

Summary of LEZ Options Examined

Scenario	Central LEZ requiring DPFs on Euro 3 Taxis	LEZ requiring bus exhausts on the roof (50% impact)	LEZ requiring bus exhausts on the roof (90% impact)	Central LEZ Euro IV Bus via engine reprogram
NOx baseline emissions, 2015	(not affected)	3,663t (all London TfL)	3,663t (all London TfL)	1164t (Central London only)
PM10 baseline emissions, 2015	41.25t	23t	23t	9.8t
NOx reduction, pa	**-**	**1,481t***	**2,667t***	**204t**
PM10 reduction, pa	**18t**	**11.75t***	**21t***	**1.3t**
PV of NOx Damage Cost	-	*£9M*	*£16M*	*£1.2M*
PV of PM Damage Cost	*£17M*	*£13M*	*£23M*	*£1.8M*
Cost Effective? (BCR)	*Yes (2.0)*	*No (1.86)*	*Yes (2.46)*	*Yes (2.41)*

LEZ Exhibit 1: Summary costs & benefits of three LEZ options in Central London. *Euro 3 DPF Taxi Retrofit LEZ; TfL Bus High Level Exhausts, giving 50% impact reduction; TfL Bus High Level Exhausts, giving 90% impact reduction; TfL Bus Euro IV-V reprogramming; The taxi DPF and bus vertical exhaust measures are assumed to have impacts across London, while the Euro IV-V bus reprogramming is expected only to affect buses in Central London.*

Introduction to LEZs

Low Emission Zones allow certain classes of vehicle to be banned or restricted from travelling or parking in a certain geographic area so that air pollution emissions are reduced. The LEZ can apply to any clearly identifiable and reasonable categorisation, e.g. engine size, Euro emissions category, CO2 emissions, vehicle age, class or weight, fuel type etc, or a combination of these. This allows considerable flexibility in targeting the LEZ at certain emissions or sources. Experience in the UK is that LEZs can take a long time to establish. London's LEZ required almost a decade of planning, while Oxfords required four years. Because of the LEZ already in force in London, the options for councils to apply new LEZs are limited to private cars, LGVs, taxis, buses and coaches. Of these sectors, LEZs for private cars and LGVs have already been shown by TfL to be non cost-effective. This leaves councils with the options of LEZ aimed at taxis and buses. In developing the potential technical requirements for such LEZs, lessons were drawn from experiences in Continental Europe where DPFs have been successfully applied for LEZs, from the USA and Australia where high levels exhausts are routinely required, and from Bristol and Manchester, where diesel engine reprogramming has been used to reduce pollution.

Euro 4 DPF Requirement for Central London Taxis

Commercially available Diesel Particle Filter (DPF) retrofit solutions exist to bring the 50% of licensed London hackney cabs that are Euro 3 standard compliant up to and beyond the Euro 4 particulate standard (though NOx emissions are unaffected). An LEZ was modelling in which Euro 3 taxis are required to be fitted with suitable DPF equipment to be allowed to operate in Central London. If all the 10,500 Euro 3 taxis choose to comply, the equipment can be purchased for £1700 each (Gerd van Aaken, HJS UK, personal communication) and installed for an additional £800. These costs are offset for drivers through a 30p per fare emissions surcharge for the taxis so modified. It is assumed that all the Central London Local Authorities collaborate to share the studies and costs required to setup the LEZ and that these amount to £0.5M in 2012, which is defrayed by a £40 per year annual certification charge to each of the 10,500 vehicles to whom the LEZ applies. The LEZ is assumed to operate from 1/1/2013-31/12/2017.

The value of the 30p surcharge to the taxi drivers doing 13 fares per day (as indicated by CCZ unique vehicle counts) for five years would more than offset the cost of the DPF. The estimated value of the air quality improvements over the life of the LEZ would be £27M, using the Damage Costs approach. This would be as a result of a reduction in PM emissions in Central London of 9 tonnes per year and in Outer London of 10 tonnes per year, on average. Agreement with TfL on the 30p surcharge would be required.

Overall, the approach is found to be cost-effective, with a Benefits-to-Costs Ratio of 2.0 equal to the TAG recommended approval threshold of 2.0.

High level or vertical exhausts for Buses

Buoyant (i.e. hot) emissions from a high exhaust outlet will result in ground level concentrations 65%-95% times lower than those from a low level outlet [CERC, 2005; AustRoads, 1993; World Bank, 1996], indeed it is on this basis that high level stacks are required for stationary sources. This effect is so demonstrable that it is a pre-requisite for bus procurement in many US and Australian states (Exhibit 2), and in 1987 the city of Santiago in Chile applied a mass retro-fit programme to all its buses with considerable success in reducing air pollutant concentrations [World Bank, 1996]. UK HGVs often have high level exhausts as this reduces both ground concentrations and resuspension of road and works dust, and conversion of HGVs from low to high level exhausts is routine and cheap. But high level exhausts are found on very few buses in the UK and conversion of low to high is unheard of. Anecdotal evidence

LEZ Exhibit 2: HIgh Level Exhaust on a single decker bus in Queensland, Australia.

suggests this may be due to the highly visible nature of exhaust emitted vertically from buses which is repugnant to bus and coach OEMs (J. Norris, personal communication). A study for Defra into the impact of vehicle exhaust location on dispersion (CERC, 2005) suggests ground level concentrations close to the vehicle is of the order of 10-20 times lower from high level exhaust than low, and the maximum concentrations in the far field are at 20m range and are half the maximum from low level exhausts. The CERC report recommended increased use of high exhausts.

To study the potential impact of high exhausts in Central London using an LEZ, an LEZ requiring high exhausts on TfL buses was modelled. The approach could equally be required of LGVs, HGVs or coaches, but these are excluded for the reasons previously outlined. As high exhaust retrofit is not a standard procedure in the UK and approaches are likely to require novel devices, such as caged downpipes, costs per vehicle have been estimated by scaling up the cost of an HGV high exhaust retrofit (typically £500) to £2,000 per unit. For the purposes of the scenario, the conversion is applied to all 8,000 TfL buses. The air pollution impact is determined as though the effect of the changed dispersion characteristics was a change in the annual emissions rate, and two scenarios were considered: a reduction of 50% and of 90% in effective emissions. The 50% reduction is representative of the down-stream impacts estimated by CERC, while 90% (or better) is representative of the kerbside impacts. Real world impacts would lie somewhere between the two, probably closer to the range of 67%-87% cited by the World Bank (1996).

The estimated impacts (Exhibit 1) are found to be equivalent to a reduction in emissions of 1,500t per annum of NOx and 12t pa of PM for the 50% case, and 2,700 NOx and 21t PM per annum for the 90% case. The subsequent reduction in socio-economic Damage Cost is £22M over 6 years for the 50% case, and £39M for the 90% case. As the cost of implementing the measure is assumed to be around £16M, this leads to a Benefit-to-Costs ratio of just under 2 for the 50% case, and 2.5 for the 90% case. As the actual outcomes would lie between the two, this suggests that the measure may be cost effective - the TAG recommended BCR threshold is 2.0.

The results suggest that if the basic physics supporting the findings in CERC's study are not undermined by other evidence, high level exhaust retrofit is likely to be a cost effective means of reducing the impact of local bus air pollution. It is recommended that a pilot study is conducted along a well controlled and suitably instrumented bus corridor to establish the veracity of CERCs models. CERC's study compared HGV outlets at low (0.3m) and high (3.5) levels on HGVs. Roof level exhausts at 4.4m on double decker buses can be expected to reduce ground level pollutant concentrations both in the near field and downstream even further. Subsequent to a validation study, LEZs requiring high level exhausts for HGVs and LGVs should also be examined.

Euro IV-V reprogramming requirement for TfL buses

The MAQS sets out a plan for replacement of parts of London's bus fleet so that between 2011 and 2015, Euro IV buses will go from 19% of the fleet to 21%, Euro V buses from 15% to 34% of the fleet, Euro VI & V-Hybrid buses will make up 2%, Euro III buses will have DPFs and NOx scrubbers fitted, and Euro II buses will be phased out. Cases in Bristol and Manchester show that in many cases it is simple and inexpensive to reprogram the engine computers of Euro IV diesel engines to achieve the Euro V standard. In Manchester, reprogramming of 39 fire appliance engines cost £34,000 and was available from OEM representatives. The Manchester case illustrates the method may be applied to other vehicles than buses, including some coaches, LGVs and HGVs, but for this scenario the bus model is used.

This scenario examines an LEZ taking advantage of this upgrade mechanism. The proposed mechanism is a Sectoral Agreement with TfL and bus operators, as a result of which they would apply a Euro IV to Euro V upgrade to all suitable buses and operate only these within the Central London area. The cost is estimated to be £1M for the 1,200 or so affected buses, based on the costs of the Manchester example. The councils' would reserve the option of imposing an LEZ through a TRO on council's Highways in the event of difficulties achieving a sectoral agreement. To account for this possibility, an LEZ setup cost of £0.5M to the councils is assumed, offset by an annual £80 certification charge. The effect on air pollutant emissions in Central London is estimated to be a reduction of 204 tonnes NOx and 1.6 tonnes PM10 per annum, and reduced socio-economic Damage Costs of £3M over six years. Allowing for a possible LEZ setup cost of £0.5M, this gives a Benefits:Cost ratio of 2.4, above the TAG cost effectiveness threshold of 2.0.

This scenario overlooks two second-order costs and benefits. The first is any efforts currently made by TfL to direct lower emission buses to Central London. The MAQS indicates that 42% of TfL buses are already Euro IV or V compliant in 2012, or some 3,600 buses. The number of buses estimated to be operating in Central London is around 4,000 (see Model of Unique Vehicles), which suggests that a substantial number of Euro III and older buses are operating in the area in 2012 and their removal and the upgrade of Euro IV buses to Euro V would be worthwhile. The MAQS indicated that around 4,000 buses should be Euro IV or better by 2013, so there should be sufficient buses to operate the Central London routes. Second, the scenario does not account for the benefit of the reduction in Damage Cost arising from moving dirtier buses from the high populated Central London to the less densely populated areas of Outer London.

A note on the bus emissions data used in Scenarios B & C

The scenario uses a simplified model of Central London bus emissions based on the 2008 LAEI projections. This includes a contribution from non-TfL mini-buses and coaches. Unique vehicle counts (UVCs) from CCZ cameras (C. Buckingham, TfL, personal communication) show that Mini-buses under 5t (M2 class) make-up 14% of buses inside the CCZ area, but only 4.4% of vehicle movements. M2 emissions per km are typically 10% of those of an M3 class bus weighing around 18t [TRL, 2009], so their total contribution to the emissions would be less than 1% of the total bus emissions. CCZ UVCs also show that each M3 class bus (which includes all TfL and non-TfL buses and coaches inside the CCZ) makes approximately 11 vehicle movements inside the zone. While it is not possible to disaggregate non-TfL coach movements from the total, it is possible to estimate their relative contributions. UVCs from the LEZ [TfL, 2008] show that non-TfL buses and coaches make up around 4,000 of the 12,000 buses in London overall. If non-TfL coaches are assumed to make two round trips per day and the 2:1 TfL:non-TfL ratio for all London holds in Central London, then TfL buses must make up about 87% of all emissions in Central London. The 2008 LAEI bus emissions data (projected forward based on the MAQS) have been corrected for this factor. The contribution of frequent inter-city buses within the home counties such as to Oxford or Luton have not been accounted for as no data is available on this.

Estimate of errors arising from un-modelled activity changes

Annual emissions changes by sector were based on fleet engine class mix data from the MAQS and TRL published emissions factors. This projected forwards the emissions assuming a steady size of fleet, making it vulnerable to un-modelled changes in fleet activity or emissions factors. This study's projections were compared with the MAQS projections, this showed that the methodology used here underestimates NOx projections by 1%/year and over-estimates PM projections by 5%/year.

Establishing an LEZ - the relevant regulations

The remainder of this chapter is given over to the processes and regulations required to establish an LEZ. LEZs in London can be setup using a number of regulatory and non-regulatory approaches. The current London LEZ was established using powers in the Greater London Authority Act to create a traffic charging scheme. But this approach would require use of the GLA process and councils would not be able to act independently. The Oxford bus LEZ was established through a Condition by the Transport Commissioner on the bus operators. Again, this route is not directly available to London Local Authorities. Section 106 LEZs can also no longer be applied.

For London Local Authorities, that leaves two approaches: A Traffic Regulation Order (TRO) or a sectorally agreed LEZ. A TRO can be used to create a penalty charge for forbidden vehicles or to establish differential parking charges by the chosen category, under powers from the Road Traffic Regulation Act (1984), the Road Traffic Act (1991) and the Traffic Management Act (2004). Establishing a TRO requires significant administration, planning and technical assessment, described in more detail later. An LEZ established by Sectoral Agreement also requires appraisal and consultation, but is less onerous than and has the potential to be implemented more quickly through negotiation. Negotiation of Sectoral Agreements can be assisted through application of a contractual condition or through consideration of proceedings to setup a TRO based LEZ, which could be more onerous for the affected sectors.

As outlined earlier, any clearly identifiable (sub)category of vehicle can be restricted by an LEZ, such as engine size, Euro class, CO2 emissions, vehicle age, class or weight, fuel type etc. The responsibility for managing the identification scheme falls to the Authority unless it is a pre-existing scheme, such as DVLA, VCA or VOSA schemes, or the Reduced Pollution Certificate scheme established by TfL for London Taxis. The identification scheme could involve paper documents, stickers or badges to facilitate manual enforcement, or number plate registration for automatic number plate recognition (ANPR) systems. Charges may be made by the Authority as part of the registration or certification process so costs can be defrayed. The Authority is also responsible for enforcement and associated costs, and must carefully consider the costs of this as part of the business case in appraising LEZ choices. The boundary of the LEZ must be clearly demarcated by signage at all entry points. Guidance indicates Sign 619 Motor Vehicles Prohibited with listed exemptions may be adequate [Defra, 2009a].

The design of the LEZ should be considered in the framework of DfT Transport Analysis Guidance (TAG), based on the now deprecated New Approach To Appraisal for transport projects. TAG is a best practice framework for all English transport projects, and has been adopted not only in other UK nations, but also by international institutions. Preparation of air quality related transport projects in conformance to TAG may accelerate their uptake. The effects of the LEZ on transport operators and users should be considered against the TAG transport objectives:

1. reducing transport's environmental impact. In London the most relevant impacts are on atmospheric pollution, noise, wildlife and historic buildings;
2. improving safety of people and property;
3. improving the economic efficiency of transport, both for consumers, business users, transport providers and the wider economy;
4. improving people's ability to get to different locations by different modes; and
5. improving transport integration.

How these objectives can be appraised is outlined later. For more detailed information on TAG see the DfT online guide at www.dft.gov.uk/webtag.

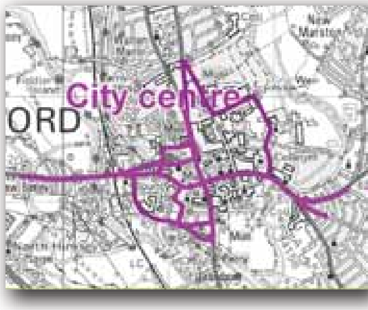
Three examples of LEZs in practice

London

- Cross part agreement, including during a change of Mayoralty.
- Staged implementation.
- LGV bulk purchase scheme arranged.
- Grant of £10M for 100 new buses from DfT Green Bus Fund.
- Those affected most able to afford implementation costs.
- Early action on the directly controlled sources - buses had particle traps fitted.
- Additional action on regulated sources - black taxis required to have Euro 4 compliance and age limits. Mini-cabs also required to meet Euro 4 standard.
- LEZ initially applied to HGVs and coaches, now also to LGVs.

Berlin

- Cross party agreement.
- Phased implementation.
- Funding for upgrade and retrofit.
- Substantial work done on stationary sources, improving access using low or no emissions modes and traffic smoothing before the LEZ was considered.
- Now described by Berlin Senate as the most effective measure applied.
- Hotspot & urban background LEZ
- Area of 88km^2
- LGVs & Cars controlled since 1.1.10:
- Diesel vehicles must be Euro 4 (post 2006) or Euro 3 + filter; Petrol vehicles must be Euro 1 (i.e. post-1993).



Oxford

- Early cross party and cross authority agreement.
- Buses could be regulated by the LTA through a Road Traffic Condition. RTC used to setup the LEZ.
- Grant of £3.5M for 43 new buses from DfT Green Bus Fund.
- Over 60% of city centre NOx emissions due to buses.
- Hotspot LEZ
- Area of 6km^2
- Affects 111 buses running through some city centre roads - buses account for 64% of local NO_x emissions.

Strategic Considerations in LEZ Design

LEZs can be used to address an air quality problem where fleet turnover and other cheaper measures are insufficient to achieve the air quality objectives and reduce or minimise the socio-economic cost of air pollution.

Design of an LEZ should aim to meet one over-arching strategic goal: **maximising the reduction in air pollutant concentrations for the minimum economic, financial and civic cost, so air quality and other strategic objectives are achieved and the health of residents benefits.**

Essential to this question is whether an LEZ is the best way to achieve the required outcome, and whether it provides value for money. Subsidiary questions to address include:

- Ensuring benefits to local stakeholders are greater than overall costs. In this regard stakeholders include transport operators, local businesses, residents, the local NHS, social care providers, and those vulnerable to air pollution and their representatives such as Asthma UK and the British Lung Foundation.
- Ensuring the actions taken are financially and politically viable for the Authority and stakeholders affected. Relevant factors include setup, operation and enforcement costs, retro-fit and vehicle upgrade costs, also political will, early cross party engagement and active public engagement. Engaging Members, other Authorities and the public should begin early in development.
- Finally, the design of the LEZ should consider the technical objectives, allowing for the UK's NO2 and PM10 objectives, the CAFÉ requirement to minimise PM2.5 concentrations, potential future evolution of the PM and NO2 objectives, and the potential for unexpected outcomes from new technologies or unfavourable weather conditions.

The decision to consider an LEZ must be taken in the wider context of other relevant spatial, economic and transport strategies. For example, can the LEZ be used to increase local footfall to businesses by reducing congestion and improving conditions for pedestrians and cyclists. Can the LEZ be used to reinforce actions to reduce health inequalities? The LEZ must be considered holistically within context of the overall Authority strategy.

Technical issues in LEZ Design

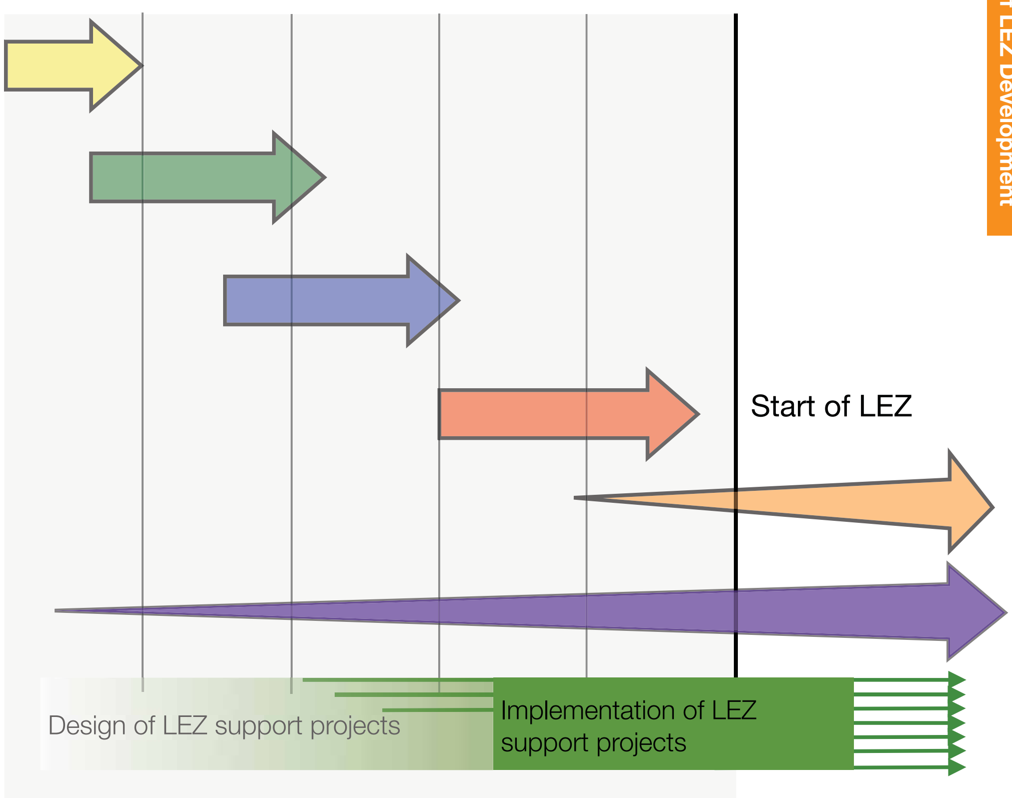
In technical terms, the key considerations are the boundaries of the LEZ, the vehicles affected and the emissions change required and the start date of the LEZ. Judicious combination of these factors can be used to focus on delivering reductions in urban background, sub-regional or local hotspot concentrations. Examples of each include the London, Berlin and Oxford LEZs respectively. While the benefits of the London LEZ are well know, evidence suggests that the sub-regional and hotspot LEZ in Berlin and and the local LEZ in Oxford have been very effective. In Berlin, cars and Light Goods Vehicles have been targeted and measurements indicate that in 2010 10-15 fewer PM exceedence days occurred inside the 88km^2 of the LEZ than in the 800km^2 of Berlin outside, a major improvement on the situation before the LEZ implementation [Rauterberg, 2011]. The Oxford LEZ targets buses inside 6km^2 of Central Oxford, and has led to a major renewal of the Oxford bus fleet through judicious application to the Green Bus Fund.

In developing LEZ technical options for appraisal, the elements to consider are:

- Source apportionment of emissions;
- Locations where concentration reductions are required;
- Number of vehicles needing upgrade to deliver the benefits;
- Level of regulatory control of those vehicles - can they be controlled through procurement or PSV licenses, or is a TRO required;
- Cost and feasibility to operators of upgrading their vehicles;

Stages of LEZ Development Process Using TRO

Stage of Development Process
Screening Assessment (4-6m) Technical appraisal: boundaries, vehicles affected, emissions standards, implementation plans, reporting process for Cabinet approval, alignment with LIP.
Intermediate & Detailed Assessments (6-12m) Including full economic CBA, updating of the detailed inventory and detailed dispersion modelling. Signage design. Possible SEA.
Consultation, Revision, Preparation (6-12m) Publication of scheme for public and police, LTA, DfT, businesses, bus co. etc. Response to objections, revised scheme, legal responses where challenged.
Setup & Installation (6-12m) Either install cameras etc, or setup scheme to manage and enforce discs. Install signage and street markings, communicate start date.
Enforce, Monitor, Report (permanent) Monitor effects on traffic & AQ. Enhance AQ monitoring to suit. Report on scheme progress and effectiveness.
Communications (ongoing) Cross-party and cross-boundary engagement. Information for stakeholders and the public on the benefits of the scheme and it's impacts. Involvement of operators and affected groups.
Projects to support LEZ (ongoing) Idling reduction, Bus routing, Smart driving, filter & upgrade grants and finance, cycle infrastructure, bus corridors, public engagement.



and cross-boundary consultation and support is likely to be essential for the measure to go forward. Other early considerations are communication with affected sectors, signage and LEZ support projects (and vice versa).

Sectoral Agrement or TRO?

Beginning discussions with affected sectors may allow the development of the LEZ through a negotiated Sectoral Agreement, instead of an administratively complex and potentially expensive TRO. Projects that support the LEZ or are supported by the LEZ could range from cycling or walking promotion, eco-driving, modal shift behaviour change programmes, car pooling programmes, low emissions procurement, business behaviour change, etc. Consideration should be given to the projects already planned by the Authority that the LEZ could support or accelerate, and vice versa, so that all can be optimised to support each other. Many programmes, actions and projects - particularly on public communications - can begin well in advance of the LEZ implementation date. Much of the success of the London LEZ has been attributed to its highly successful communication campaigns.

Signage

While Defra's guidance suggest that standard signage (Sign 619) may be used, your LEZ design choices may make this unfeasible. In the event that new signage needs to be designed, this will require approval from the Secretary of State, and so signage considerations and development should begin very early.

Intermediate and Detailed Assessments

Thereafter Intermediate and Detailed Assessment will be required. These should address in detail the business case for the LEZ scheme, affected sectors and vehicles, the enforcement method, the air quality and transport outcomes, economic and environmental and other costs and benefits (using the TAG framework and recommended tools) as well as any procurement of the enforcement system required. After consultation with the statutorily mandated organisations and groups and any resulting amendments to the plans, the required legal instruments are created, any required procurement begins, signage is installed and the enforcement process is established, so the LEZ can be implemented on the chosen date. Thereafter an ongoing process of monitoring of the LEZ impacts should be put in place, which feeds back into future developments and amendments to the scheme.

Air quality improvement measures involved

The effects on air pollution will depend on the choice of LEZ design, as shown in the three LEZ options presented. At the least, reductions in exhaust emissions of NO2, PM and CO2 should be planned for, but potentially also changes in transport behaviours and practices.

Who should lead on Central LEZs?

For Central London local highway LEZs leadership should be by the Local Authorities with involvement of the GLA, TfL and DfT, whose support will be essential in delivering such a project.

Cycling

New cyclists in London will on average save £786-£860pa each, and research by TfL shows that 60% of road journeys in Central London would be done more quickly and cheaply by bicycle, about 1M daily. Along with economic and demographic trends this suggests London is primed for a cycling revolution that could raise it to rates seen in Amsterdam or Copenhagen. Central London vehicle emissions could be cut by up to 900tpa of NOx and 67tpa of PM.

Central London already has significant cycling infrastructure, with a cycle lane density approaching that found in Amsterdam. But the quality and safety of the infrastructure is much lower than that found in cycling exemplar cities and this deters women, older and younger cyclists. Central London residents belong to demographic groups with a strong propensity to cycle if encouraged to do so, although the many hard pressed families require special attention.

A tiered programme of promotion, harmonisation and improvement of cycle infrastructure is needed to realise this revolution, beginning with co-ordination of cycling events, progressing to harmonised and unified signage and maps and increased signage density across the six cycle networks, and eventually including new cycle tracks and extended cycle hire schemes. The initial steps can be delivered for under £5M. Completing the outstanding lanes on LCN+ and TfLs road will cost £12M, and the remaining Superhighways £28M. Upgrading lanes to cycle tracks would cost about £10M using Spanish style tracks and an additional £23M is needed to resolve outstanding junctions. Doubling the cycle hire scheme would cost an extra £23Mpa, unless additional sponsorship is found, but gives the greatest increase in cycling per £ spent. There is unequivocal evidence that these actions would lead to dramatic net benefits for Londoners - the NPV for years 1-6 is estimated to be £1.75B (sic), primarily in financial terms, with BCR of 7-17, similar to other studies.

Travel Mode	NOx emission per passenger km (2010), tonnes/Mkm	PM emission per passenger km (2010), tonnes/Mkm
Motorcycles	0.29 - 0.45	0.08 - 0.12
Taxis	0.76 - 0.83	0.10 - 0.12
Cars	0.32 - 0.48	0.04 - 0.04
Buses	0.90 - 1.78	0.01 - 0.03
Cycle	0	0
LUL, DLR	0	0
Walking	0	0

Cycling Exhibit 1: Estimated emissions of different modes of transport by passenger km, shown in tonnes/million passenger km. *One million km is equivalent to 1,000 cyclists each travelling 5km per day on 200 days per year. Data shown are for 2010 - this was the latest passenger travel data available. Data are shown in ranges due to uncertainties in the passenger travel data.*

How this framework is organised

Air quality analysts are familiar with cycling as a mode of choice for air quality purposes, but less familiar with the steps needed to improve it. This framework seeks to address that gap, first looks at the benefits of cycling from first principles, showing how much air pollution and money a cyclist saves, reviewing some of the evidence on overall health benefits, and assessing the total potential pollution decrease in Central London.

Evidence is then reviewed on who already cycles in Central London, who new cyclists are likely to be and where, and what works to increase cycling in London. The cost per additional cyclist is estimated and compared with the benefits, as well as options for lower cost infrastructure. Taken together, this evidence suggests an obvious sequence of measures to increase cycling in Central London at low cost.

Air Quality Benefits of Switching To Cycling

The benefits of cycling for air quality are widely documented. The City of Copenhagen states that cycling reduced socio-economic damage from air pollution by $1.9M between 1995 and 2010 [Copenhagen, 2011], while a 2010 World Bank report describes air pollution reduction as a key co-benefit of improved cycling policies [World Bank, 2010]. Hook [OECD, 2008] goes further, pointing out the inevitable failure of policies that treat cycling as an outdated mode of transport to be replaced with motorised modes. Such policies instead lead to worse transport outcomes and dramatically increased air pollution, and are usually reversed. Closer to home, the DfT states that cycling is a vital part of any plan to improve air quality [Dft, 2008], while a Department of Health report cites numerous references showing air pollution benefits [DoH, 2010] as part of a broader economic cost-benefit analysis of cycling. For Cycling England, SQW estimated that in 2008 an urban commuter making half their trips by car and half by bicycle eliminated £34.57 worth of air pollution annually [SQW, 2008].

How can emissions reductions in Central London that are attributable to additional cycling be estimated?

Improvements in air quality from cycling will only occur if there is a reduction in polluting traffic relative to growth trends as a result [DfT, 2009], and evidence suggests that in Central London this is the case for new cyclists [TfL, 2010e]. In 2009, cycling into Central London reached 3% of peak time travellers, the highest levels in 3 decades and double the average over that period [TfL, 2010]. Passengers travelling in by car halved to 10% of journeys over this period. Taxi use remained steady at 2%-3% of journeys, although bus use did increase to 14% of journeys, almost double the usage in the 1990s.

Estimated emissions per passenger km from modes replaced by cyclists

On this basis the emissions per passenger km can be estimated from total emissions by mode and total passengers km travelled by mode. Pollutant emissions can be determined from the LAEI'08 and MAQS with relatively high

Damage Cost alleviated	NOx DC, £/1000 cyclists	PM DC, £/1000 cyclists	Total DC, £/1000 cyclists
Taxis	£506	£16,540	**£17,047**
Motorcycles	£238	£15,299	**£15,537**
Cars	£254	£5,361	**£5,615**
Buses	£938	£3,340	**£4,278**

Cycling Exhibit 2: Socio-economic Damage Costs to health alleviated by 1,000 commuters switching to cycling from another mode of transport on 200 days per year for a 5km round trip. *Data shown are for 2010 as this was the latest passenger travel data available and use a central estimate of the pollutant emissions.*

spatial resolution, and passenger travel data from TfLs London Transport Demand Survey 2011 [TfL, 2010c] and Travel in London Report 3 [TfL, 2010a], and the DfT National Travel Survey [DfT, 2011] provide some data, but these are not spatially disaggregated below the London regional level. After some manipulation, crude estimates of the emissions per passenger km by the different modes were obtained (Exhibit 1). More recently, highly disaggregated data has been made available from the LTDS - it is recommended that this be used in a follow study to improve these estimates.Cycling Exhibit 1 suggests that mode of transport used by the new cyclist strongly affects the overall emissions reduction. These figures also allow estimates of the socio-economic Damage Cost that would be alleviated by 1,000 commuters switching to cycling (Cycling Exhibit 2). This approach to estimating the air pollution impacts suggests that taxi and motorcycle users switching to cycling (or another zero emission transport mode) would give the greatest socio-economic benefits to health, with car and bus users a lower priority. They also suggest that if travellers are making short journeys by bike in Central London, then the monetised air quality benefits are somewhat less than the £34 found in SQW (2008). TfL's research suggests that around 1 Million daily Central London journeys can easily be cycled [TfL, 2011b], similar to the levels in Amsterdam,

	Motorcycles, tpa	Taxis, tpa	Cars, tpa	Buses & Coaches tpa	Total, tpa	% of total
2015 MAQS NOx emissions	**18.6**	**159.9**	**529.5**	**799.4**	**1507.4**	**100%**
Scenario 1, Modal switch to 27%	8.5	80.0	214.2	604.5	907.1	60%
Scenario 2, modal switch to 14%	4.2	40.0	107.1	302.3	453.6	30%
2015 MAQS PM emissions	**4.2**	**30.0**	**90.2**	**18.8**	**143.2**	**100%**
Scenario 1, 27% (62%)	1.9	15.0	36.5	14.3	67.6	47%
Scenario 2, 14% (31%)	0.9	7.5	18.3	7.1	33.8	24%

Cycling Exhibit 3: Reduction in vehicle air pollution emissions from cycling, *for two plausible scenarios**.** Scenario 1 is based on the maximum potential for easily cyclable journeys in Central London [TfL, 2011b], which is similar to that found in Amsterdam or Copenhagen, being 27% of all journeys or 62% of road journeys. Scenario 2 is half that, at 14% of all journeys and 31% of road journeys in Central London.*

Cambridge or Copenhagen. This is 27% of journeys by all modes in Central London, and 62% of modes by passenger motor vehicle. TfLs analysis allows the number of journeys that can be displaced by cycling in each mode to be estimated approximately, and thus the overall potential air pollution reduction due to a modal switch to cycling.

To do this, two scenarios were considered (Exhibit 3). In one all potentially cyclable journeys are made by bike in Central London, a modal shift to 27% of all journeys or 62% of road journeys. This would cut vehicle NOx by 60% and PM exhaust and TBW emissions by 47%. The second scenario assumes half of cyclable journeys are cycled, reducing NOx and PM emissions by 30% and 24% respectively (Cycling Exhibit 3).

Financial & Transport Benefits of Cycling

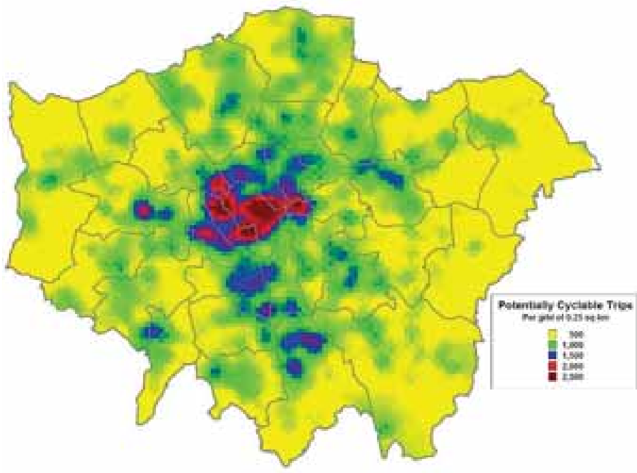
The cost of cycling to the rider are modelled assuming that the cycle-to-work tax incentive scheme was used. To this end data was obtained from Cyclescheme Ltd, showing that for each employee purchasing a bike, on average the employer saves £3 in NIC and the employees saves £74 in tax, per annum, plus commuting fares. Fares were modelled using the mix of modes (except rail) from the TfL 2009 Travel Demand Survey, with costs weighted according to the mode and frequency and based on estimates of a 5km journey, giving an average cost per journey of £5.24, or avoided cost per year of £786 for 150 working days when the bike is used, or £4600 over six years. It is assumed that the cost of the bike, helmet etc for the employee is £700 and the bike lasts for six years. Allowing for these costs, reduced damage from air pollution and carbon emission and excluding the tax relief as this nets off, the NPV of benefits is about £4,500 over six years (see accompanying work sheets).

This approach only estimates the financial benefits to the rider of cycling and not society at a whole. The benefits of cycling to the wider economy were reviewed by the Department of Health in 2010 in the report An Economic Assessment of Investment in Walking and Cycling. Their review found that the benefits of cycling to the UK economy outweighed the costs by a ratio of 19:1, and 13:1 in other countries, suggesting that cycling is better value for money in the UK than elsewhere. In a report for Cycling for England, SQW found that each additional cyclist in urban environments generated benefits of £64 per year in terms of reduced congestion [SQW, 2008].

Health Benefits of cycling

The health benefits of cycling have been reviewed by the Department of Health, which found that a consensus exists among experts in many OECD countries that significant public health benefits can be realised through greater use of active transport modes (walking and cycling), [DoH, 2010]. Similarly, Pucher et al stated simply that bicycling is healthy [Pucher, 2009], citing thirteen major scientific reviews of the medical evidence available.

A DfT study into the conversion of a canal towpath in London sought to quantify this monetarily and found that the infrastructure improvement work led to £28M in health benefits to the cyclists with a Benefits:Costs ratio of over 24. Reduced absenteeism also led to a reduction of £5M in business costs [DfT, 2005]. Work for cycling England suggests that for each 100,000 new cyclists per year, 50 fewer deaths per year will occur, equivalent to 1,660 life years. This estimated the value of the extended life years to be £50M, or £500 per cyclist [Rutter, 2005]. And SQW used the WHO/UK HEAT model to determine that in summary health benefit amount to £408 per year in 2008 terms [SQW, 2008], and they calculated that the benefits to the NHS amount to £28 per cyclist per year.



Cycling Exhibit 4: Map of potentially cyclable trips in London, *determined by combining cyclability of the journey, propensity to cycle of the population segment, and the distribution of population segments in London [TfL, 2010b, Figure E1].*

Who already cycles in Central London and how much?

TfL has conducted extensive research into cycling in London both as part of their rolling programme of London Travel Demand Surveys and for specific studies like the Analysis of Cycling Potential [TfL, 2010b] and the Superhighways Evaluation [TfL, 2012]. Data in this research shows that Central London's frequent cyclists are:

- Commuting to work 85% [TfL, 2012];
- White (79%), [Tfl, 2010c];

- Middle or high-income earners (69%), [Tfl, 2010c];
- Aged 25-44 (68%), [TfL, 2012];
- Male (66%), [Tfl, 2010c].

The statistics show a strong skewing of frequent cycling towards professional, young, male commuters, which is explicable given the evidence that cycling is the fastest and most reliably fast means of making a journey in London [TfL, 2010b; 2012]. Cyclists in the Central London boroughs make about 168,000 trips per day, 80% over distances under 5km (20 minutes ride) and 39% under 2km (8 minutes ride).

Who could be cycling and how much could they do?

TfL's Analysis of Cycling Potential [TfL, 2010b] suggests that up to 35% of journeys by mechanised modes of transport in London could readily be made by bicycle. The criteria used to define a cyclable journey are that:

it is made by an able bodied person between 5 and 64 years old, who travels a distance less than 8km between 0800 and 1800 which would be no more than 20% slower by bicycle than by other means, involves no heavy or bulky loads and would not otherwise be made by van, dial-a-ride, plane or boat.

Research suggests these criteria effectively capture the main factors that are likely to maximise an increase in cycling [van Hout, 2008; Davis, 2010]. Considering these criteria (and other factors explained below), Central London has by far the greatest potential for increasing cycling per square km in London (Exhibit 4), with a total of about 1 million journeys in Central London being very easy to cycle [TfL, 2010b]. This is two-thirds of all road journeys in Central London or 27% of all journeys in Central London, a level comparable with Amsterdam or Copenhagen. If all of the easily cyclable journeys were cycled in Central London, it would amount to a 700% increase on 2008 ridership, a 1400% increase on cycling in 2000, or 3-4 times more than the London Cycling Strategy target for 2025.

Archetype	% of Londoners	% of potentially cyclable trips in All London	High proportion in Central London?	Relative propensity to 100=average
Urban Living	**23%**	**21%**	**Yes**	**140**
Hard pressed families	**21%**	**19%**	**Yes**	**85**
High earning professionals	**11%**	**13%**	**Yes**	**106**
Suburban lifestyle	17%	19%	No	102
Young couples & families	15%	15%	No	113
Manual Trades	5%	6%	No	42
Comfortable Maturity	8%	7%	No	30

Cycling Exhibit 5: London's potential cyclist types, *the proportion of cyclable journeys they could make, where they live and their relative propensity to cycle [TfL, 2010b]. Those most prevalent in Central London are shown in bold face.*

TfL's research is detailed insight into who is most likely to take up cycling, and presents an approach to marketing cycling to this near market. The analysis suggests that the Londoners with greatest potential for cycling in Central London fall into three socio-economic archetypes (Cycling Exhibit 5), which were defined as follows [TfL, 2010b]:

1. **Urban Living:** These people tend to be young (54% under 35), white (74%), well educated, reasonably well-off and usually live in town/city centre (41% in central London). Many choose to live without a car (44%).

2. **Hard pressed families:** These people often have difficult family finances, and live in inner city flats and tower blocks, especially in east (25%), west (28%) and central (27%) London. Low car ownership (49% no car).

3. **High earning professionals:** These people are typically well educated, affluent, white (83%), often working in multinationals. Tend to use personal rather than public transport, and have high car ownership (81%). More likely than average to live in central London (24%).

Four other archetypes were used by TfL to segment the population and survey data from the LTDS: Suburban Lifestyle; Young Couples and Families; Manual Trades; and Comfortable Maturity. The former two segments are not highly represented in Central London, while the latter two were found to have a lot propensity to cycle.

Of the segments living in Central London, the Urban Living and High Earning Professionals were assessed as having a high propensity to cycle. Hard Pressed Families were found to have a lower propensity to cycle, but could be persuaded because of cash savings if appropriate messages were designed for them. These three segments represent 53% of potential cyclist journeys in London, and a much higher proportion in Central London (see [TfL, 2010b] for more details).

What makes people cycle more?

The following two pages review evidence on the propensity to cycle for the interested reader - for measures applicable in Central London, skip ahead to the next section What can Central London councils do to increase cycling?

Evidence abounds as to what works to increase cycling [Pucher, Dill & Handy, 2010; Van Hout, 2008; SQW, 2008; Davis, 2010]. A major review of research [Van Hout, 2008] into what factors influence cycling propensity across Europe cyclists divides them into individual, social environment and physical environment factors. This categorisation is supported elsewhere [Davis, 2010], so these categories and their sub-elements and their relevance in Central London are reviewed below.

Individual factors

The individual factors are:

- Age - younger people tend to cycle more;
- Gender - men tend to cycle more;
- Education - people with higher education levels tend to cycle more;
- Cyclist experience - the level of cycling experience strongly influences people's willingness to cycle and cycling is habit forming. This in part appears to be because the cycling experience changes individual perceptions of travel times, safety, convenience, infrastructure and the level of exertion required.

Cycling experience can be directly influenced by borough policies. Interventions such as car-free or cycle only days, cycling taster courses and cycling proficiency schemes can all deliver the required effect, and councils have the ability to lead by example by enacting these in the council workplace.

Social Environment factors

Factors in the social environment that influence cycling are:

- Policy - cycling will increase if policies make it more attractive and the alternatives less attractive, e.g. better cycling infrastructure combined with fare or fuel price rises. In the Central London context this is likely to mean more and better cycling infrastructure and more cycling promotion and more deterrents to car use, such as less parking availability, higher parking prices, increases in the Congestion Charge and increases in public transport fares. All of these factors are currently happening to some extent, so cycling is likely to increase;

- Car availability and cost - more access to cheaper cars leads to less cycling. In Central London car ownership is already comparatively low, but could be reduced further through greater uptake of car clubs (see the Car Clubs Factsheet);

- Bicycle culture - this is the societal habit of cycling that reflects the sharing of increased individual cycling experiences across social networks. This has been found to include a positive feedback effect - more people cycling encourages more people to cycle - which feedback accelerates when cycling reaches 10% modal share. Clearly it is possible for councils to encourage the social exchanges needed for such enculturation through cycling resource groups and NGOs, and by encouraging individual experience development amongst council staff and leadership, beginning the process with the council workforce;

- Bicycle theft - rates of bicycle theft and the fear of being inconvenienced by a bicycle theft deters potential cyclists. This is clearly an area in which councils can lead, by installation of cycle parking facilities, particularly secure or supervised facilities, at major activity centres, and by prioritising bicycle theft during liaison with the Metropolitan Police.

- Road safety - cycling is generally perceived to be the riskiest mode of transport, but perceived safety improvements in cycling have an aggregate elasticity value greater than 1 so safety improvement in cycling attract proportionately more cyclists than safety improvements in other transport modes. This is an activity in which Authorities can lead both through new and better infrastructure and promoting cycle safety and awareness amongst cyclists and other road users. Tfl studies into cycle network schemes show significant improvements in cyclist perceptions when cycle lane schemes are implemented [Tfl, 2007] and increased ridership [TfL, 2011a].

Physical environment

The physical factors that affect cycling are:

- Weather - bad weather discourages cyclists, particularly the inexperienced. Nonetheless, in Denmark and the Netherlands where weather is much wetter and colder than in London, much higher rates of cycling have been delivered since the 1970s.

- Topography - inexperienced cyclists are discouraged by hills, although many hilly cities (such as Basel, Switzerland) have high levels of cycling. This is not a major factor in Central London.

- Distance and trip time - shorter journeys are more likely to be conducted, as are quick and reliably fast journeys. As previously outlined, 1.4million Central London journeys have excellent conformity with these criterion.

- Infrastructure - there is an unequivocal, positive correlation between bicycle use and the quality of cycle infrastructure, both from European studies [van Hout, 2008], UK studies [SQW, 2009] and studies of cycling in London [Tfl, 2007 & 2011a]. The most cited infrastructure elements are cycle lanes - particularly those that are physically separated from other traffic, lighting and bicycle parking/racks at destinations, and one study indicates that even road surfaces are also positively correlated [see references in van Hout, 2008]. Older cyclists are more likely to cycle if lanes are separated from other traffic, as are BME and women cyclists. Cycle lanes in mixed traffic discourage cyclists, as do frequent stop signs or a higher stop frequency (e.g. resulting from traffic lights phased to suit motor vehicle speeds), as do lanes along parked cars. The key attributes of successful cycle infrastructure are safety, coherence (i.e. connectedness and lack of stops and barriers), directness, comfort and attractiveness. Provision of successful infrastructure is a key power of councils, in particular traffic calming and safe routes to schools, both identified as two of the five key measures identified by the National Institute for Clinical Excellence in promoting cycling [NICE, 2008].

The correlation between cycling growth and infrastructure varies strongly by project, as it will depend strongly on the population densities locally, the local cycling culture etc, as illustrated by Exhibit 3.6. For example in the London Cycle Superhighway example, the cost of cycle lanes per additional cyclist is estimated to be between £2,600 and £98,000 per cyclist (depending on how the additional cyclists are estimated and counted), while in Hull it is £250. It is striking that both the London and Barcelona cycle hire schemes are comparatively low cost per additional cyclist at £440-£990 each.

What can councils do to increase cycling?

In summary, councils in Central London can take many measures that will unequivocally increase cycling towards the 1 million per day that are easily cyclable. These measures are:

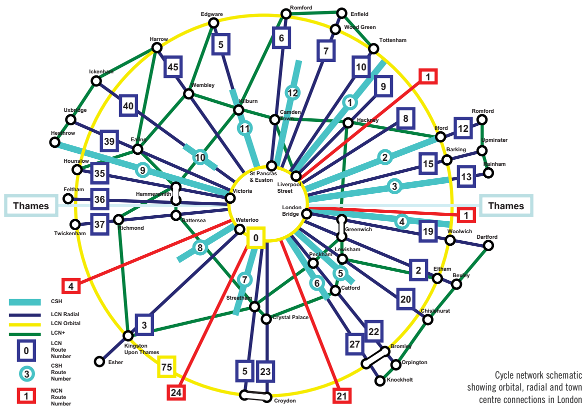
- Providing cycle infrastructure that is safe, coherent, direct, comfortable and attractive, including cycle tracks and lanes, parking and appropriate signage. Ideally, this will be segregated from other traffic so that women, BME and older cyclists will be encouraged, and in other cases involve traffic calming schemes to restrict motor vehicle speeds. It also includes extending cycle hire services such as Barcelona's Bicing and London's Barclays Cycle Hire. Infrastructure will be more successful if it's co-ordinated, with similar approaches, signage and branding across boroughs and service providers, as well as common or shared information resources.
- This infrastructure must be publicised, or it is much less likely to be used (see for example reference 35 in [Davis, 2008]). This publicity should comprise both passive measures, including signage, and active measures. A good example of the latter comes from the city of Odense, where on designated promotion days, children learning to ride bike were given balloons, sweets, free bike accessories and other gifts, and adults were invited to try out different types of bikes, trailers, company bikes etc;
- Increasing road safety and perceptions of road safety, both through infrastructure and awareness, and through feedback mechanisms whereby cyclists help decide the future planning priorities. This should include educating road users in the legal status of mandatory cycle lanes;
- Reducing bicycle theft through provision of parking facilities and secure parking where possible, and increasing the importance of cycle theft in discussion with the police. An important approach to this includes bike-hire schemes, such as the Barclays Cycle Hire scheme, which are guaranteed to be secure.

- Discouraging other modes of transport, whether by reducing allocations of road space to motor vehicles, car free days on roads or at offices, or allowing public transport fares to rise;
- Developing a cycling culture, by encouraging experience sharing between cyclists and non-cyclists, including leading by example in councils.
- Encouraging people to increase their personal experience of cycling through cycling publicity and tryout schemes;

What services and infrastructure is already in place?

Despite public perceptions to the contrary London has extensive cycle infrastructure. This comprises both advisory and mandatory cycle lanes, separated cycle tracks, a cycle hire scheme and a multiplicity of cycle training and ridership promotion activities. Allowing for already planned additions, by 2016 Central London will have about 300km of cycle lanes paths over an area of 148km^2, or 2km/km^2. This density is better than that found in Amsterdam which has 400km of cycle lanes over 212km^2 although London's infrastructure is much lower quality, built to a much lower safety standard and is less coherent. The infrastructure is comprised of the following seven heterogeneous, largely incoherent networks and additional services:

- **London Cycle Network (LCN)**, comprising 350km of back streets and quiet roads with small adaptations for cycling;
- **London Cycle Network Plus (LCN+)** provides 90km of advisory cycle lanes and 3km of cycle tracks in Central London;



Cycling Exhibit 6: Schematic of London's cycle infrastructure *(from The Science of Network Planning by B. Deegan, in Get Britain Cycling, 2012 Yearbook, courtesy of the author)*

- **Cycle lanes on TfL's Road Network,** include 122km of mandatory cycle lanes in Central London, with another 20km planned, mainly along busy roads in mixed traffic, often with traffic speeds limits of 30mph or 40mph;
- **Greenways** are pleasant corridors in parks and other areas of amenity that suit leisure cyclists;
- **Olympic Greenways**, are greenways leading to the Olympic site;
- **National Cycle Network**, setup by Sustrans;
- **Cycle Superhighways** consist of 26km of mandatory cycle lanes in Central London, which will be extended to about 140km over coming

years, at a cost of about £0.7M/km, with many local barriers to cycling removed.

- **Barclays Cycle Hire**, provides 8,000 bikes for low cost hire at 570 docking stations in Central London. The system will be extended east and west in years to come and has led to a 53,000 increase in frequent new cyclist. While costs are high compared with similar schemes elsewhere (Cycling Exhibit 7) the cost per additional cyclist is one of lowest of any scheme.
- **Local and London wide cycle promotion activities** are conducted by all boroughs to a greater or lesser extent and by TfL. Some - such as the SkyRide - are conducted with commercial partners. The scheme details vary from borough to borough but include school cycling promotion, cycle training and cycle safety promotion.

What must be done to increase cycling enough to reduce air pollution significantly? How much might this cost?

Many of the socio-economic conditions for cycling to increase are already in place and as a result cycling is already becoming more popular: fares are rising, petrol is becoming more expensive, people have less money, more cycle infrastructure is being built and cycling promotion services are ongoing. If current trends continue, the London Cycle Strategy target will easily be achieved in 2025. But there are parts of Central London where current cycle infrastructure is being removed or downgraded. This will certainly reduce cycling and consequently increase air pollution.

Project	Infrastructure km	Cost	Additional cyclists/day	Cost per additional cyclist
Priory Vale [SQW, 2009]	18km cycleway in Swindon	£3.8M	129	£ 29,000
Lancaster [SQW, 2009]	Bridge over River Lune	£1.8M	138	£ 13,000
Guildford [SQW, 2009]	Advisory cycle lanes	£0.16M	16	£ 10,000
U. Surrey [SQW, 2009]	Cycle Route at Manor Park	£0.3M	123	£ 2,400
Hull roadway [SQW, 2009]	New cycle lanes on 5 roads	£0.15M	585	£ 250
London [TfL, 2011a]	Superhighway BCS3,12km	£8.2M	100-1700, average +86%	£ 4,800-£82,000
London [TfL, 2011a]	Superhighway BCS7,14km	£9.8M	100-1500, average +46%	£6,500-£98,000
Barcelona Bicing	Cycle Hire, 6,000 bikes	€32M/£26M pa* [Anaya & Bea, 2009]	28,251 [Rojas-Rueda, 2011]	£ 990
London cycle hire [TfL, 2010a]	8,000 hire bikes	£140M 2010-2016 (£23M pa)	53,000 **	£ 440

Cycling Exhibit 7: Examples of cycling growth due to new cycle infrastructure, *from seven example projects. Bicing figure (*) includes additional cost of 40km of cycle track of £1.6M. Barclays Cycle Hire figure (**) estimated from published statistics - of the 111,000 members, 60% are new cyclists and 80% use it more than once a week, and the cost per cyclist is assessed using the annualised scheme cost.*

Cycling Exhibit 8: Barcelona example of a low cost Spanish Cycle Track *using small bollards bolted to the road, estimated to cost 10%-20% of typical UK cycle tracks [B. Deegan, personal communication] (Photo www.copenhagenize.com).*

It has been demonstrated unequivocally [Pucher, 2010; Davis, 2010; and references therein] that much greater increases in cycling can be delivered in urban centres on the scale of Central London, up to 20%-30% as outlined in Section 3.4. To achieve this requires concerted, coherent long term programmes whose objective from the outset is to increase cycling to high levels [Pucher, 2010]. Amsterdam and Copenhagen are the exemplars of this, and are being joined by other mega-cities (Paris, New York, Bogota, Beijing, who've concluded that motor vehicle focussed transport policy fails [OECD, 2008].

Two scenarios were presented earlier for the impact of cycling uptake on air pollution, cycling making up 13%-27% of journeys, reducing road vehicle emissions by 24%-60%. It is beyond the scope of this work to precisely define how such ambitious objectives could be delivered, but it is possible to crudely estimate what might be required and what this would cost. An important constraint is that to increase ridership to high levels, more female, older, younger and BME cyclists will have to be recruited, and studies show this means that cycle lanes must be segregated from traffic, e.g. be replaced by cycle tracks and greenways.

A tiered approach, cheapest and easiest first

Considering this constraint, we can estimate that London will need the following measures. These are presented in order of cost and ease of delivery, with cheapest and easiest first.

1. **Co-ordinate current cycle promotion and information** between councils, the GLA and private initiatives, to maximise the outcomes of planned expenditure by combining advertising and other resources (estimated cost, < £50kpa). It is not possible to estimate the impact of this measure from available evidence, but research indicates that better information can increase cycling significantly [Davis, 2010].

2. **A coherent network plan** that combines the seven cycle networks together and treats them as a single whole, including public information services, maps and mapping systems (estimated cost, < £1Mpa). As with (1), the impact is difficult to estimate but positive outcomes can be expected.

3. **New signposting at 200m intervals** across the seven networks that integrates them using a common singposting and visual language and shared references (e.g. signposts on LCN+ towards superhighways and cycle hire parking stations, signposts on superhighways that point out LCN routes). The estimated cost is £4M, though the impact is difficult to quantify. Neither the review by Puch et al (2010) nor that by NICE (2008) found

A cost–benefit analysis (CBA) of the cycling infrastructure generated a standardised cost–benefit ratio of 1:11 which, from a transport perspective, is very cost effective
National Institute for Clinical Excellence, PH008, 2008

evidence to quantify the impact of signage, but it is frequently referred to as a key informational aid for new cyclists. Opportunities also exist to coordinating this and learn from the Legible London programme.

4. **Complete the incomplete networks:** Remaining gaps in the LCN+ and Superhighways should be closed up and barriers removed.
   - The remaining 36km of LCN+ and lanes on the TLRN in Central London are estimated cost £12.6M [B. Deegan, personal communication]. Properly estimating the impact is beyond the scope of this work, but if we assume a correlation between cycle lanes and ridership, an estimate can be made. Expansion of the LCN+ from 30km to 122km from 2002-2009 was accompanied by a 100% increase in cycling, to about 110,000 per day. If the correlation is linear and represents an actual effect, the addition 35km more cycle lanes would create 21,000 additional cyclists.
   - Completion of the remaining 40km of Superhighway in Central London is estimated to cost £28km. This should be used wherever possible to eliminate the major barriers[1] between cycle links in Central London. Based on cyclist counts on the current superhighways, this is likely to lead 15,000-20,000 additional cyclists per day.
   - The 18 barriers not removed by the Barclays Cycle Superhighways programme will cost about £23M to upgrade (ibid), to render the network coherent, though this cost may be reduced by TfL's current junction review. Again impact is unclear, but as coherence is generally held to be the key attribute of a successful cycle network, an increase in ridership of perhaps 20%-50% may be achievable by this action.

4. **Upgrade to cycle tracks:** The resulting 250km of coherent Central London cycle paths should be upgraded to segregated cycle tracks. Using current DfT approved cycle track designs this is likely to cost about £100M, but this could be reduced to £10M-£20 if low cost cycle track designs are used after approval by DfT and TfL (see Cycling Exhibit 8). Safety and perception of safety is a critical pre-requisite for a successful network and in previous cases in London where lanes were upgraded to tracks increases of 58% were observed [Puch, 2010].

5. **Extension of the Barclays Cycle Hire** programme north and west to a contiguous area that includes the red and blue zones of Cycle Exhibit 4 (see map on page 20 [TfL, 2010b]). Given the current cost of the service of £23M/yr over 44km, this would roughly double the annualised cost to £46M. Potentially this cost could be entirely offset with advertising revenue, as has occurred in cities like Paris & Barcelona. Given the success of the

[1] At 140 important locations, there is no safe cycling inter-connection between links on the cycle route network [Camden, 2006], of which 53 are in Central London. These disconnects, called barriers, are often dangerous for cyclists, being busy or complex junctions or gyratories, or corridors with adverse motor traffic.

current scheme, this is likely to deliver at least an additional 53,000 cyclists at an additional cost over six years of £0M-£138M. When combined with (2), (3) and (4) and the 44km^2 of hire stations already in place, the number of additional cyclists could potentially be greater.

6. **High profile, sustained and co-ordinated publicity, cycle training and car/bus free events** across Central London. Co-ordinating the timing of events is likely to increase public awareness of them. For example, Skyride days could be accompanied by a car free day on Oxford St, cycle sampler lessons on Highbury Fields and Coram Fields, and promotion in schools and at council work places during the week before etc. Co-ordination of the visual language to harmonise cycling associate websites, signage, leaflets etc across TfL and Authorities assets would also increase impact and reduce costs, as has already been done between the Barclays Cycle Hire and Superhighways schemes. Finally, co-ordination of information sources, such as websites, helplines, etc would help reduce duplication and increase the impact of these. The cost of such co-ordination could likely be absorbed into current costs, but it is not possible to quantify the benefits of the action.

Adding these together, an increase in cycling of perhaps 360,000 journeys can be achieved in Central London, bringing total cycle journeys to 474,000 per day, or 13% of all journeys, approximately the level in Scenario 2. But the costs are substantial, some £100M-£250M more than is already planned for current projects (depending on whether cycle hire is sponsored).

The begs the question: would the benefits exceed the costs?

Would the benefits outweigh the costs?

One economic model of the benefits of cycling [SQW, 2008] suggests that each additional cyclist created by a cycle promotion project generates about £10,000 of benefits in terms of health, money savings, social benefits and air pollution reduction. By this logic, 360,000 additional cyclists would create about £3.6Billion of benefits over the lifetime of the projects (in 2008 £). Another model comes from the National Institute for Clinical Excellence [NICE, 2008] which produced guidance on how best to improve physical environments to improve levels of physical activity. This work found that a cost–benefit analysis (CBA) of the cycling infrastructure generated a standardised cost–benefit ratio of 1:11 which, from a transport perspective, is very cost effective.

An alternative approach to estimating the benefits focuses solely on the economic value to the rider and on air quality. Using the estimated benefits of switching to cycling (see earlier section), we can calculate that over six years the 360,000 additional cyclists would each personally benefit financially by about £4,700, totalling £1.7Billion, some 10 times the cost of the infrastructure.

In addition, air pollution emissions in Central London over the period would be reduced by about 453t NOx pa and 33.8t PM pa, giving a damage cost reduction in 2012 £s of £0.4M.pa for NOx reduction and £8.3M.pa for the PM reduction, or a total of £52M over six years.

This gives a total benefit from the investment in infrastructure of £1.75Bn over six years, with a cost-benefit ratio in the range of 7-17. This agrees with many other estimates of the benefits and costs of cycling.

An additional benefit would be a considerable reduction in noise from traffic in Central London, by about 30%.

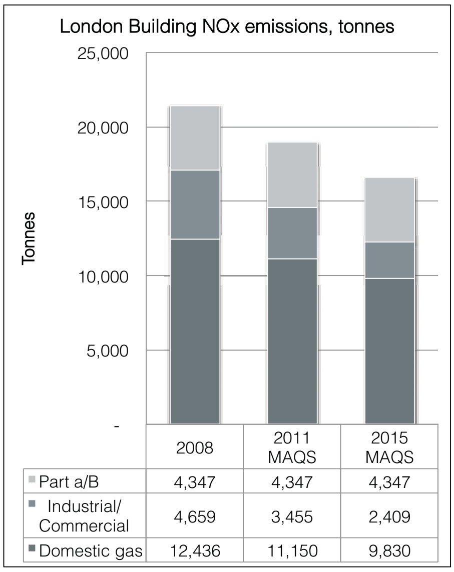
Buildings and Air Pollution

Summary

Buildings emit 44% of the NO2 in Central London and cause about £21M of socio-economic damage each year. To achieve the MAQS targets of a 693t/yr NOx reduction from buildings, three actions are required: (1) business as usual replacement of old commercial and domestic boilers with new ultra-low NOx models, can in principle deliver up to 566t.pa of NOx if the oldest boilers are prioritised, though in practice somewhat less is likely to be delivered; (2) improving the fabric energy efficiency of 5.5% of existing Central London buildings by 15 SAP points each year would reduce NOx emissions by a further 28t.pa and saving £19Mpa; (3) new developments should be air pollution neutral or better, using low energy design strategies, very energy efficient fabric and Zero Emission (ZE) heat technologies. All can be delivered at zero, net zero or low cost given renewable energy subsidies. Changes in building regulations will strongly affect pollution emissions and must be carefully managed to prevent new biomass boiler installations which developers tend to favour, despite the associated expense. Uptake of grant schemes to promote energy efficiency should be encouraged, in particular Warm Front grants for the elderly in fuel poverty. The evidence strongly supports the GLA proposal to require new major developments to be air quality neutral or better.

How this framework is organised

Building emissions impacts are reviewed, as are methods of reducing them. The relationship between building energy efficiency, fuel use, fuel type and pollutant emissions is explained, along with the expected changes in Building Regulations and the air pollution implications. Approaches to using the CSH, BREEAM, Passivhaus and CarbonLITE standards to help manage air pollution are described, and a simplified development analysis framework is presented. Zero pollution energy technologies are described as are subsidies.



***Buildings Exhibit 1: NOx emissions from London's buildings** according to the Mayors Air Quality Strategy, tonnes per year.*

Building emissions and their effects in Central London

After road transport, buildings are the second largest source of air pollution in London, emitting 44% of the total NOx (Buildings Exhibit 1) in Central London, or about 2,950t/yr. Buildings are also the second largest anthropogenic source of PM after road transport, contributing 18% of Central London emissions through gas heating, large boilers and Part B plant. Building emissions arise primarily from combustion to provide space and water heating and some industrial processes. Domestic sources, primarily water heating gas boiler exhausts, are distributed over wide areas, diluting their pollution. While commercial heating plant emissions can be intense, since the 19th century these have been required to have tall chimneys, and more recently special abatement equipment, to minimise concentrations downwind and the chances of a plume reaching the ground. As a result buildings do not tend to create pollution exceedence hotspots, contribute substantially to the urban background pollution concentrations.

Effects of these emissions

In Damage Cost terms, Central London building NOx emissions in 2012 would cause about £19M of socio-economic damage, and their PM emissions a further £2M. In addition to these toxic air pollutant emissions, buildings in Central London emit about 10Mt of greenhouse gases, some 90% of local emissions, which given a Shadow Price of Carbon of £27.80 in 2012 would amount to about £278M of costs. These emissions are all strongly associated with energy waste in buildings that are poorly insulated and over ventilated, with consequent amplified energy costs.

Greenhouse gas vs air pollution - it need not be a trade off

Attempts to control greenhouse gas emissions from buildings have become a significant problem for air quality management as some low or zero carbon energy technologies are intense sources of NOx or PM. Biomass fuel emits over 10 times more PM than an ultra low NOx gas boiler (Exhibit 2) as well as contributing to local traffic congestion and emissions. This is because of the low energy density of wood fuel, which requires frequent top-ups of fuel bunkers by lorry. Gas fuelled CHP systems can also elevate NOx emissions as the boilers run more intensely in order to supply power to the building and sometimes even the Grid. Many are over-specified for the heat and energy density required in an area, with inter-connections between adjacent developments often poorly planned or executed, or not at all.

This framework shows how both greenhouse gas and air pollution can be reduces from buildings cost effectively, if the right design choices are made.

Fuel type	NOx emissions, mg/kWh	PM emissions, mg/kWh	CO2 emissions, g/kWh	Payback time with RHI, years
Solar thermal	**0**	**0**	**0**	**16-20 years**
Heat pump	**0 (but 283mg/ kWh non-local)**	**0 (but 8mg/ kWh national)**	**132g/kWh**	**4-8 years**
Ultra Low-NOx boiler	**< 40mg/kWh**	**< 1mg/kWh**	**185g/kWh**	**N/A**
Oil fired boiler	< 120mg/kWh	16mg/kWh	245g/kWh	N/A
Biomass Boiler	< 530mg/kWh*	< 107mg/kWh*	0	5 years
Electric heating (grid)	0 (1132mg/kWh non-local)	0 (33mg/kWh non-local)	527g/kWh	N/A

Buildings Exhibit 2. Toxic air pollutant and carbon dioxide emissions from a number of building heating technologies*, and their estimated payback times with RHI [BRE, 2012]. Emissions data are derived from the Croydon Development Emissions Tool, Defra proposed biomass limits for RHI and DECC. * shows boilers eligible for the RHI - more polluting systems are also available.*

How buildings emissions can be reduced overall

In London the MAQS requires NOx emissions from homes to fall by a consistent 372t each year over coming years (or 3%/yr on the 2008 baseline), while those from commercial and industrial sources will need to fall by 321t/yr (7%/yr). Similarly, PM emissions will need to fall by 2t/yr (2%/yr) from homes and 3.5t/yr (5%/yr) from other buildings. Although unquantified in the MAQS, such reductions can in principle come about through three mechanisms:

1. replacement of worn-out old boilers with ultra-low NOx boilers;
2. achieving additional reductions in existing buildings by energy efficiency;
3. requiring new developments to be air pollution neutral or better.

1. Replacement of worn-out old boilers with ultra-low NOx boilers

As boilers wear out and are replaced by newer models and when Consequential Improvements are required for a large building under Part L, a reduction in local NOx and PM can be expected. Turnover of boilers in domestic and commercial buildings is estimated by Defra to be 5% per year, and boilers on sale today are all low-NOx, being Class 4 or 5 under EN BS 483 (Exhibit 3). Class 5 is recommended by the MAQS, and the highest standard (ultra low-NOx boilers emitting under 40 mg/kWh) are required for maximum points under BREEAM and the Code for Sustainable Homes, and cost nothing extra [CLG, 2010a]. If a Class 5 boiler replaces a Class 1, a 73% reduction in NOx emissions per boiler will be achieved. Since domestic boiler turnover is about 5% per year then a 3.6%/yr reduction in NOx emissions would be achieved (about 108t.pa NOx in Central London, 566t.pa across London) by this mechanism.

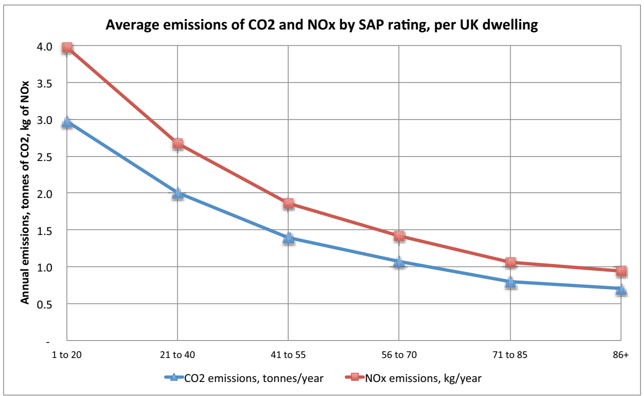
In practice, many boilers due for replacement in the next 5-10 years will already be better than Class 1, so only a fraction of the maximum possible NOx reduction is likely to be achieved. In addition, many of the measurements of boiler performance are made under hot water heating operation, not space heating operation, and anecdotal evidence indicates that actual performance for space heating is considerably worse (D. Raval, personal communication). Therefore replacing worn-out boilers alone is unlikely to deliver the required reductions and additional actions will be needed.

Buildings Exhibit 3: Boiler NOx emissions classes 1-5 *under standard CEN 483/BS EN 297:1994. Also shown are the CSH & BREEAM points awarded for Class 4 and 5 boilers and the requirement to achieve the maximum points under category Pol 2.*

Boiler Class	Maximum NOx Emissions, mg/kWh
1	260
2	200
3	150
4 (CSH/BREEAM 1 point) Low NOx	100
5 (CSH/BREEAM 2 pts) Low NOx	70
CSH/BREEAM 3 pts Ultra-Low NOx	40 (under 20 also available)

2. Achieving additional reductions in existing buildings by energy efficiency.

Additional reductions can be achieved by reducing heating demand in existing buildings through energy efficiency measures or installation of zero emission renewable energy (described in detail later). A typical major insulation retro-fit including deep loft insulation and solid or cavity wall insulation gives about a 15 point SAP rating improvement, though it depends strongly on the insulation applied (see [Element, 2011] or [Holdaway, 2009] and resulting SAP calculations. This would typically result in a 17% reduction in pollution and fuel consumption (Exhibit 4) which in Central London would save £340M per year. The Mayors energy strategy [GLA, 2010] plans that all London homes will undergo major insulation by 2030, suggesting that about 5.5%pa will undergo these measures giving an additional NOx reduction of 28t each year over coming years in Central London and 145t.pa London wide. Such measures are facilitated by CERT, CESP and from later this year Green Deal and ECO, while renewables are support by FiTs and RHI. All are detailed later in this document. On average Green Deal measures are expected to cut fuel use by 46% [DECC, 2011b].



Buildings Exhibit 4: *Variation in average CO2 and NOx emissions from a dwelling with SAP rating, with CO2 in tonnes/year and NOx in kg/year. Based on [CLG, 2006] and [LAEI, 2008].*

3. How new developments can be air pollution neutral or better

Given that total annual reductions from (1) and (2) are likely to reduce NOx emissions by at most 711t.pa, and more likely much less, if the MAQS target of 693t.pa is to be delivered, new developments should emit at least no more pollution and ideally even less pollution than the buildings they replace, even in cases where the development leads to more intensive use or occupation of the site. Such an Air Quality Neutral requirement is currently being considered by the Greater London Authority for major new developments in London[2], and the previous evidence clearly support the needs for this.

Excellent fabric energy efficiency

Since local toxic emissions are driven significantly by space heating and hot water demand, the pre-requisite for ensuring air pollution emissions are minimised is requiring the building fabric to be as energy efficient as possible. This will minimise the need for space heating which causes 75% of onsite fuel consumption. Increasing fabric energy efficiency will reduce the overall emissions that can be expected from the building by about 10% per 10 point increase on the SAP scale (Exhibits 4 and 5) [CLG, 2006], and studies indicate that SAP ratings in the range 87-95 have an additional cost of only 0%-2% for many developments [CLG, 2010a; ZCH, 2011; AimC4, 2012; CLG, 2012]. But most developers lack the skills to implement them cheaply.

Getting heat from renewables before using boilers

For both space and hot water heating, solar hot water or heat pumps are zero-emission heat sources that be used to minimise demand for additional heating after energy efficiency measures have been specified. Incentives for these technologies are available under the Renewable Heat Incentive (RHI - see later). Electric heating should be avoided as it is very expensive, except to drive heat pumps. More details on these energy sources are given later.

Using only ultra-low NOx boilers is a zero-cost improvement

To ensure sufficient heat after zero emission renewables have been included, ultra low-NOx gas boilers (Exhibit 3) can be specified and give a 60% NOx reduction compared Class 4 gas boilers. These are a requirement of CSH Codes 3 and 4, which is now required for all new social housing.

Work for CLG on the CSH shows that a large number of ultra-low NOx boilers are commercially available and cost no more than Class 4 or 5 boilers, so requiring ultra-low NOx should add no cost to a development [CLG, 2010a].

[2] Elliot Treharne & Daniel Barrett (Greater London Authority), private communication.

Standard	Net CO2 emissions onsite/ TER	Approx. Heat Energy Demand**	Energy Efficiency Rating	Air quality requirement in code?	Main approach	Date of legal application
Part L 2006	24 kg/m^2.yr	≤55-60kWh/m^2.yr	60-70	No	Carbon & fabric standards	1/10/2006
Part L 2010	18kg/m^2.yr (-25%)	≤45-55kWh/m^2.yr	65-80	SEDBUK A or B		1/10/2010
CSH Level 3				NO2 < 40mg/kWh required	Carbon, fabric & sustainability standards	None
CSH Level 4	13kg/m^2.yr (-44%)	≤43-52 kWh/m^2.yr	85-92			
Part L 2013		≤43-52 kWh/m^2.yr or ≤39-46 kWh/m^2.yr		SEDBUK A gas or biomass permitted	Carbon & fabric standards	2013
CSH Level 5	0kg/m^2.yr for heat/ -100%*	≤39-46 kWh/m^2.yr	> 95	Gas boilers alone insufficient - PV or wind probably, but biomass should be avoided	Carbon, fabric & sustainability standards	None
CSH Level 6	0kg/m^2.yr for all energy/-140%*		97-113			
Zero Carbon Home/ FEES/Part L 2016	10-14kg/m^2.yr (-44% to -60%)*				Carbon & fabric standards	2016
CarbonLITE Silver	22kg/m^2.yr (-70%)	42 kWh/m^2.yr	> 97	Biomass discouraged under these standards	Energy demand target with fabric guidelines	None
PassivHaus/ CarbonLITE Gold	4kg/m^2.yr (-94%)	10-15 kWh/m^2.yr	> 100			
CarbonLITE Platinum	0kg/m^2.yr*	10 kWh/m^2.yr	> 110 (est)			

* includes net reduction from onsite renewables and other offsets.
** Depends on building type, e.g. flat, semi-detached house, etc. Derived from [CLG, 2010], [BRE, 2011], [AECB, 2007]

Buildings Exhibit 7. UK building standards *and their effects on energy efficiency and carbon emissions.*

SAP rating	Average CO2 Emissions per home, t/year	% cut in CO2 from +10 SAP increase	Estimated NOx emissions per dwelling, kg/year	Estimated PM emissions per dwelling, g/year	Propor'n of London dwellings	Propor'n of UK dwellings
86+	0.71	50%	0.9	13	0%	1%
71 to 85	0.79	17%	1.1	15	15%	11%
56 to 70	1.07	17%	1.4	20	36%	30%
41 to 55	1.40	15%	1.9	26	36%	37%
21 to 40	2.01	16%	2.7	37	10%	17%
1 to 20	2.98	19%	4.0	56	2%	4%

Buildings Exhibit 5. CO2, NOx and PM from dwellings. *Variation in CO2 emissions (tonnes/year) from dwellings with SAP rating [CLG, 2006] and estimated variation in dwelling NOx (kg/year) and PM (g/year) based on the LAEI (2008). Also shown is the proportion of London and UK homes falling into this category from [CLG 2006] and [Cambridge, 2009].*

Are oil, biomass or CHP suitable?

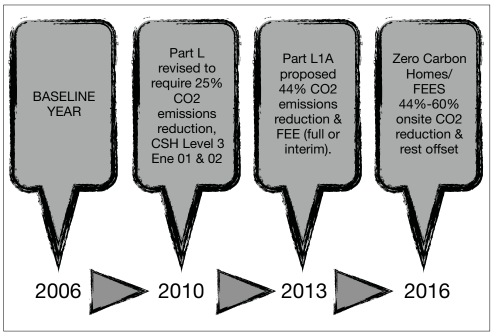
The high emissions of NOx and PM from oil boilers (Exhibit 2) effectively preclude their use in London, unless a Detailed Assessment demonstrates they are locally air quality neutral. And though biomass boilers are net zero carbon, they emit over 100 times more PM and 13 times more NOx per kWh than the best gas boilers and ideally should not be considered at all in AQMAs. In the case of new developments that increase site intensity, the need for air pollution neutrality limits the increase in site use unless the most energy efficient strategies and best renewable heat approaches are adopted at the design stage. To do this, building regulations and standards can be a useful guide.

Building Regulations, Green building standards and how they can be used to improve air quality

Building regulations and standards are increasingly used by regulators, planners and developers to control and specify the environmental performance of new buildings, and can be used limit air pollutant emissions effectively. Some are particularly relevant for air quality as they specify air quality emissions limits from boilers. Others specify certain levels of energy efficiency and with care can help planners direct developers to suitable design strategies, standards and technologies that can minimise heating demand and subsequent air pollution. The main UK standards are:

- UK Building Regulations 2010 (Part L & subsections 1A, 1B, 2A & 2B);
- Code for Sustainable Homes (CSH) for dwellings;
- Fabric Energy Efficiency Standard (FEES) / Zero Carbon Homes Standard, referring to new dwellings from 2016, and influencing the 2013 Part L1A&B;
- BRE Environmental Assessment Methodology 2011 (BREEAM 2011) for buildings other than dwellings.
- Passivhaus standard, for dwellings and some other buildings;
- AECB CarbonLITE standards for dwellings and some other buildings.

Part L is being harmonised with the CSH and FEES, as the government moves towards a Zero Carbon Homes standard for 2016 (Exhibit 6). As a result the 2010 Part L used energy efficiency elements of CSH Level 3, and the proposed 2013 Part L uses CSH Level 4 and elements of FEES. The 2016 Part L will based on FEES.



Buildings Exhibit 6: Expected changes in the regulation of new home CO2 emissions *through energy efficiency in fabric and zero carbon energy generation.*

Building Regulations 2010-2016

In UK Building Regulations, Part L specifies energy efficiency in new buildings and buildings undergoing major refurbishments or extensions [HMG, 2010a-d]. Greater energy efficiency is required by the 2010 revisions to Part L and is expected in the 2013 and 2016 revisions (Exhibits 6 & 7). In the 2010 Part L this is expressed as a Target CO2 Emissions Reduction (TER) 25% better than the 2006 Part L, as well as building fabric standards. In 2013 this is expected to increase to a 44% TER, and will include a fabric energy efficiency standard. A higher standard again is expected in the 2016 revisions.

To achieve the 2010 and expected 2013 and 2016 TERs, developers can combine energy efficient fabric and design with renewable energy technologies. Depending on the choices made this can lead to less or more air pollution. To minimise air pollution, developers should use design strategies that maximise energy efficiency, solar hot water (SHW) and heat pumps (see later), minimise thermal bridges and ventilation, ensure excellent build finish and use ulta-low NOx boilers, eliminating the need biomass heating or CHP. It has been shown that the Part L 2010 25% reductions can be delivered through fabric efficiency at zero or very little additional cost [Arup, 2010; CLG, 2011], while increasingl evidence suggests that the 2013 44% TER can also be delivered through fabric and design at zero or low additional costs [CLG, 2010a; ZCH, 2011; AimC4, 2012; CLG, 2012]. In either case considerable fuel savings will result over the building lifetime. But these build costs depend heavily on the skills and experience of the developers, architects and builders involved, and many lack the skills and experience to deliver low emissions homes cheaply. Once energy efficiency conditions are imposed on a new development, it is essential that Building Control Officers strictly enforce them otherwise the improvements will not be delivered. Evidence suggests [Griggs, 2004] that poor enforcement of energy efficiency has in the past led to poor compliance by builders.

Part L is divided into 4 sub-sections (L1A, L1B, L2A and L2B), each with different impacts on new and existing buildings, and homes and other buildings.

2010 Building Regulations for New Dwellings (L1A)

Part L1A 2010[3] specifies a TER of 25% compared with a similar new dwelling built according to 2006 regulations measured using SAP, giving a SAP rating of 65-80. Existing dwellings in London and the South East on average have SAP rating of 54 [Cambridge, 2009], so conformance to 2010 Part L1A will deliver about a 20% reduction in heating energy demand. This is helpful for air quality purposes as it reduced load on boilers. Part L1A also requires that new boilers achieve SEDBUK A or B efficiency, 8%-12% better than the average UK domestic boiler [Energy Savings Trust]. Between these two requirements, a Part L1A conforming home should emit about 28% less NOx than an average home. If in addition an ultra low NOx (<40mg/kWh) boiler is specified, the new dwelling can be expected to emit 60%-70% less NOx than average. Ensure that Building Control enforces Part L1A conformity in any new development.

[3] Part L approved text may be downloaded from http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved

2010 Building Regulations for Existing Dwellings Refurbishment (L1B)

Part L1B regulates existing dwellings undergoing any major refurbishment or replacement of the major thermal elements (e.g. heating system, roof, windows). In this case the newly installed services or fabric must achieve at least the current minimum efficiency standards (e.g. Part L1A). If the building is larger than 1,000m^2 then the rest of the building fabric must also undergo an energy efficiency retro-fit to the current standards, known as Consequential Improvements, and NOx reductions as per Part L1A can be expected.

2010 Building Regulations for New Buildings Other Than Dwellings (L2A)

As with Part L1A, this specifies a TER of 25% for new buildings compared with 2006, but aggregated over the whole development rather than each building in a development. An energy efficiency assessment must also be completed at the design stage, which can be used in planning to improve energy performance.

It is often the case that developers seek to use biomass or CHP energy sources to deliver the TERs required for major new developments under Part L2A. Although it may be a simpler design solution for the developer, it may be a more expensive design to build. Work by Arup has shown that the 2010 Part L TER can be achieved through design and fabric changes for an additional 1%-3% per square meter [Arup, 2010] over the 2006 Part L on a typical 13,300m^2 office building, while assessments for CLG on dwellings indicate that achieving the required TER is done most cheaply by avoiding use of biomass [CLG, 2011] - similar considerations are likely to apply for non-dwellings.

If the new development significantly intensifies use of the site, e.g. by increasing the occupied or heated floorspace on the site, an air quality improvement is likely to require all of higher fabric efficiency standards, careful building design, ZE energy sources and ultra low-NOx boilers. The pollutant emissions will need to be modelled carefully at the same time as the energy efficiency assessment during design using a tool such as CDET (see later), and an ultra-low emissions design strategy - such as Passivhaus - should be considered.

2010 Building Regulations for Existing Buildings Other Than Dwellings (L2B)

As with Part L1A, buildings undergoing major refurbishment of the fabric or heating systems are required to bring the fabric and heating system up to the latest standards (see above).

In summary, strict enforcement of 2010 Part L can cost-effectively reduce air pollution emissions by about 30% through boiler and fabric energy efficiency and by 60%-70% if ultra-low NOx gas boilers are also specified.

Going beyond the minimum for more air pollution reduction

Part L is a minimum requirement - additional air pollution reductions can be delivered using Code for Sustainable Homes, FEES, PassivHaus or CarbonLITE, and for developments that increase the site intensity by more than a factor of 2-3 these higher standards will be needed to deliver air quality neutrality.

Code for Sustainable Homes (CSH)

Adopted by CLG in 2008, the Code for Sustainable Homes (CSH) [CLG, 2010] has six ratings (Levels 1-6, from worst to best) that assess the overall sustainability of new homes against criteria under the categories Energy & Carbon (36.4%), Pollution (2.8%), Water (9%), Materials (7.2%), Surface Water Run-Off (2.2%), Waste (6.4%), Health & Wellbeing (14%), Management (10%) and Ecology (12%), where the percentages show the proportion of points available in each category. Within these categories, certain sub-criteria are mandatory to achieve each level. New social housing must achieve CSH Level 3 and all new homes must be rated against the CSH, or nil-rated. Application of CSH criteria are likely to be most effective if they are considered at the development's design stage, so early communication between developers and local planners is recommended.

Achievement of a whole CSH Level is not required to minimise air pollutant emissions. The sub-criteria important for air pollution are: Pol(lution) 2, Ene(rgy) 1, 2, 7, 8 & 9, and Man(agement) 1. Care is required with Ene 1 and 7, as biomass and CHP can be awarded points. The key criteria for air quality are:

- Pol 2 - Boiler NOx emissions: Requiring maximum Pollution Pol 02 points means that ultra low-NOx boilers must be used, which CLG has shown to add zero additional cost to the development (see [CLG, 2010a] pp39).
- Ene 1 - Dwelling Emission Rate: A Level 3 requirement is identical to the 2010 Part L requirement of a 25% TER, while Level 4 is that expected in the 2013 Part L of 44% and Level 5 a 100% TER. The Level 3 standard is achievable economically using building fabric improvements alone [CLG, 2010a] and there is evidence to suggest that Level 4 can also be achieved through efficient design and building materials [AimC4, 2012; CLG, 2012]. If developers propose use of CHP or biomass systems, these should be discouraged. The Level 5 standard currently requires renewable energy sources on site, in which case SHW and heat pumps should be the first options for heat supply, community gas CHP a second tier option, and biomass avoided. Additional points are available between Levels 4 and 5 for improvements to overall emissions. Thus at present, a Level 4 requirement for Ene 1 is optimal for air quality and economic construction.
- Ene 2 - Fabric Energy Efficiency: This gives points for better fabric performance as measured in kWh/m^2.yr and is based on the Fabric Energy Efficiency Standard (see below). Requiring maximum points will help reduce air pollution emissions by minimising onsite heating demand.
- Ene 7 - Low or Zero Carbon Technologies: Using SHW or heat pumps will significantly reduce the amount of heat required from onsite combustion. But under Ene 7 points can also be given for biomass heating, which should be avoided. So while Ene 7 should be required to maximise air quality improvements, biomass and CHP should be excluded from this.

The following criteria may also help reduce local air pollution:

- Ene 8 - Cycle storage: requiring Ene 8 is likely to encourage use of cycles by the residents, reducing transport associated air pollution.
- Ene 9 - Home Office: installation of services to support a home office may help reduce air pollution from commuting when people can work from home.
- Man 1: This requires developers to provide home owners/occupiers with guidance or training on how to take advantage of the features of the building. This will help occupiers to minimise their onsite heat use and thus reduce local air pollution from heating.

Overall, requiring CSH Level 4 can be expected to reduce air pollution emissions by about 10% more than Part L1A due to energy efficiency and by another 40%-60% through the ultra low-NOx boilers requirement, and even more if solar hot water or heat pumps are used. Since Level 4 will be required from next year under the new Part L, it seems reasonable to require it now, in particular if the development intensifies the site by more 200%-300%.

For very intensive prestige developments, some developers might consider CSH Levels 5 or 6. Unfortunately these often lead to onsite energy generation using biomass or CHP energy plant, increasing local air pollution. In these cases, solar hot water and heat pumps should be emphasised in discussions with developers, or alternatively ultra low emissions/ultra high efficiency design strategies like Passivhaus or CarbonLITE Silver may be a better alternative due to the assistance they provide in delivering reductions through fabric efficiency.

Fabric Energy Efficiency Standard - FEES

The FEES has been developed by the Government's Zero Carbon Hub as part of the plan to ensure that from 2016 new homes are built to a zero carbon standard [ZCH, 2012], with the result that it sets a higher standard of fabric energy efficiency than Part L 2010 or 2013. FEES specifies the performance of the building fabric in terms of heating energy demand measured in $kWh/m^2.yr$ for several typical dwelling types and will become the Part L1A requirement from 2016. The FEES is designed so it can be achieved using a variety of building types, including traditional construction methods at no or low additional construction cost. Two FEES standards are being consulted upon for inclusion in the 2013 Part L:

- Full FEES: $39kWh/m^2.yr$ for flats up to $46kWh/m^2.yr$ for detached houses.
- Interim FEES: a less onerous standard from $43kWh/m^2.yr$ for flats up to $52kWh/m^2.yr$ for detached houses.

Research at the Zero Carbon Hub indicates that blocks of flats can be built to Full FEES standard now at no extra cost [ZCH, 2012], though in practice developers may lack the skills to deliver this to a high standard.

As with the CSH Ene 02 criterion, requiring either proposed FEES standard will result in a reduction to the home heating demand and therefore air pollution, with Full FEES giving the most benefit. Compared to Part L 2010, Interim FEES would reduce energy demand - and hence air pollutant emissions - by 5%, while Full FEES would reduce it by 17%. Additional reductions in NOx would accrue from an Ultra-low NOx boiler.

Passivhaus

The Passivhaus standard specifies buildings in which a comfortable interior climate can be maintained without active heating and cooling systems, hence the term passive. It was developed in the 1980s in Germany by physicist Wolfgang Feist[4] and is the fastest growing building energy standard in the World, with over 30,000 buildings completed. Passivhaus requires heating energy demand of less than $15kWh/m^2.yr$ through use of passive solar heating from appropriate building orientation and windows, solar hot water, excellent ventilation management and heat recovery and minimisation of thermal bridges, and specifically precludes increased use of grid electricity. Though intended to minimise carbon emissions, an effect of Passivhaus design strategies is to minimise or even eliminate onsite fuel use, with the result that toxic air pollution will also be minimised. Fuel costs are also virtually eliminated, with typical annual fuel costs of under £30 for a dwelling and similar low costs for other buildings. The reduction in local air pollution emissions from a Passivhaus building compared to the 2010 Part L is in the range 73%-100%, so the standard may be useful for very intensive new developments.

Passivhaus buildings can be built for similar costs to average buildings, but very few developers have the skills to do so. As a result, Passivhaus building design and materials can be expected to cost 10%-30% more than a standard Part L building. Support for the Passivhaus standard is available from the Passivhaus Institute, the UK Passivhaus Trust[5], BRE[6], and a number of building designers and consultants (visit the Association for Environmentally Conscious Building website, www.aecb.net, for more information).

AECB CarbonLITE Standards

The AECB has developed three building fabric efficiency standards that - like Passivhaus and FEES - are intended to minimise heating energy demand. Unlike the CSH, CarbonLITE standards focus solely on energy efficiency, with no additional sustainability, materials or transport requirements. The Silver standard sets an objective of $42kWh/m^2.yr$ - similar to FEES - while the Gold Standard is identical to Passivhaus with a $15kWh/m^2.yr$ standard. The Platinum standard aims to reduce heating demand to under $4kWh/m^2.yr$. The

[4] See the Passivhaus Institute website: http://www.passiv.de/07_eng/index_e.html

[5] http://www.passivhaustrust.org.uk/

[6] http://www.passivhaus.org.uk/

CarbonLITE standards are particularly good for air quality as they preclude use of biomass fuel for reasons of its air pollutant emissions.

The Silver Standard can be expected to achieve similar air pollutant performance to the FEES or CSH Level 4, and in combination with solar hot water and an ultra low-NOx boiler is likely to minimise potential air pollution during building use. The Gold Standard - like Passivhaus - will virtually eliminate local air pollution, and the same can be expected of the Platinum Standard.

Costs of implementation are not well established, but for the Silver Standard can be expected to be somewhat less in materials costs to CSH Level 4 as the standard refers solely to building fabric, while the Gold Standard will have the same additional cost of 10%-20% as for Passivhaus. Costs for the Platinum Standard could not be established.

A database of dwellings, offices and public buildings built to these standards can be browsed online[7] and includes both design and operational data on the buildings, segregated by building type and standard.

BRE Environmental Assessment Method - BREEAM

The BREEAM 2011 assessment system [BRE, 2011] is similar in structure to the CSH (CSH is derived from a BREEAM standard for dwellings) but can be used to assess any new development. Points up to 100% are given over 49 criteria in 10 categories: Management (12%), Health & Wellbeing (15%), Energy (19%), Transport (8%), Water (6%), Materials (12.5%), Waste (7.5%), Land Use & Ecology (10%), Pollution (10%) and Innovation (an extra 10%). The BREEAM levels are Unclassified (<30%), Pass (30%-44%), Good (44%-54%), Very Good (55-69%), Excellent (70%-84%) and Outstanding (≥85%).

An important aspect of the BREEAM 2011 standard is that it requires developers to contact assessors and local planners before the design stage. Interventions at this stage are often critical for minimising air pollution and energy efficiency. The points given for pollution include use of low-NOx or ultra low-NOx boilers, while those for energy efficiency refer mainly to reductions in the TER, and use of low or zero emissions technologies. Points are also given for designs that encourage use of public transport, cycling, walking and discourage car use, so these too will help reduce air pollution. To minimise air pollution emissions, achievement of whole BREEAM 2011 levels is not required, only:

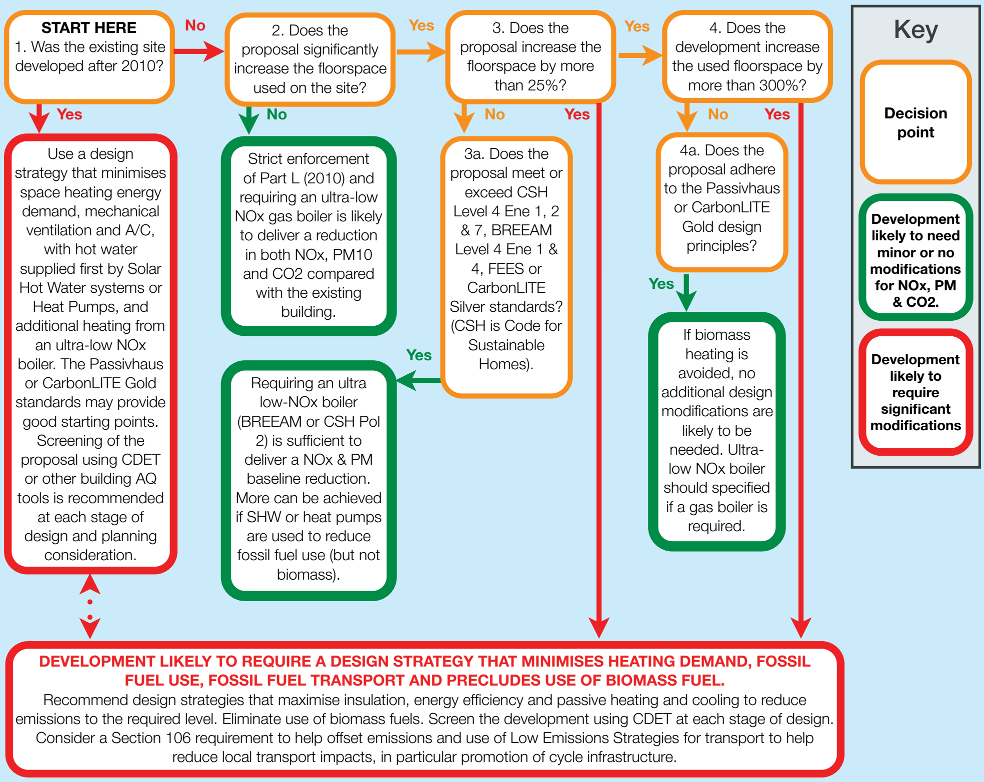
- Pol(lution) 02 - Boiler NOx emissions: Requiring maximum Pollution Pol 02 points means that ultra low-NOx boilers must be used;
- Ene(ergy) 01 - Reduction of CO2 emissions: Requiring more than 6 points on the Energy Ene 01 criterion is equivalent to the current Part L 25% TER. Requiring 10 points is equivalent to the 2013 Part L 44% TER. Up to 15 points may be given for Ene 01 energy efficiency requirements, equivalent to zero net CO2 emissions from the building, but such a requirement may lead to use of biomass energy onsite given current building technologies. As with Part L, there is some evidence to suggest that 10 points can be achieved a little or no extra cost using appropriate design and fabric.
- Ene 04 - Low and Zero Carbon Technologies: Requiring use of Low or Zero Carbon alone is not sufficient to lead to a local air pollutant reduction, as biomass and in some cases waste incineration energy generation are acceptable options. To ensure an air quality improvement, the Ene 04 requirements should be supplemented with a condition for use of local zero emission technologies, such as SHW, PV, heat pumps or wind power.

In addition the following criteria may also help reduce air pollution:

- Ene 02 - Energy Monitoring: Energy sub-metering encourages more efficient use of energy (both heat and electrical) within a building, which can

[7] http://retrofitforthefuture.org/projectbrowser.php

Simplified Air Pollutant Minimisation Framework For New Developments given an objective to emit the same or less pollution than the current site or area average.
Applicable under the 2010 Building Regulations Part L. Not valid after introduction of 2013 Part L Regs.



***Buildings Exhibit 7. Simplified decision framework for development assessment** for air quality, where air quality neutral developments are required. This decision framework is valid under 2010 Building Regulations, but not after implementation of 2013 Part L.*

result in lower heating energy demand and lower air pollutant emissions.

- Tra(nsport) - 01, 02, 03 & 04: The transport criteria can all have a significant impact on air quality emissions from a development in use. The four sub-criteria (01-Public Transport Accessibility, 02-Proximity to Amenities, 03-Cyclist Facilities, 04-Maximum Car Parking Capacity) are all designed to encourage modal shift to more sustainable forms of transport, making better use of local infrastructure and public services and relying less on private cars.
- Man(agement) - 04 & 05: These criteria ensure that the building will be designed to meet the needs of its users and that those users know how to operate and maintain the building to minimise emissions.

Simplified development analysis framework

The complexity of these many standards makes screening proposed developments a non-trivial exercise. Using the information presented in previous pages a simplified analysis framework has been developed for screening proposals (Exhibit 7). This assumes that new developments are required to emit no more air pollution than the existing site baseline. The framework allows many developments to be screened against this objective given certain key criteria and in some cases suggests cost-effective measures that can deliver a lower toxic air pollutant baseline.

Development pre-screening using CDET

Development emissions baselines and scenarios may be readily screened using the Croydon Development Emissions Tool (CDET), and use of this tool by planners and developers is recommended. CDET allows development emissions to be estimated based on fuel type, building use class and building size, and compared with an existing building or greenfield site. The development can be screened against the space it replaces and the local reduction target for NO2, PM and CO2, and scenarios for fuel use and energy efficiency be tested.

Zero Emission heating and energy technologies that reduce air pollution from buildings

A number of cost-effective zero emission heating and electricity systems can be installed in new or existing London buildings that reduce the need for gas, biomass or CHP systems. These are supported by government RHI and FIT incentives making them a worthwhile investment over the lifespan of the technology. The main non-polluting technologies are:

Non-polluting Renewable Heat & Electricity Sources Suitable for Central London

- Solar Hot Water / Solar Thermal Heating (heat - supported by the RHI);

- Heat pumps, ground and water (heat - supported by RHI);

- Photo-Voltaic panels (electricity - supported by FITs).

Other technologies to generate heat and power are supported by incentives (such as wind, hydroelectricity, waste incineration, biomass wood-chip, anaerobic digestion, and deep geothermal) but are less likely to be suitable in Central London due to availability or air quality considerations.

Solar Thermal / Solar Hot Water

Solar Hot Water (SHW) is cost effective everywhere in the UK with the RHI subsidies. Data from DECC and BRE indicate that with planned RHI tariffs lasting 20 years, a typical SHW system will pay for itself in 16 years (Exhibit 2), but particularly so in London which gets some of the best sunlight in the UK at 1100kWh/m^2 on average [BRE, 2012]. SHW is excellent for off-gas grid locations or large area locations such as gyms or swimming pools, as it displaces demand for grid electricity. In Summer, SHW systems will typically meet a homes hot water needs, while in winter SHW systems pre-heat the water going into a gas water heating system, reducing heating fuel consumption onsite. Systems typically operate for 20 years before needing replacement, and the two main technologies - flat plate and evacuated tube -

will generate up to 450 kWh/m^2 or 550 kWh/m^2 of hot water per year, respectively. To receive the RHI, suitable accrediation is required under the Micro-generation Certification Scheme, MCS, or by Ofgem for installations over 45kWh.

Heat pumps, ground and water source

Ground and water source heat pumps concentrate low grade thermal energy, for example ambient warmth in the ground, into heat suitable for buildings, much in the manner of how a refrigerator operates but in reverse. Heat pumps are zero emission locally, but require power from the electricity grid and so cause air pollution and carbon emission at the power station. Ground source heat pumps usually need to be installed over very wide or deep volumes, while water source systems require a good flow of water. As they use grid power heat pumps must be carefully specified and installed to ensure they collect 3-4 times more energy from the environment than they consume in electricity.

Heat pumps should only be used in extremely well insulated buildings. If a building is well insulated, payback times are expected to be of the order of 4-8 years with the RHI. Heat pumps work well in combination with solar hot water and solar thermal heating. Careful study of each implementation is required as the payback time depends strongly on the building's SAP rating and the heat pump equipment efficiency. Poorly designed projects may lose money.

Photo-Voltaic Cells / Solar Electric / Solar PV

Photo-voltaic electricity can be used to offset demand for power from a CHP system or from the grid. A range of PV technologies are available, from inefficient but cheap amorphous cells (3%-6% efficiency and 15-20 year lifespan), to expensive hybrid systems (18% efficiency and 25-30 year lifespan). In the UK 850 kWh/kWpeak can realistically be achieved. With the FITs available today PV will pay back in London in 12-20 years based on this power generating capability [ibid]. Another financial consideration is the need to replace broken cells and systems from time to time, and the gradual drop in efficiency of the cells, which is typically 1% per year due to environmental degradation. Finally, the panels should be insured for storm damage or theft. The global market for PV means that prices of cells are expected to fall by 13%-17% year for some years to come [Ernst & Young, 2011], thus reducing the payback times.

Wind turbines

While average wind speed in London are some of the lowest in the UK and winds are typically disrupted by the urban canopy, in some developments wind power may be suitable. Turbine size is critical - power output is proportional to the cube of the wind speed and the square of size of the rotors, and any installation design must allow for an appropriate scale of wind turbine for the proposed development. A 9m high 6kw turbine will power 3 homes and cost about £20k, while a 200kw, 36m high turbine costing £0.6M will supply power for 85 houses. As a general rule in London turbines rated to generate less than 6kW of electricity are not likely to be cost effective, which here requires a turbine with a 7m diameter rotor and at least a 9m tower. Payback on a typical investment with FITs is expected to be about 10 years [BRE, 2012].

Financial support for building energy efficiency and ZE energy

A number of incentives, support schemes and funding sources exist or are in preparation to encourage energy efficiency and use of renewable energy in new and existing buildings. These include the previously mentioned RHIs, FITs and Green Deal for domestic and commercial buildings, and Warm Front for households under threat of fuel poverty and LEEF for London's public buildings. A small number of private sources of low-cost finance are also available for renewable energy schemes.

Authority	Number in Fuel Poverty in 2008	Estimated homes eligible for Warm Front grants
City of London	304	110
Camden	12,286	4,451
Hackney	13,806	5,001
Islington	13,015	4,715
Kensington & Chelsea	8,765	3,175
Lambeth	15,950	5,778
Southwark	14,564	5,276
Westminster	11,059	4,006
All	89,749	32,512

***Buildings Exhibit 8. Number of homes in fuel poverty in 2008 in Central London**, and estimated number eligible for Warm Front grants.*

Renewable Heat Incentive for onsite heat sources

The RHI supports renewable heating installations through a tariff payment of several pence per kWh of heat energy produced. By compensating for the excess cost of the renewable heat source compared to a fossil fuel alternative, it is intended to reduce the greenhouse gas emissions from heating which are responsible for 47% of the UK's total carbon emissions. The value of the tariff varies by energy source and is set so as to incentivise investment in renewable heat by giving a payback of about 12% on the investment over the 20 year term of the tariff (somewhat lower for SHW). Larger installations qualify for smaller subsidies as these are expected to cost less to install due to economies of scale. Phase 1 of the RHI has been operational since late-2011 and applies to non-domestic buildings. Phase 2 is expected in 2013 and includes dwellings. In all cases, the installations must be certified either under the MCS or by Ofgem before the subsidy can be paid. More details are available from Ofgem, DECC or in reference [BRE, 2012].

The RHI presents both challenges and opportunities for air quality management. DECC's Impact Assessment for the RHI indicates that 49% of uptake is expected to be from biomass heating installations, and will be given to systems that emit over 100 times more PM and 13 times more NOx per kWh than cost effective ultra low-NOx gas boilers. But it also subsidises the installation of zero emission heat sources, ensuring that cost objections should not hamper their installation.

Feed-In-Tariffs for renewable electricity onsite

Renewably sourced electricity can be used as a heat source to reduce onsite pollution emissions. FITS subsidise onsite renewable electricity generation by ensuring they are a good commercial investment through a per kWh subsidy for energy generated or exported. FITs operate on a similar principle to RHI and are available to power installations up to 5MW limits. Installations do not need to be connected to the grid to get the FIT, but the systems must be suitably metered. As with the RHI, installations under 50kWh must be installed by an MCS accredited installer, though additional assurances of suitable qualifications may be worth getting (see footnote 5), while larger installations must be approved by Ofgem. FITs are given for 20 years for PV and 25 years for other energy sources. As with RHIs, the tariff varies with the technology and installation size, with lower subsidies for larger installations.

Warm Front home energy efficiency retro-fit scheme

Some 4 million households in the UK live in fuel poverty [Hill, 2011], which under the Warm Homes and Energy Conservation Act (2000) means the household members are on lower incomes and the home cannot be kept warm at a reasonable cost. In practice this is defined as a household that has to spend more than 10% of its income on keeping the temperature at 18C-21C. Of these 4 million living in fuel poverty, some 1.8 million households [DECC, 2011d] are older than 60, an age group that are particularly vulnerable to both the impacts of low temperatures and air pollution. Of these some 400,000 are in London.

Authority	Lower Super Output Areas Qualifying for CESP	Total estimated number of households
Camden	26	18,087
Hackney	88	61,217
Islington	33	22,957
Kensington	10	6,957
Lambeth	30	20,870
Southwark	22	15,304
Westminster	19	13,217
Grand Total	**228**	**158,609**

***Buildings Exhibit 9. Number of Lower Super Output Areas qualifying for CESP** and estimated number of households in those areas, [DECC, 2009b].*

Households in fuel poverty are generally found to be those with a SAP rating less than 65, in other words those that are poorly insulated where most heat energy is wasted [DECC, 2011d]. As a result, heating systems need to operate intensively generating disproportionate air pollution and CO2, as well as imposing severe costs on the householders. Such homes should therefore be a priority for energy efficiency schemes as part of a local air quality strategy, as there are multiple benefits, in health, cost, carbon and air quality terms.

The Warm Front scheme is intended to ensure that pensioners on benefits are not in fuel poverty. About 77% of households over 60 who are in fuel poverty are eligible for a grant - in Central London this is estimated to be some 32,000 households based on 2008 data (Exhibit 8). Warm Front will grant up to £3,500 to a household for insulation, central heating and ventilation improvements, and £6,000 where oil fired heating is in use. Those eligible must be in receipt of specified benefits[8] and in a dwelling with a SAP rating less than 55. A site survey is conducted to calculate the SAP rating before the grant is given and an installer and works specified. Gas boilers may be serviced as part of the work.

The air quality impact of Warm Front can be estimated using the LAEI average emissions from a home in London per year (56g PM, 4kg NOx, 3t CO2) and scaling this up for 32,500 homes. The average improvement in SAP rating after Warm Front is 21 points [Green, 2008], which is roughly equivalent to a 30% reduction in fuel consumption in Warm Front eligible homes [CLG, 2006]. This gives a total annual reduction of 39t NOx, 0.5t PM and 29,000t CO2 once all Warm Front eligible homes have been retro-fitted.

While these amounts are not a substantial proportion of total emissions, taken with co-benefits of health improvement, extended life expectancy and fuel cost reductions for some of the most vulnerable Londoners [Green, 2008], encouraging uptake of Warm Front is undoubtedly a worthwhile air quality improvement measure.

CERT & CESP

Since 2002 the government has operated a series of schemes to improve home energy efficiency. As previously discussed, improved home energy efficiency can reduce local pollution from heating systems, so uptake of grants and subsidies for such schemes should be encouraged as part long term air quality strategies. A number of grant schemes are currently available (CERT & CESP), which will be replaced by the comprehensive Green Deal scheme in December.

[8] For details see: http://www.direct.gov.uk/en/MoneyTaxAndBenefits/BenefitsTaxCreditsAndOtherSupport/On_a_low_income/DG_10018661?CID=MTB&PLA=warmfront&CRE=lowincome

The main scheme currently operating is the **Carbon Emissions Reduction Target** (CERT) in which energy companies reduce their carbon emissions by paying for energy efficiency upgrades to homes. Under CERT, some 3.5 million homes are to be insulated between 2008 and 2012, with £5.5Bn in subsidies from energy companies. CERT schemes will continue to operate until December 2012, when CERT will be replaced by the Green Deal. For more information on CERT see the Energy Savings Trust website[9].

The **Community Energy Savings Programme** (CESP) aims to reduce carbon emissions through improved energy efficiency standards in 90,000 lower income homes in 4,500 locations in the UK, through community schemes of insulation, heating upgrade, district heating and microgeneration. Administered by Ofgem, CESP will operate until December 2012, and in principle projects can be accepted by Ofgem for funding up to December 3rd, 2012. On average homes upgraded under CESP are eligible for about £3,000 worth of measures, similar to the scale of improvements under programmes such as Warm Front, and capable of delivering up to a 20 point improvement in SAP rating.

With only 30,588 homes improved so far, the scheme has fallen short of its target so new projects are welcome even in the final months. Projects can be processed in the scheme quickly - some 20,000 homes were improved in the last six months of 2011 - so it is not too late for schemes to be developed and receive a subsidy. In principle about 160,000 homes in Central London are in areas eligible (Exhibit 4.9), though in practice only a fraction of these could be delivered in 2012 (the total UK target for CESP is 90,000 households).

The potential air quality impact of CESP in Central London can be roughly estimated using the LAEI average emissions from a home in London per year (56g PM, 4kg NOx, 3t CO2) and scaling this up for an estimated number of homes that could realistically be delivered in the time available, estimated to be 15,000. Given an average improvement in SAP rating, roughly equivalent to a 30% reduction in fuel consumption, this gives a total annual reduction of 19t NOx, 0.25t PM and 15,000t CO2 once all the homes have been improved.

Green Deal for domestic and commercial buildings

Under the Energy Act (2010), the Government is establishing the Green Deal scheme by which buildings owners can receive 100% loan for energy efficiency measures, which is then paid off through charges on the energy bill. The efficiency savings achieved are required to be greater than the costs. In addition to this finance, subsidies will be available for some buildings under the Energy Company Obligation, which - as with CERT and CESP - uses funding from the energy companies to reduce their carbon emissions through end use efficiency measures. The precise mechanisms of Green Deal have yet to be established and the measures implemented will differ on a building-by-building basis but, if fuel prices rise as expected in years to come, Green Deal measures will reduce energy expenditure by about 10% [DECC, 2011b]. On average, Green Deal measures are expected to reduce fuel consumption by 46% per building [DECC, 2011b], though the exact results will vary greatly from building to building.

Local Authorities are expected to play a key role in promotion and uptake of the Green Deal, because it provides a financing scheme that can be used for local regeneration, home and commercial energy efficiency and advancing other strategic priorities such as air quality. In particular there's a role for councils to act as Green Deal service providers themselves or to foster the development of local social or commercial enterprises. Additional information on Green Deal for councils can be found on the DECC website[10].

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9 http://www.energysavingtrust.org.uk/Take-action/Grants-and-savings/About-CERT

10 http://www.decc.gov.uk/assets/decc/11/consultation/green-deal/3499-local-authorities-green-deal-info.pdf

The potential impact of Green Deal on Central London air quality can be roughly estimated by using data from the Green Deal Impact Assessment and on the London building stock. The projected average Green Deal reduction in emissions through fabric improvements is 46%, while 48% of the London dwellings have SAP values under 55 (Exhibit 4.10) and are most likely to benefit from Green Deal (this 48% are responsible for 61% of the CO2 emissions). If we assume that the same SAP distribution applies to non-dwelling buildings, complete application to all properties and dwellings with SAP rating lower than 55 in Central London would result in a reduction of 22% of domestic and commercial emissions in Central London, or 650t/yr of NOx and 6t/yr of PM.

LEEF

The London Energy Efficiency Fund (LEEF) is a £100M low-interest investment fund to enable the delivery of energy efficiency retrofit projects in public buildings in London. LEEF has been setup jointly by the GLA and RBS and offers finance to any public building (including council offices, schools, social housing, etc). It will support measures that will deliver a 20% energy efficiency improvement and a 20% CO2 improvement for a price of £1500/tonne of CO2 reduced. Typically this would give a payback of 5-7 years. It is estimated that some £500M is required for energy efficiency measures in public buildings in London, so LEEF will only enable a small proportion of those needed, but for these it will provide up to 100% of the required finance.

LEEF presents both a threat and an opportunity for air quality management. Most of the measures eligible under LEEF are likely to lead to energy demand reduction. Some of the technologies eligible for support under LEEF may increase local air pollutant emissions, including biomass boilers, and biomass, gas or oil CHP. Therefore it is essential for air quality officers to investigate LEEF projects at the design stage to ensure that they don't lead to local increases in toxic air pollution.

To estimate the potential for reductions via LEEF if air quality improving measures are selected, the NI 194 returns for 2008 were used as a baseline. Assuming that the worst 40% of buildings emissions would be be treated, achieving a pollutant emissions reduction of 20% for each, and given an annual baseline of 108t of NOx and 3t of PM from the eight Central London boroughs, this gives a reduction of 9t of NOx and 200k of PM.

Enhanced Capital Allowances

These are a tax incentive for business to purchase low emission plant and equipment, allowing them to write-off the whole capital cost of the vehicle or plant against tax in the first year. The list of eligible technologies includes a number of zero-emission energy technologies, such as solar hot water and heat pumps, and also zero emission or low carbon vehicles. For the full list, see the DECC website at etl.decc.gov.uk or the HMRC website.

Private Funds available for carbon reduction and energy efficiency investment

A number of private funds are available to support energy efficiency and carbon reduction projects. A few are listed below:

- PURE Community Energy Fund
  Funds from Barclaycard Breathe 0.5% levy which provides low interest loans for small scale renewable technology projects over periods up to five years. The Fund is operated as a non-profit charity.
- OneDestination Carbon Fund from BA
  Fund from BAs carbon offsetting programme are used to finance small local renewable energy projects in the UK.
- FSE Group Community Generation Fund
  This provides funding for both renewable energy project design and construction for projects over 25kWp.

Addendum - the Green Deal and Air Quality

Green Deal measures can cost effectively reduce emissions of NO2 and PM, as well as CO_2, with the magnitude of the reduction strongly determined by primary heating fuel in the building and the type of insulation applied. This suggests several possible strategies for prioritisation of homes for recruitment into Green Deal by councils, depending on whether they wish to maximise CO_2 or local NO_x or PM benefits. Prioritising solid wall insulation is expected to be more cost-effective than cavity wall insulation.

Introduction & Relevant Regulations

The government plans to legislate to create a legal framework - the Green Deal - through which home insulation and other energy saving measures can be paid for by householders over many years, even allowing for changes of home ownership [DECC 2011a]. The framework includes an Energy Company Obligation - ECO - through which energy companies will subsidise insulation for less well off or particularly difficult to insulate homes. The Green Deal's Golden Rule limits total loans to the net benefits in fuel costs from the insulation, so householders will pay no more than their energy bill would have been without the insulation measures. Expected uptake of the Green Deal is expected to be large, of the order of 100,000s of homes over the next decade [DECC 2011b]. and councils are expected to play a lead role in promoting the plans locally.

Air Quality Improvement Measures Involved

The air quality improvements come about through reductions in local and national emissions of toxic air pollutants and greenhouse gases. In the case of home with electric heating, no improvement will occur locally as all the emissions occur elsewhere. To determine the potential for air quality improvements arising from Green Deal measures being promoted by councils, the following data were used:

- Emissions of NO_x, PM and CO_2 per kWh by fuel in homes [NAEI & CIBSE];
- An expected reduction in home heating energy consumption of 16% for Cavity Wall Insulation (CWI) and 46% for Solid Wall Insulation (SWI), [DECC, 2011b and 2011c];
- Average household energy consumption [Ofgem, 2011];
- Dwelling size and fuel type from the English Housing Survey [DECC, 2009];

These data were used to model the air pollution impact of applying Cavity or Solid Wall Insulation to 1,000 90m^2 dwellings each year between 2013 and 2017 inclusive, with the impacts integrated over the likely lifespan of the whole Green Deal loan, 25 years. For all-electric homes, it was assumed that the CO_2 intensity of the fuel would decrease by 1% per year due to renewables uptake. This calculation was performed for each of the home heating fuel types:

- Coal; Electricity; Gas Oil; Burning Oil; LPG; Natural Gas & Wood Biomass.

The cost to the council was estimated assuming an advocacy role, using data from RE:NEW in which each household recruited to the scheme cost about £100. Thus it was estimated that recruiting 1,000 homes in each borough each year would cost £100,000 and a setup cost of £50,000 was assumed. Costs to the householder, the energy company and the Green Deal service provider are each expected to net off and are not considered in the analysis. The results of the analysis are shown in Green Deal Exhibit 1.

Heating Fuel Type and Energy Efficiency Measure	Air Quality and CO2 Benefits over 25 years (NPV in 2012)	Ratio of total Benefits / total costs	Total NOx reduction (tonnes)	Total PM10 reduction (tonnes)	Total CO2 reduction (tonnes)
Coal (none in London) & SWI	£ 4,767,134	8.52	534	363	287,045
Electric Heating & SWI	£ 3,186,480	6.03	861	25	397,658
Gas Oil & SWI	£ 1,227,936	2.94	168	14	219,487
Burning Oil & SWI	£ 1,177,115	2.86	139	14	214,119
LPG & SWI	£ 961,013	2.52	281	8	186,956
Electric Heating & CWI	£ 789,593	2.46	299	9	138,316
Gas Heating & SWI	£ 696,451	2.10	205	3	161,451
Wood/Biomass heating & SWI	£ 471,151	1.74	471	116	-
Gas Heating & CWI	£ 171,184	0.73	71	1	56,157

Green Deal Exhibit 1: Socio Economic Impacts of a reduction in air quality emissions *over the years 2012-2036 due to installation of Solid Wall or Cavity Wall Insulation in 1,000 homes each year from 2013-2017 with different primary heating fuels. Statistics shown are: Net Present Value of aggregated Damage Costs of NOx and PM and Shadow Price of Carbon, Net Cost effectiveness, Ratio of Benefits-to-Costs, and total reductions in NOx, PM and CO2 over the period. Table is ordered by Benefits NPV.*

These suggest that the largest impact on CO_2 emissions reduction in London can be obtained by prioritising homes with electric home heating for SWI, which represent some 9.7% of UK dwellings (English Housing Survey, 2009). The largest local impact on NOx air pollution would be obtained by prioritising homes with natural gas heating for SWI, which makes up more than 83% of dwellings, and the largest local impact on PM pollution would come from targeting homes using gas oil or burning oil, which is sometimes popular in social housing, for SWI. This suggests that before investing in local Green Deal roll-out programmes, councils should consider whether to prioritise the reduction of local toxic air pollution or global warming pollutants. This suggests that SWI would be substantially more cost effective than CWI.

Who should lead?

Outcomes for Green Deal locally include opportunities for improved health outcomes, regeneration and job creation. The Green Deal consultation sets out an important role for local authorities, with three routes possible: service provision, service partner or local advocate. In either case, the council will play an important role in providing information for local residents.

Iarla Kilbane-Dawe, Par Hill Research Ltd

EPISODE REDUCTION

CAMPAIGN DAYS
CMA APPLICATION
(SEE ALSO IDLING ENFORCEMENT)

Four episode reduction measures were considered: street cleaning, CMA application, engine idling wardens and campaign days. Of these, idling enforcement, CMA applications and campaign days were found to be cost effective (BCR≳2). Idling enforcement is detailed in the next chapter, as it is also a Quick Win measure.

Iarla Kilbane-Dawe, Par Hill Research Ltd

Campaign Days for Episode Management

Programmes of branded short-term advertising campaigns promoting traffic reduction on days preceding forecast high pollution episodes have been found to reduce in-day traffic in California by 3%-10%. If the same impacts on private cars and motorbikes were repeated in London, total PM10 emissions would fall by 1%-3% on a targeted day. The cost of such a campaign for each episode is estimated at £75,000, based on a multi-day radio advertising campaign with a single day newspaper campaign. Co-benefits would include a reduction of 0.1-1.2kt of CO2, reduced socio-economic damage and health costs of £35,000-£123,000, a temporary reduction in congestion and noise pollution, and a small reduction in mortality. A pilot project would require at least six months to setup including procurement and could cost £550,000 for a three month pilot covering 5 episodes. Roughly three times this amount, or £1.5M would be needed for an annual programme of 20 episode Campaign Days. In terms of socio-economic payback, the programme would be net-benefit if it reduced car and motorbike traffic by an average of over 6% per Campaign Day.

How this framework is organised

Campaign Days for air quality management are a novelty in UK air quality management. The framework reviews the methods applied in the US to deliver effective campaign days, lists the key technical challenges, outlines a potential plan for a pilot programme, sets out the options for how a programme can be organised and lists potential funding sources for a programme of campaign days.

Cost per full operating year	Cost savings	Socioeconomic benefits	Cost per tonne of PM10 saved	Example PM reduction
£1.5M	Nil	£0.7-£2.5M	£1.36M	0.03-0.12 ug/m3 Shaftesbury Ave

Episodes Exhibit 1 Key Statistics about Campaign Days

Introduction

Mitigation of PM10 exceedence episodes in London is required under the terms of a Time Extension granted to the UK under the CAFÉ Directive [EU Decision 2011]. Episode mitigation is done by various methods around the World: dynamic road pricing in Singapore, variable congestion charging by episode season in Milan [Ecopass 2012], vehicle bans and variable LEZs in Europe, road cleaning and dust suppressants in the UK and commuter behaviour change in the USA. Episode mitigation is difficult as the weather conditions that allow episodes can be difficult to forecast and once an episode has begun, mitigation can be limited to slowing the pace of already increasing pollution.

In the USA significant in-day behaviour changes have been achieved using pre-episode advertising campaigns backed up by enforcement actions against dirty vehicles and stationary sources and community outreach. The best known example is the Spare the Air (STA) programme in California's Bay Area. There, on average 387,603 fewer road trips were taken on each of the 7 campaign days in 2010 [STA 2010], a 6.6% reduction in road trips in a location where 68% of commuting is by single occupier vehicle.

London's commuters have much better public transport choices than California residents and are accustomed to switching mode or working from home as a result of disruptions. This suggests that an in-day modal change campaign programme has the potential to be effective in London.

Monetised benefits of PM, NOx and CO2 reductions

Although driver responses in London would be different to those in California, we can use the results of the Bay Area STA to provide impact scenarios for London. Over the period 2002-2010, the lowest impact delivered by an annual STA programme was a 2.8% reduction in private vehicle trips per STA day. The average impact in these years was 7.4% per STA day, and the highest impact was 9.8%. These figures are used for Low, Average and High London scenarios.

Assumptions & Methods

The calculation assumes that cars and motorbikes of all classes are reduced in number count equally, all trips are of equal length, emissions are the same every day, there are no changes in HGV, LGV, train or bus traffic, advertising is London-wide and traffic reductions are uniform across London. Emissions and concentration changes are based on source apportionment and baseline emissions data, socio-economic impacts are estimated using the IGCB Damage Cost methodology for PM and NOx and HM Treasury Social Carbon Cost methodology for CO2 emissions.

Results

All scenarios suggest the approach would reduce total PM_{10} emissions in-day by 1%-3%, as both exhaust, brake and resuspension emissions are reduced. NOx reductions would be less at 0.3%-1%, while CO2 would be reduced by 1%-4% (see Table 20.1). The socio-economic costs of pollution are significant - Defra's IGCB calculates that PM_{10} emissions in Outer London have socio-economic Damage Costs to human health of £148,949 per tonne, with higher impacts in Inner and Central London [Defra, 2009]. HM Treasury figures put the social cost of carbon in 2011 at £82 per tonne. Even applying the Outer London PM figure for an All-London calculation, the socio-economic benefit of a traffic reduction Campaign Day that reduced traffic emissions by a few percent would be significant (Exhibit 2) as traffic reduction reduces both PM, NO2 and carbon emissions.

Car & Motorbike activity reduction	Daily PM_{10} reduction, kg & % of all London emissions	Daily NO_x red'n, kg & % of all London emissions	Daily CO_2 red'n, tonnes & % of total emissions
Low - 2.8%	55kg / 0.84%	393kg / 0.31%	330t / 1.26%
Average - 7.4%	144kg / 2.22%	1037kg / 0.81%	872t / 3.33%
High - 9.8%	191kg / 2.94%	1374kg / 1.08%	1155t / 4.41%

Episodes Exhibit 1: In-day reductions from Campaign Days *for the 2.8%, 7.4% and 9.8% car and motorbike traffic reduction scenarios. Reductions in kg/day & % of London daily total for PM and NOx, and tonnes/day & % for CO2.*

As each Campaign Day is estimated to cost c. £75,000, a traffic reduction of more than 6% would be required for the socio-economic benefits to outweigh the Campaign Day costs, as in the Average and High scenarios. The break-even point would be lower if the higher socio-economic costs of PM for Inner and Central London were accounted for in the calculation [Defra, 2009]. The benefits of a 20 episode one-year programme are shown.

Car & Motorbike activity reduction scenario	PM_{10} Damage Cost, per Campaign Day	NOx Damage Cost, per Campaign Day	Social Cost of Carbon, per C-day	**Total Benefits per Campaign Day**	**Total Benefits for 20 Campaign Days**
Low - 2.8%	£ 8,135	£ 375	£ 26,731	**£ 35,241**	**£ 704,820**
Average - 7.4%	£ 21,501	£ 991	£ 70,647	**£ 93,139**	**£1,862,780**
High - 9.8%	£ 28,474	£ 1,312	£ 93,560	**£ 123,346**	**£2,466,920**

Episodes Exhibit 2: Monetised socio-economic benefits (£/Campaign Day) *of in-day cuts in PM_{10}, NO_x and CO_2 emissions from car and motorbike traffic reductions in London of 2.8%, 7.4% and 9.8%.*

The air pollution concentration impacts of these changes can be estimated using results of Source Apportionment modelling studies. An example result is shown for a receptor at Shaftesbury Avenue in Camden, based on published studies [CERC Camden SA]. From estimates of the concentration change an estimate of the consequent reduction in mortality - which is a subset of the overall impact on health - can be inferred using the method of Pope [refs: POP, IOM study, EEA study].

Car & Motorbike activity reduction	△PM_{10} at Shaftesbury Ave, annual mean ugm^{-3}	△NO_x at Shaftesbury Ave, annual mean ugm^{-3}	Mortality Reduction In London, for 1 Campaign Day	Mortality Reduction In London for 20 Campaign Days
Low - 2.8%	0.0344	0.364	0.07	1.4
Average - 7.4%	0.091	1.998	0.1	2
High - 9.8%	0.1206	2.646	0.13	2.6

Episodes Exhibit 3: *Reduction in PM10 and NOx concentrations at Shaftesbury Avenue, Camden, given a 2.8%, 7.4% and 9.8% reduction in private car & motorbike traffic, and estimate reduction in mortality London wide for a single campaign and 20 campaigns.*

Exhibits 2 and 3 show that although overall socio-economic benefits in terms of health and climate change impacts would be significant and of the same order as the costs, the impact on mortality in London to due PM would be small. This is due in large part to the non-London origins of much of the PM found in London's environment.

Air quality actions that could be advertised

A key lesson from US experience is that a few simple clear messages are more effective than detailed options for action. Initial campaign messages include:

- modal switch from cars to tubes, buses, cycling and walking;
- car pooling / sharing and smart driving;
- working from home and other trip reduction and linking measures.

In later campaigns, more complex options could be advocated:

- taxi sharing / use reduction, high profile taxi idling enforcement;
- school walk trains, parent accompanied cycling & idling campaigns;
- demolition suspension or additional construction mitigation measures;
- high profile on-street exhaust emissions & bus idling enforcement.

Outline of Key Actions, Processes and Timescale

Delivery of a campaign sufficient to effect a significant behaviour change in the London population on a single day would require a dedicated team, with a substantial media and communications skills and based on accurate air quality forecasting capabilities. The following steps would be required:

Pre-launch phase

1. Secure agreement to proceed between the Central London boroughs (and other boroughs if possible), GLA & TfL, and other stakeholders such as London councils, Defra and the Environment Agency. Agree a plan and lead Borough. If necessary, appoint a contractor to assist in delivery of steps 2-4.

2. Secure pilot project finance for an initial target period, such as the months running up to and including the Olympics. Possible pilot funding sources include the Olympic Delivery Authority, Defra and the DfT Clean Air Fund.

3. Seek partnerships with London based media and potential sponsor such as The Evening Standard, News International, BBC London, Capital FM etc. Doing this could greatly reduce the cost of advertising and outreach. Also contact NGOs who could assist in delivery of the project.

4. Determine available forecast accuracy and pilot phase timing. Using statistics from the forecasting systems currently operating over the London domain (airTEXT/CERC yourAir, MACC/PASODOBLE, Defra/AEA, ERG/Kings College, London, PREV'AIR, and UK Met Office), determine how many days warning can be given for an episode with greater than 70% accuracy, this being the accuracy of the persistence forecast in many domains. Alternatively, determine the persistence forecast accuracy for London and compare the statistics with this. Using measurements, determine the time of year when exceedences are most likely and can most accurately be forecast if this varies strongly during the year.

5. Issue and award a competitive tender for the work. The specification should include Tasks 6-11.

6. The contractor should appoint suitable qualified staff to deliver the work, with experience in air quality forecasting, communications, Local Government or NGO partnerships and behaviour change.

7. Agree a brand name to be used across all communications, such as Spare The Air or Leave the Car Behind Day. Use a focus group to test and refine this brand. Develop initial, simple marketing collateral to support the pilot including desktop and mobile websites, posters, stickers etc.

8. Develop plans for:

    8.1. Co-ordination of actions with Borough communications and enforcement teams, and those of TfL or other actors if involved.

    8.2. Alignment with other London AQ initiatives, such as airTEXT etc.

    8.3. Outreach plan with community groups for the pilot project.

    8.4. A Forecast Protocol stating how the forecast is made, a Campaign Day is decided upon, when and by whom, and presenting statistics of the protocol's historic accuracy from an evaluation exercise.

    8.5. In-campaign evaluation, both overall and by campaign action, that estimates behaviour changes and resulting emissions reductions.

    8.6. The Campaign Day protocol, including the actions to be taken, how they will taken and by whom, and how they will be evaluated.

The Pre-launch phase is complete on completion of Tasks 8.1-8.6.

Pilot Operation and Evaluation Phase

9. During the Pilot Operation and Evaluation Phase, the contractor should execute the plans agreed in (8.) above. For costing purposes, we assume that each campaign includes 200 London local radio adverts in the two-three days before and during the designated Campaign Day and an Evening Standard half page ad on the evening before the designated Campaign Day.

10. On completion of the pilot, an overall evaluation should be conducted that estimates total air pollutant emissions reduced, visibility amongst commuters, and acceptance and enthusiasm by stakeholders and partners. This can be used to develop proposals for ongoing funding and stakeholder involvement.

Ongoing Operation

Detailed analysis of ongoing operation is beyond the scope of this work as it depends strongly on the results of the pilot project, but would likely require:

11. Secure appropriate funding for 3 year and revise the governance and management structure based on experiences in the pilot;
12. Review technical evidence for the seasons when campaigns are most appropriate from episode occurrence and forecasting accuracy.
13. Modify tender terms to provide security for the contractor to lower costs and allows the development of a longer term communication strategy. A 3 year contract with annual reviews and revisions of plans may be appropriate.
14. Modify plans (8.1-8.6) to reflect lessons from the pilot, in particular developing new schemes for sponsorship and fundraising and community development, NGO involvement and outreach.

Costs

An effective project team should include a forecaster, a press officer and a marketing officer, one of whom would act as project manager. At least 3 months would be required for setup, and the services of professionals to design websites, posters, leaflets and adverts. Pilot operation would require this team, an on-call evaluation team to conduct interviews during campaign days to assess impacts, plus the cost of advertising.

The cost of an annual campaign can roughly estimated by quadrupling the pilot cost, giving £1.5M per year for a full year programme of 20 Campaign Days, athough actual planned days would depend on outputs of workstreams (4) and (12). Savings would be achieved by bulk advertising purchase, long term staffing and partnership media channels or sponsors. Additional costs would arise from annual revision and renewal of programme marketing material, forecasting etc.

Cost Centre	Outline Cost Breakdown	Est. Cost
Pre Launch Phase: PR Officer, Marketing Officer & Forecaster/ Manager	£150-£400 per day for up to 3 staff at 22 days per month for 3 months	£ 60,000
Pre Launch Phase: Development of marketing collateral, radio ads, posters, websites etc	£500 per day for 3 staff for 20 days	£ 30,000
Pilot Phase Evaluation: 10 Campaign Day Evaluation Staff	£150 per day for 10 staff over 5 days plus one training day	£ 9,000
Pilot Phase Advertising for 5 Campaign Days	5 half pages adverts in ES @ £25,287 and 1000 LBC & Capital radio slots @ £70 each.	£ 196,435
Cost per Campaign Day		**£ 59,087**
Pilot Project cost, including setup, 5 episodes & Campaign Days		**£ 295,435**
Operational Annual cost, 20 episodes & Campaign Days		**£1,181,740**

Episodes Exhibit 4: Est. costs per Campaign Day, *for a 3m pilot and full year.*

Who should lead?

The Boroughs have indicated during consultations that effective delivery of such a programme would require borough leadership, and that an effective campaign will require the involvement of authorities and actors across the London Region. These constraints permit several options for delivery of a programme:

1. borough Delivery;
2. borough Commissioned Delivery;
3. community Based Delivery;
4. hybrid Approach.

Borough Delivery would require the setting up and financing of a specific team in the borough(s) taking leadership, with responsibility for the project and programme development. Strong co-ordination on branding, communications and enforcement actions is needed to deliver an effective campaign, as well as co-ordination with comms teams in TfL, GLA etc. The usual approach would assign project leadership to a Borough that would arrange finance, resource and establish the required team. This approach has the disadvantages that it requires a borough to make substantial commitments to hiring or reassigning staff and developing strategic and tactical plans for the project and is likely to draw resource from other projects in a time of resource challenges.

Borough Commissioned Delivery would require boroughs to obtain funding for the project or programme then tender competitively to external contractors. A private operator delivers the campaigns, with boroughs forming the steering committee. This would benefit from including representation of other relevant bodies: GLA, TfL, EA, NHS, Defra, DfT and HPA. The work specification could require actions to develop long term financial support for the programme.

Community based delivery is advocated for many activities in the Big Society initiative. This requires strong co-ordination of community based groups and NGOs, with leadership and delivery by a community group. Some CLAQCG Boroughs have Big Society programmes, but using this model could create substantial hurdles in setup - despite the presence of British Lung Foundation (BLF), CCAL, and other NGOs, there is no obvious lead community group for such a project in London, so significant borough work could be spent identifying an NGO lead at the outset. Community engagement may be better delivered within the second phase of the project.

A Hybrid Approach would allow boroughs to act as the commissioner of the Campaign Days Programme, allow borough resources in press, communications and street enforcement teams be involved in programme design, co-ordination and delivery, and use community engagement in follow-on campaigns with schools, NGOs to help sustain the programmes future. NGOs could be invited to tender for the pilot project. As with borough Commissioned Delivery, boroughs would form the steering committee, engaging other relevant actors such as TfL and NGOs. The advantages of this approach are:

- it can be procured quickly by a contractor through tendering;
- it quickly creates a central team tasked with delivery of the primary communication and outreach campaigns;
- it leverages borough powers and resources where available, co-ordinating the central team actions with enforcement, communications and outreach resources in boroughs;
- if objectives are not delivered or resources dry up, it can be ended readily.

These advantages suggest this approach gives the most flexibility for Boroughs to commission and deliver a programme quickly and efficiently.

Potential funding sources

Potential contributors to a pilot project include:

- Defra Air Quality Grants;
- a one-off DfT Clean Air Fund grant;
- borough contributions;
- private sector sponsorship (e.g. Barclays);
- EU LIFE programme finance.

While the NHS would be a project beneficiary, experience suggests that NHS support for such a programme is unlikely until medical efficacy is proven.

Timescale To Implementation

Once funding is secured, procurement would require 3-6 months. Thereafter the pilot project could be established in 3-6 months for a 3 months pilot operation and evaluation. This gives a lead time of 6-12 months from securing funding.

DfT grants can potentially be drawn down quickly if political support is obtained, in time for a Summer 2012 pilot. If Defra finance is sought, it's likely that the pilot project would not be funded until late 2012, in time for launch in 2013. Although Boroughs could finance a pilot (combining contributions from all 33 London boroughs would reduce costs to about £17,000 per borough), the lead time to establish such a consortium project is likely to be long and action before 2013 is unlikely. The ODA may also provide support if the pilot it trialled in the run-up to the Olympics. Private sector sponsorship is possible but unpredictable. EU LIFE finance is possible under the Environment-Urban Transport or Environment-Environmental Management Themes, and a similar project was supported in 1999 [ITWC, 1999]. However, the lead time from a LIFE application to decision is usually well over one year. A combination of DfT short-term finance and Defra annual support may be the most suitable approach in the first instance.

Essential Steps

- Agreement to collaborate and deliver the project from the boroughs, which borough should lead, and which model of delivery is used;
- Agreement with other major actors on collaboration, such as TfL, BBC London, DfT, Defra.
- Secure substantial finance for a pilot project.

Risks and Ways to Mitigate Them

Low forecast accuracy leading to mistaken declarations. This can be mitigated by adequate technical analysis in advance of the pilot project, and by ensuring that actions recommended are cost-neutral as far as possible, e.g. traffic reduction, cycling to work, working from home.

Message complexity. US experience highlights the need for keeping the behaviour change message simple, at least in the early years of the campaign. Otherwise individuals are overwhelmed with choice and fail to act.

Finance too small. As more than half the finance is dedicated to advertising, this could be mitigated by securing agreement with media partners or by reducing the number of pilot campaign days.

Episode coincident with another major media event. In the event that a major media event (such as disaster) is coincident and likely to drown out the Campaign Day, the best decision may be not to declare a Campaign Day and save the advertising funds for another occasion.

Key Partners for Success

- Public authorities, including TfL, GLA, Defra & DfT;
- Forecasters providing data including CERC, AEA, UK Met Office and EU financed public projects such as MACC and PASODOBLE;
- NGOs including British Lung Foundation and Asthma UK;
- London media and communications companies e.g.
  - Evening Standard;
  - BBC or ITV London;
  - Capital FM.

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Dust Suppressants

Dust suppressants have been trialled extensively in Scandinavia and other European locations for some years [AQC, 2009], and a recent trial has been conducted for TfL in London [URS, 2011] and has proved effective at preventing the re-suspension of PM sufficient that concentration reductions of 10%-14% were observed.

The effect of dust suppressants is modelled using data from [AQC 2009], [Johansson, 2010] and [URS, 2011]. The cost per km of CMA application is based on data from TfL of £16/km, while the data from URS are used to inform the rate of PM reduction, being 14% per day of tyre and brake wear emissions from these links. It is assumed that CMA is applied on 50 days per year when exceedences are a risk. It is assumed that 75km of the very worst polluted roads are sprayed on these days, and the emissions on those roads are equivalent to those on the Euston Road, LAEI Link 33269. The effects of the emissions due to the CMA sprayers was neglected as these are negligible compared to the reduction in PM. The model was based on a single CMA sprayer being used, at a conversion cost of £14,000 (data from TfL). The measure was assumed to run from 2012-2021 inclusive.

The results of the analysis suggest that application of CMA is a cost-effective way to reduce PM10 locally, as it has a BCR close to 2. This also suggests that the approach could reasonably be scaled up to cover other very polluted roads.

Summary

Application of CMA to 75km of roads on 50 days per year from 2012-2021

Net Costs £s (NPV, 2012)	Cost £ (NPV 2012)	Annualised cost to TfL	Benefit-Cost Ratio	Timescale
£0.3M	£0.35M	£0.05M	1.78	Hours
0	-0.27t	0	£0.012M	75km
NOx change, annualised	**PM change, annualised**	**CO2 change, annualised**	**Cost per tonne reduced**	**Roads affected**

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QUICK WIN ACTIONS

BUSINESS ENGAGEMENT PROGRAMMES (BCR > 22)
CAR CLUBS (BCR > 13)
ECODRIVING FOR TAXI DRIVERS (BCR 6)
ZE LAST MILE DELIVERIES (BCR 4)
IDLING ENFORCEMENT WITH PCN CODE 63 (BCR 4)

Quick Win projects can be delivered quickly and easily, albeit with a small impact on air pollution.

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Business engagement: Walk to the Client example

Improvement of business processes and behaviours so polluting activities are reduced has been trialled in the City of London. This involved face-to-face meetings with facilities, energy, sustainability, operations and communications managers in 100 businesses. The process involves several stages, including message development, measure discovery and mobilisation. While the engagement process leads to the development and potential of many measures options - e.g. fuel use, buildings energy reduction, supply chain consolidation etc - as this is at such an early stage of the process, the data collected so far has been for a single measures - replacing short taxi journeys with walking, encouraged through provision of maps and elimination of expense refunds for short taxi journeys. It was found that the benefits of this measure alone applied to 20 of the largest businesses outweigh the costs of the engagement programme by a factor of 26-to-1, suggesting that this is very good value for money. Net Benefits (in 2012 PV terms) exceeded £4m in one scenario, at cost to the council of £0.2M (NPV terms) over six years (annualised cost of £0.04M). Much of the benefits are in fuel savings rather than pollutant reductions. While mobilisation of additional measures is likely to require additional resource, a similar approach to assessment could be used to refine which measures deliver most benefits for local businesses and for local air quality. These engagements also prepare business to engage in more complex AQ improvement measures. Indeed, the engaged businesses have already been key in the development of best practice guidance and case studies, showing the opportunities going forward.

Summary

Business Engagement on taxi use reduction, ongoing 2012-2017

Benefits £s (NPV, 2012)	Cost to council £ (NPV 2012)	Annualised cost to PS	Benefit-Cost Ratio	Timescale
£4.6M	£0.22M	£0.04M	22.11	Months
0.07t	0.01t	34t	£4.8M	120
NOx change, annualised	**PM change, annualised**	**CO2 change, annualised**	**Fares Reduc'n (NPV 2012)**	**Businesses involved**

Air quality improvement measures involved

The measure was assessed against the reduction of taxi journey emissions over the period 2012-2017 inclusive. To account for emissions when idle the reduction in taxi emissions was reduced by 35% [CERC, 2011a]. Data indicates that in the 20 businesses participating who had more than 2,000 employees, the 300 taxi journeys per week per business were reduced by 10%. The reduction in taxi journeys was modelled as journeys of 2km or less, estimated cost £8 in 2012. Taxi emissions [TRL 2009] were modelled assuming 22.1kph and the taxi fleet mix projected for London from 2012-2017 inclusive [MAQS 2011]. Two scenarios were modelled: 1. business recruitment only in 2012; 2. business recruitment every year from 2012-2017 (shown above).

Relevant Regulations & Who Should Lead

This activity could be classed as falling under Environmental Protection Act 1990 Section 4. councils in co-operation with businesses and business group are best placed to develop such local actions. These could also be classed as measures to support local businesses.

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Car Clubs

Summary

Car club membership has grown rapidly in recent years and pressure is growing to consider whether they have reached saturation point in Central London, both in terms of parking spaces displaced, air pollution and wider impacts. Results from an independently conducted survey of car club users (Harmer & Cairns, 2011) indicates that car clubs significantly reduce car ownership; 55% of car owners who joined reduced the cars they own by at least one. The data suggests that annual mileage of Londoner's households decreases by over 2,300km when a householder joins a car club and the member's use of public transport increases significantly, including taxi use. The indicated reduction in mileage of London users in 2010/11 is the opposite of the evidence for all UK car club members in 2009/10, which suggested that household mileage increases, though the 2009/10 data may be unreliable (Harmer & Cairns, 2010).

The reduction in household car use in London was used to estimate the change in NOx, PM10 and CO2 emissions. Although car club members households use the car club vehicle for only 22% of journeys, the higher average efficiency of car club vehicles (123gCO2/km vs 189 gCO2/km for an average London car) combined with the lower overall mileage per household indicates that car club vehicles lead to significant reductions in NOx, PM10 and CO2 emissions. This suggests car club users should be encouraged to use the car club vehicle instead of another car. The location of the reduced emissions is poorly evidenced. Short journey mileage increases while long journeys decrease, and this makes it difficult to asses the location of the air pollution improvement, which may not be in London.

The business case for individual car users or for car clubs themselves was not examined, nor were relative operating costs of the vehicles. It was assumed that car club users were making an economically efficient decision for the journeys they need to make and that the car clubs are solvent.

Taking into account the charge to car clubs by boroughs for the use of parking spaces and the Net Present Value of Damage Costs and the Shadow Price of Carbon for the six years considered, the findings suggest that car clubs are an extremely economically efficient way to reduce air pollution, greenhouse gas emissions, noise and fuel use in London. An additional scenario was considered in which car clubs were required to use very efficient (99gCO2/km) vehicles instead of the average car club vehicle (123g CO2/km). This improved total benefits substantially through reduced CO2 emissions.

Car Clubs - 1000 CC bays & typical CC cars 123gCO2/km

NPV in 2012 £s	Setup cost to private sector	Annualised cost to PS	Benefit-Cost Ratio	Timescale
£7.4M	not considered	not considered	13.36	Months
28.53t	1.6t	149,982t	14Ml	1000
NOx change, annualised	**PM change, annualised**	**CO2 change, annualised**	**Fuel saved, annualised**	**Number of vehicles**

Car Clubs - 1000 CC bays with extra efficient cars 99gCO2/km

NPV in 2012 £s	Setup cost to private sector	Annualised cost to PS	Benefit-Cost Ratio	Timescale
£11.2M	not considered	not considered	13.6	Months
27.73t	1.6t	297,619t	26Ml	1000
NOx change, annualised	**PM change, annualised**	**CO2 change, annualised**	**Fuel saved, annualised**	**Number of vehicles**

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Introduction

Car club membership in the UK has risen dramatically since the concept was introduced in the late 1990s in Glasgow, with over 160,000 members in about 400 local authorities. Car clubs promote their environmental and social as well as economic benefits, relying on data that suggests their cars have better fuel economy and lower toxic pollutant emissions than the average private car. The social impact of car clubs and their effects on reducing car ownership and access to cars by the socially excluded have been widely studied (see for example ODPM (2003)), and a number of studies for Defra [AQC (2009) & Kollamthodi (2005)] have looked at their potential for air pollution impacts. Previous studies have looked at the macro-effects of car clubs or on behaviours. For this study, the measures impacts on household mileage were used to directly estimate the air pollution improvement, potential revenue raised for councils and reduced socio-economic damage arising from car club growth.

Car club member behaviours compared with the general population

In 2011 a survey of 8,540 car club member' behaviour was conducted by TRL for Carplus [Harmer & Cairns, 2011]. Of those surveyed 61% were London residents, and in some cases the data supplied was only for Londoners, in particular the data of greatest interest for this study, that on mileage before and after joining. The survey data categorically show that car club members have much higher than average rates of use of public and other low emission transport, and much lower car usage. Indeed, the survey suggests that this behaviour is reinforced by joining the car club, with weekly use of trains and underground, buses, walking and cycling all increasing by about 5% after joining. However, use of Taxis and Minicabs appears to increase when people join car clubs, from 21.3% using a taxi or minicab at least once per month before to 23.5% afterwards. By comparison, only 11% of those surveyed in the 2010 London Travel Demand Survey [LTDS, 2010] took a journey by Taxi at least once per month. In London, taxi pollutant emissions are significantly higher per km than those of the average private car (see Fleet Emissions data in attached data sheets), so this change in behaviour is likely to be an air pollution disbenefit.

The survey also shows that car ownership decreases substantially when Londoners join a car club. The proportion of London car club members owning one or more cars before they joined the club is 44.1%, while the proportion that own one or more cars afterwards is only 19.9% - i.e. about 55% of car owners stop owning at least one car on joining, and overall 24% of car clubs members have given up a car entirely. Overall it is suggested by the data that every car club vehicle reduces the number of privately owned cars by 20 [Harmer & Cairns (2010) & Harmer & Cairns (2011)].

Finally, the data indicates that Londoners joining car clubs travel much less in cars (5,676km pa) than the general population (9,652 km pa), and their car usage decreases by over 2,300km pa once they have joined. This is in contrast to the all UK data from 2010, which suggested an overall increase [Harmers & Cairns, 2010].

Relevant Regulations

Car clubs are usually controlled using a Traffic Management Order in accordance with Section 6 of the Road Traffic Regulations Act 1984 and the Local Authorities Traffic Orders (Procedure) (England & Wales) Regulations 1996. Under these terms, the council may choose to hold a public enquiry as a result of objections raised during the TMO consultation. Facilitating car clubs also meets the requirements of the Network Management Duty (Part 2 of the Traffic Management Act 2004), especially the requirement to reduce demand for car trips [Swinburne & Brill, 2009]. The charge for the car club bay is widely used to incentivise the use of particular car types and emissions classes, prevent the use of certain vehicle emissions classes, and offset loss of revenue from parking due to giving up a parking bay. councils usually require that the car clubs fully recompense the council for costs arising from the conversion of the parking bay from its current state to a car club bay.

Air quality benefits

The main air quality benefits of car clubs in London comes from the reduction in household annual mileage, their use of a cleaner, newer fleet of cars than the average car fleet, with additional benefits from greater use of low and zero emission transport modes, and increased use of public transport, walking and cycling. The sole disbenefit arises from a slight increase in the use of highly polluting taxis. Many councils incentivise the use of low emission vehicles by car clubs through the parking charges, many car clubs prioritise the purchase of low emission cars in any case, as they have lower fuel consumption than average cars thus improving the prospects of the car club's business model.

Costs and Benefits

It is beyond the scope of this work to investigate the business models of car clubs or the economics for car club membership versus car ownership for individual members. For the purposes of assessing the economic costs and benefits, we assume that the competitive market of car clubs (there are four operating in London) ensures that members get good value, and the ongoing investment in and rapid growth of car clubs indicates that car clubs are a viable business model. For these purposes, we net off the costs and benefits to members and to the clubs themselves, and solely consider the economic consequences for councils and any amenity, Shadow Price of Carbon and Damage Cost benefits. In this regard, it is clear that councils benefit financially from car club spaces - it is within councils powers to ensure that car clubs repay in full the costs of parking bay conversion, and to ensure that any loss of parking revenue is compensated by the net parking charges, and most councils do so.

For the NPV calculation over 2012-2017, the figure of £610 per parking bay for the cost of conversion was used, and £300 per bay for the annual car club parking bay charge. This is much lower than the charge by some councils, and so the results can be considered as a lower limit on the revenue benefits. We have considered the case of 1000 car club cars, so the results are readily scalable. Two scenarios were considered, (a) using average car clubs cars as found in the current fleet which achieve about 16.8km/l and emit 123gCO2/km, and (b) requiring extra efficient cars with 21km/l and 99gCO2/km. In both cases Euro 5 cars were assumed. In both cases, the costs and revenue to the council were estimated to be the same, with substantial revenue over the period of £2.4M in 2012 Net Present Value, or £0.43M annualised. Reduced fuel use was also indicated, of 87 Million Litres in scenario (a) and 161Ml in scenario (b).

Scenario	(a) Average CC cars	(b) Extra efficient CC cars
Setup cost to Authority	£ 610,000	£ 610,000
NPV Revenue to Authority, Annualised	£0.43M	£0.43M
Setup cost to Private Sector	Nil	Nil
Operational Cost to Private Sector, Annualised	Nil	Nil
Reduction in fuel used	87 Ml	161Ml

Car Clubs Exhibit 1: Costs and benefits of 1000 new car club bays and cars on 1.1.2012 over the period 2012-2017.

PM10, NOx and CO2 Emissions Reductions & Monetised Benefits

To determine the net air pollution implications of extending car club usage, ideally detailed and accurate data on car mileage, location and vehicle type before and after joining a car club would be used. Clearly this is not feasible. In their surveys of car club members, Myers & Cairns (2009) and Harmer & Cairns (2010 & 2011) have done the next best thing and collected self-reported data on household car usage. This work was refined between 2009 and 2011, and the 2011 data offer reliable statistics for Londoners (see Table 9-10 Harmer & Cairns (2011)). The figures suggest car cub households have annual mileage of 3307km, of which 722km is in a car club vehicle, while households of those joining have higher annual mileage of 5676km.

Car clubs also report that their cars are on average more efficient and cleaner than the average fleet, with average fleet emissions of 123gCO2/km, from which we can infer from VCA data NOx and PM emissions of 0.109 g/km and 0.0003 g/km respectively, given Euro 5 vehicles. By comparison in 2012, the average London 1400-2000cc car with the London mix of pre-Euro to Euro 5 vehicles emits 189g/km of CO2, 0.239g/km of NOx and 0.013g/km of PM10. Clearly, the mileage in the car club vehicle will emit much less pollution than that in the average London car.

It is impossible to determine where the emissions are located. Harmer & Cairns (2011) supply some data on trip length vs frequency, but this is insufficient to determine where the pollutants are emitted, which is critical for London air pollution appraisal and modelling. The data show that most of the journeys are under 50km and the number of these actually increases on joining, suggesting they are within or close-to London, but a significant proportion are longer than this. It is from a reduction in these longer journeys that the overall mileage reduction of car club households occurs. So there is an important question - which cannot be resolved - as to where the air pollution concentration reduction actually occurs, in London or elsewhere. For the purposes of Damage Cost estimation the Inner London PM Damage Cost has been used. But more broadly, this question poses councils with a question of to what extent their own residents will benefit from the air pollution reductions that car clubs bring. The estimated NOx, PM and CO2 reductions and Net Present Values of Damage Costs and the Shadow Price of Carbon are given in Exhibit 2.

Scenario	(a) Average CC cars		(b) Extra-efficient CC cars	
NOx reduction	**171.6t**		**166.4t**	
PM10 reduction	**8.40t**		**8.45t**	
CO2 reduction	**150,000t**		**297,619t**	
PV of NOx Damage Cost	*£*	*168,950*	*£*	*164,265*
PV of PM Damage Cost	*£*	*1,299,545*	*£*	*1,307,985*
PV of Shadow Carbon Price	*£*	*4,020,168*	*£*	*7,976,572*

Car Clubs Exhibit 2: Air pollutant emissions reduction and monetised benefits for 1,000 car club cars installed on 1.1.2012 and operated until 31.12.2017.

It has been reported that NOx emissions performance of many diesel vehicles does not achieve the expected Euro 5 improvements, so NOx reductions could well be less. This might also suggest that requiring car clubs to use petrol vehicles might be judicious.

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Ecodriving training programmes

Summary

Ecodriving is a well established method of improving the performance of road vehicles by about 5% and forms the basis of government schemes such as SAFED. It has proven road safety benefits. As well as reducing CO2 emissions, it can also reduce toxic pollutant emissions and noise. Ecodriving (SAFED) certification is a requirement for drivers of HDVs, but take up is poor by LGV, car and taxi drivers. Four potential ecodriving schemes were compared for London taxis and three types of private car owner. Only a scheme for London taxis was found to be close to cost effective (e.g. BCR > 2), but unless drivers are willing to pay for their training, higher BCR programmes should take priority.

Summary Statistics for Taxi Training Scenario

NPV in 2012 £s	Setup cost to authority	Annualised cost to Auth:	Benefit-Cost Ratio	Timescale
£3.7M	£ 200,000	£ 220,000	1.89	weeks-months
-3.5t	-0.31t	-1,686t	1.2M litres	10,000
NOx change, annualised	**PM change, annualised**	**CO2 change, annualised**	**Fuel saved, annualised**	**Vehicles affected**

Introduction

Ecodriving training schemes have been well documented elsewhere [AQC, 2010b] and have proven benefits in terms of fuel savings, air pollutant emissions reduction and road safety. Ecodriving training is now standard for freight road vehicles and driver training schemes for private cars are widely available both in hands-on form and as computer based training. Evidence shows that ecodriving of petrol vehicles significantly reduces their toxic emissions (5%-40%), but can increase NOx emissions from diesel cars unless the training scheme is adapted for diesel engines. Ecodriving training can be conducted quickly, typically in a half day course, and the benefits are immediate. Four ecodriving training programme scenarios were compared: London Taxi drivers, heavy diesel car owners, higher mileage diesel car drivers and average London drivers.

Air quality benefits

Ecodriving results in a direct reduction in fuel consumption and tailpipe emissions. Fuel consumption decreases by 5%-30% [SAFED]. This has been shown to lead to reductions of 5%-40% in PM and NOx emissions in petrol cars [AQC_NO2]. Ecodriving techniques require slight modification for diesel vehicles to achieve good results. We have modelled the impacts assuming only a 5% improvement in fuel, NOx and PM10 emissions. An improvement in brake wear and resuspension emissions of PM is also to be expected due to reduced acceleration, deceleration and braking, but no data on this is available.

Noise, Road Safety and other benefits

The road safety benefits of ecodriving are well known and documented in the DfT SAFED programme. Some noise benefits could be expected due to reduced acceleration and deceleration of vehicles. Training for private car drivers often includes information on air pollution impacts and the benefits of trading down to cleaner more efficient vehicles, so future vehicle choices may be influenced.

Who should lead?

This depends on the scenario and approach. Local Authorities have direct control over residents parking and Kensington & Chelsea has succeeded in applying a diesel surcharge for residents parking - this could be used as mechanism to incentivise uptake of ecodriver training if a surcharge discount was given. Targeting higher mileage residents is likely to be difficult, as they would be hard to identify. Mass communications would probably be needed and this is often impractical for a council and might be better led by the GLA, DfT or the Energy Saving Trust, who all have ecodriving programmes. Targeting London Taxi Drivers would be best done either through council LEZs or in collaboration with TfL, as TfL regulates them directly.

Scenarios Modelled

Most London drivers travel only 7.3km per day (National Travel Survey) - given the average fuel consumption and emission of private cars in London, targeting this group of drivers was found not to be cost beneficial or to deliver substantial improvement in air pollution (calculation not shown). Three alternative scenarios targeting more polluting sectors were developed for (a) London Taxi drivers (b) heavy diesel car owners and (c) longer mileage diesel car drivers. For each full details on mileage, emissions, fuel consumption and operational costs are included in Sections 3, 4 and 5 of the accompanying Worksheets (20.5.a-c).

(a) London Taxi Drivers

London taxis are a small vehicle sector with high mileage and emissions, 21,000 easily identified vehicles and well established stopping places at ranks. They are also directly regulated by a relevant authority, TfL. In addition, councils could choose to regulate taxis directly though an LEZ on council roads (see the Framework description on LEZs for a taxi LEZ scenario). Drivers on average do 60km per day, 250 days per year (LTDA private communication) and it is directly in drivers own interest to increase their vehicle fuel efficiency - London taxis achieve only 25mpg driving up operating costs for drivers.

(b) Heavy Diesel Car Drivers

Diesel cars weighing more than 2.5 tonnes emit as much as four times more toxic pollutants per mile than smaller cars, so targeting these heavier vehicles for an eco-driver training programme could bring particular benefits. The programme could be delivered through a combination of a heavy vehicle diesel surcharge (as in Kensington & Chelsea) combined with a surcharge discount for ecodriver trainees.

(c) Longer Mileage Diesel Drivers

Using variational analysis of the CBA, the break-even daily mileage for net payback over the period 2012-2017 was found to be just under 16.7km per day. Roughly 3% of daily car journeys in London are this length or greater. Targeting drivers doing 17km per day or more was included as a scenario, although in practice identifying these drivers is likely to be a practical challenge.

Costs and Benefits

For all three scenarios, fuel performance improvement was modelled as 5% ([Vermeulen, 2009] & others), but as each vehicle sector has different baseline fuel performance and mileage, fuel savings in each scenario differed substantially.

(a) London Taxi Drivers

It is assumed that setup of the scheme would be through voluntary compliance, regulatory agreement with TfL or a sectoral LEZ scheme, with an enforcement start date of 1.1.2013. Setup costs to the councils were modelled as £200k pa assuming 3-5 FTE staff, and a similar requirement thereafter for enforcement across the eight Boroughs. This gives a Present Value (PV) of the costs to the councils of £1.2M or annualised costs of £220,000. Fuel costs to the drivers excluded VAT as this can be reclaimed. The costs of ecodriving training could also be offset against tax by the drivers, but this is not included as it depends on individual tax rates. Mileage of London taxis was modelled as 5.56km/l (25.6mpg), determined from TRL emissions factors, VCA fuel usage data and CO2 emissions data and confirmed by LTDA. The training for drivers is modelled at £300 per driver - considerably higher than charges for SAFED and similar schemes, but this might allow for fitting of a reminder device in the taxi.

Ahead of the start date, it is assumed the effect of the scheme encourages the equivalent of 2,500 taxi drivers to receive training. After the start date, it is assumed that 10,000 of the 23,000 licensed drivers (of 21,000 licensed taxis) choose to work in the eight boroughs and receive training. This results in charges of £3M for the drivers for training, or annualised costs of £563,000. For the whole period, the fuel savings are found to have a PV of £7.2M for the drivers, or annualised benefit of £1.4M.

(b) Heavy diesel car drivers

It is assumed the scheme is run through a residents parking surcharge on large (> 2.5 tonnes) diesel vehicles and an offer of offsetting this surcharge if accredited ecodriver training is taken by the registered driver. This is assumed to have a setup cost to the council of £50,000, giving a PV of £50,000 or annualised costs of £9,400. This figure may underestimate the costs or net revenue via the diesel surcharge and requires more detailed modelling. Training for the drivers is modelled as £150 per person (i.e. £150,000 pa), with the cost borne by the driver. One thousand drivers per year of heavy diesel cars across the eight boroughs are assumed to take up the offer starting in 2013. The PV of these costs is £1.2M or £220,000 annualised costs. The resulting 5% improvement in fuel efficiency generates fuel savings of £747,000 (PV) or £140,000 (annualised).

(c) Higher mileage diesel drivers

While targeting higher mileage diesel drivers could be cost-effective, identifying the individuals for training may be difficult. We assume a setup cost of £50,000 to the councils in 2012, probably an underestimate unless distance logging is included as part of parking permit registration. The PV of this is £50,000 or £9,383 annualised.

Once identified and engaged, the costs of training to these drivers is modelled as £150 each for 1000 drivers per year for six years, with PV of £1.2M or £220,000 annualised costs. The fuel savings PV was found to be £1.2M or £225,000 in annualised terms.

Monetised Benefits of AQ Improvements

As with all vehicles in this study, the baseline emissions used are derived from the fleet mix data from the MAQS projected forward from 2011 through to 2017. NOx, PM10 and CO2 emissions per km are derived from the TRL 2009 polynomial coefficient using an average speed of 22kph, the Central

London vehicle speed determined from the latest TfL London Travel Survey. In all cases the reductions were modelled as a 5% reduction in NOx, PM and CO2, although some studies indicated NOx and PM reductions can be as much as 30%-40%. The results for the three 6 year scenarios are presented opposite in Exhibit 1.

Scenario	(a) Taxi drivers	(b) Heavy diesel car drivers	(c) Diesel drivers doing >17km/ day
NOx baseline	425t	22.84t	42.85t
PM10 baseline	37t	0.39t	1.81t
CO2 baseline	202,322t	21,425t	21,694t
NOx reduction	**21.26t**	**1.14t**	**2.14t**
PM10 reduction	**1.86t**	**0.02t**	**0.09t**
CO2 reduction	**10,116t**	**1071t**	**1,085t**
PV of NOx Damage Cost	*£ 20,823*	*£ 1,111*	*£ 2,083*
PV of PM Damage Cost	*£ 434,387*	*£ 4,614*	*£ 21,075*
PV of Shadow Carbon Price	*£ 269,242*	*£ 28,269*	*£ 28,663*

Ecodriving Exhibit 1: *Emissions, emissions reductions and socio-economic benefits of ecodriver training for (a) 10,000 London Taxi Drivers, (b) 1,000 drivers of diesel cars weighing more than 2.5 tonnes per year for six years, and (c) 1,000 drivers of diesel cars doing more than 17km per day each year for six years.*

Potential funding sources

These approaches are sufficiently low cost in setup to be covered by an Air Quality Grant or small grant from DfT, London councils or the GLA. In some cases, revenue from PCNs (for taxis) or a diesel surcharge could also defray the cost to the council. The costs to drivers are small and rapidly offset by fuel cost savings.

Relevant Regulations

Ecodriving regulations apply only to large goods vehicles and public service vehicle drivers, through the Certificate of Professional Compliance requirement of the Good Vehicles Act (1995) which implements EU Directive 96/26EC. Private cars and light duty vehicles have no compulsory requirement.

Another route to requiring training could come through an LEZ - indeed ecodriving could form the first phase of a sectoral LEZ. This would require a vehicle and driver certification scheme (see the LEZ section for details). Finally, private drivers could be encouraged to take training through a parking permit surcharge on large engined vehicles, which would be offset if the owner was certified as a trained ecodriver.

Finally, for LGVs and taxis, ecodriving certification of drivers can be included as a requirement within procurement contracts.

Zero Emission services

A number of businesses provide services at competitive rates in which they use Zero Emission modes of transport or delivery[11]. Data reported by these operators indicates that overall mileage in polluting vehicles can be reduced by 60% with resulting reductions in CO2, PM and NOx, especially in the location of the final deliveries. Assuming a one-off cost to the procuring entity of £1,000 in switching to the ZEV supplier who would deliver 0.4M items per year, these data suggest the socio-economic benefits-to-cost ratio would be over 5, indicating the service would be good value for money. Much higher ratios would be likely if larger amounts of cargo were being delivered, although the services are unlikely to be suitable for loads of more than a 100kg-400kg. Additional benefits arise from reduced noise, reduced congestion from parked LGVs and reduced parking congestion - the daily mileage parked was found to be 52% less than in the LGV baseline.

Summary Statistics, 2012-2017

Benefits £s (NPV, 2012)	Cost £ (NPV 2012)	Annualised cost to PS	Benefit-Cost Ratio	Timescale
£ 4046	£ 1000	£ 187	5.05	Weeks
0.021t	0.011t	20.5t	£4.8M	0.4m
NOx change, annualised	**PM change, annualised**	**CO2 change, annualised**	**Fares Reduc'n (NPV 2012)**	**Parcels delivered**

Air quality benefits

The air quality benefits arise from a reduction in local pollutants by replacement of the last leg of delivery using a ZEV. Delivery using an IC vehicle to the micro-consolidation hub still causes local pollutant emissions. Delivery using this method for 0.4M parcels (approximately the number of parcels delivered to all London councils per year, using a crude extrapolation of data provided by one council). A study by Leonardi (2010) on the GnewtCargo Company indicates that micro-consolidation centres created by them for ZEV last mile delivery reduce total distances travelled to make deliveries by about 54%, and reduction mileage in polluting vehicles by 64%.

The data from this study was projected forwards from 2012 to 2017 and compared with equivalent mileage using a class N1(III) 3.5 tonne LGV. The service modelled uses 50% cargo bikes and 50% small EV trucks. The trucks are charged using renewable energy, so the overall CO2 emissions reduction is 64% based on the change in mileage using IC LGVs. There are no local emissions of toxic pollutants by the cargo vehicles, so the overall reduction in toxic pollutants is at least equivalent to the mileage reduction of 64%. The activity factor was determined using data from Leonardi (2010), and from this the total NOx, PM and CO2 reductions and consequent socio-economic cost reductions were determined.

Costs to service procurers were modelled as a one-off cost of £1000, assumed to be the cost of adopting a policy of competitive ZEV last mile deliveries. The services are otherwise provided on a competitive basis, so other financial costs and benefits were not counted. Additional benefits of reductions in noise pollution and parking congestion should also be noted - parking mileage per day was calculated to be reduced by 52% (ibid).

[11] See for example: www.gnewtcargo.co.uk or www.outspokendelivery.co.uk or Sainsbury's home food deliveries.

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Idling enforcement using PCN Code 63

Engine idling can be subject to a Penalty Charge Notice under Code 63, which can be enforced by council traffic wardens on any road vehicle. The logistics of idling enforcement mean that it can only practically be applied at bus stands or taxi ranks, or opportunistically in places where HGVs or LGVs are parked for lengthy periods.

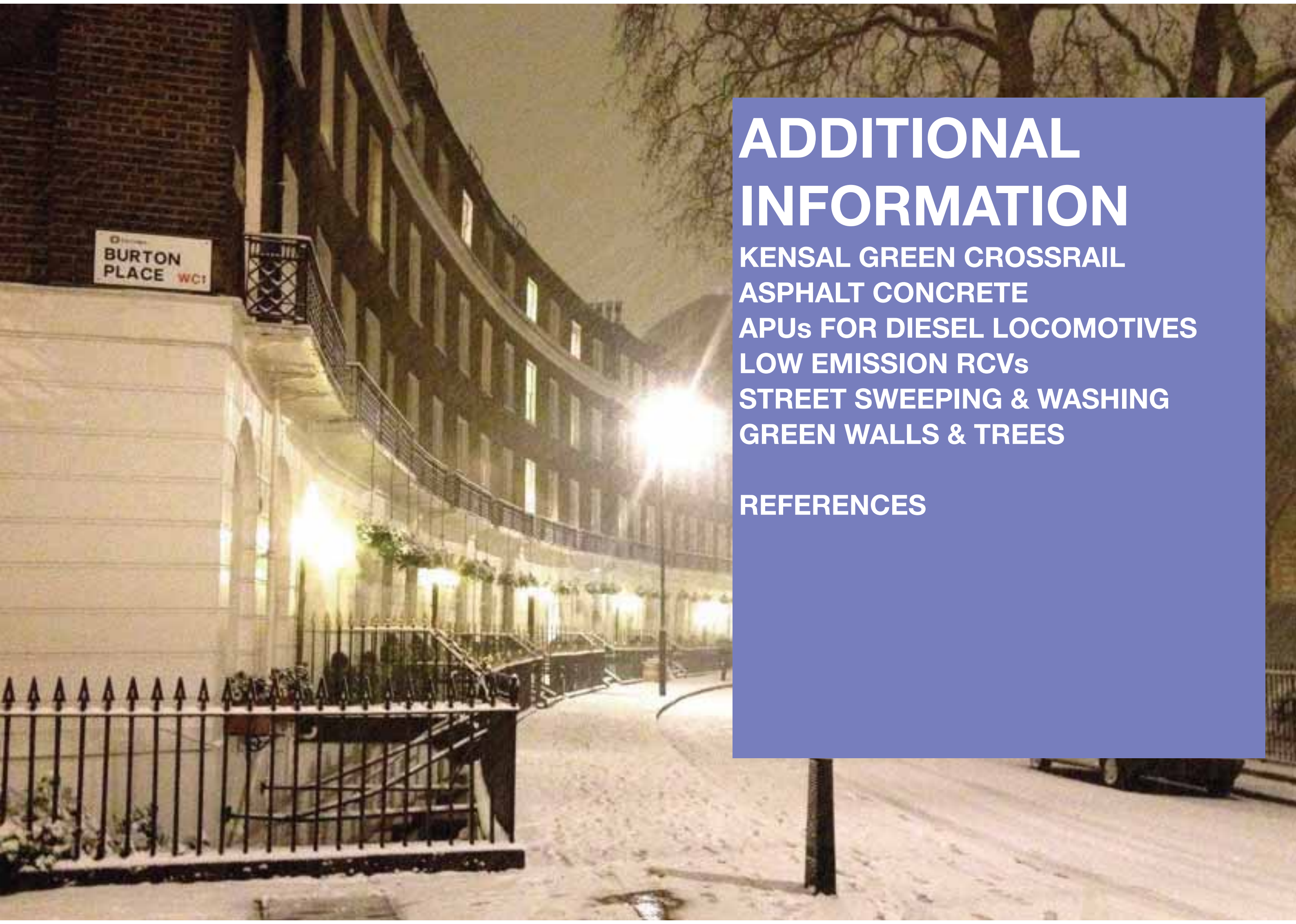
To estimate the impact of enforcing idling switch off, it was assumed that a warden would work 8hours per day, 220 days per year solely on idling enforcement. Engine emissions at idle were obtained from [TRL, 2009] assuming a vehicle speed of 5kph. For the initial analysis, taxis ranks were modelled with levels of compliance varying from 25% to 100% in response to the enforcement action. Taxis were assumed to remain on rank for 30 minutes, and the resulting reduction in emissions of PM, NOx and CO2 was calculated based on the number of equivalent-kms of driving that were avoided (for example, with 25% compliance a 50 taxi rank will avoid 900,000km of engine emissions per year). At each level of compliance the cost effective minimum taxi rank size was determined, where a Benefits-Costs Ratio of 2 or greater is achieved from Damage Cost and Shadow Price of Carbon reduction. It was found that the higher the level compliance, the smaller the rank would be cost effective.

The smallest taxi rank size that can be cost effective is 49 taxis (at 100% compliance) while at only 25% compliance a 200 capacity taxi rank will be cost effective. The result is not sensitive to the residence time on rank, but is sensitive to the rate of occupancy of the rank - only the time of day when ranks are full should undergo enforcement action. The greatest benefit will be achieved if large ranks undergo enforcement and high compliance is delivered. For example, 100% compliance on a 50 taxi rank will reduce PM by 200kg (BCR 2.0), while 50% compliance on a 200 taxi rank will reduce PM by 400kg (BCR 4.0).

Compliance Rate	Minimum Rank Size for BCR > 2
100%	49
75%	65
50%	97
25%	194

The relative emissions of HGVs, LGVs, buses, cars and taxis were compared at idle and it was found that enforcement against these vehicles is unlikely to be cost-effective, except for bus, HGV or LGV stands occupied by 7-10 vehicles.

Idling Enforcement



ADDITIONAL INFORMATION

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Crossrail At Kensal Green

Crossrail is Europe's largest civil engineering project and will increase London's rail transport capacity by 10% [Ferrary, 2005]. The potential air quality effects of a Crossrail station at Kensal Green was considered based on studies of its expected impacts on London wide traffic patterns and local air pollution near the major sites and stations.

Impact on road traffic across London and resulting air pollution effects

Overall, Crossrail is expected to lead to a reduction in London's road traffic of 2% compared with the baseline in 2016 [Mott MacDonald, 2005], and so can be expected to reduce air pollution from passenger vehicles by a similar amount across London. No data is available on the mix of vehicles affected so a more detailed assessment is not possible.

Impacts at major Crossrail sites

Studies at the major Crossrail sites in the Central London section (see table) found that local traffic at most sites is not expected to increase significantly, with the exception of Farringdon. These traffic changes are expected to have an insignificant effect on annual average PM and NO2 [ibid].

Crossrail was also examined for emissions of toxic pollutants from vent shafts from the railway. In all cases in Central London the impacts were found to be insignificant. All the Crossrail stations platforms will be partitioned from the line, reducing venting of brake wear emissions to the surface. Additional mitigation of PM by regular tunnel sweeping was specified by the consulting engineers.

Air pollution is expected to increase temporarily due to construction at the sites.

Expected increase in local air pollution due to Crossrail during operation at the major Central London sites [Mott MacDonald, 2005]

Site	Authorit y	Air Pollution Increase	Site	Authority	Air Pollution Increase
Canal Way	RBKC	None	**Tottenham Court Rd**	CoW & Camden	Insignificant
Portobello Junction	RBKC	None	**Bond St**	CoW	Insignificant
Royal Oak	RBKC & CoW	None	**Farringdo n**	CoL, Islington, Camden	< 2.5% NO2, < 0.6% PM
Paddington	CoW	No PM change, < 0.2ug/m^3 NO2	**Liverpool St**	CoL & Tower Hamlets	Insignificant
Hyde Park & Park Lane Shafts	CoW	Insignificant			

How would a Crossrail station at Kensal Green affect air quality?

A station at Kensal Green is likely to attract significant local passengers intending to travel to Heathrow in the West and Central London eastwards. If the pattern at most other stations in Central London and elsewhere on the route is replicated, road traffic in the immediate vicinity would not increase significantly or worsen any air pollution problems.

Crossrail journey time savings are expected to cause some drivers to switch to using Crossrail [ERM, 2005]. If the London-wide pattern of a traffic reduction of some 15,000 car journeys during the morning peak is replicated in the area of Kensal Green and surrounding neighbourhoods, then an accompanying reduction in local air pollution emissions from traffic compared to the baseline will occur.

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Asphalt Concrete Types

There have been some suggestions that different asphalt types result in different rates of PM re-suspension, in particular a difference was suggested between Hot Rolled Asphalt (HRA) and Bituminous Macadam (BM) and reference was made to work at Imperial College. A recent laboratory study [Jarvis & Parry, 2011] compared the composition of well worn HRA and BM samples from the Cromwell Road, London with PM caught in a particle trap at a nearby receptor. The study was not designed to elucidate the relative impacts on re-suspension of road surface types, but rather to investigate the relative mass spectra of road surface types and whether these spectra could be used to distinguish the surface wear contribution to the airborne re-suspended PM. The study showed that mass spectra could be used, but the results were insufficient to suggest whether the two surface types made different contributions.

A review by Boulter [2006] found evidence of a positive correlation between bitumen content and road wear. Bitumen is used as the main component of binder in asphalt concrete and asphalt concrete approved for use in the UK typically contains 4.5%-6.6% [DMRB, 1999; BSI, 2010], as illustrated in Exhibit 9.1. Bitumen makes up 50%-100% of this binder and the composition varies with the road safety and road wear characteristics required of the asphalt.

Johansson [2006] found that the speed of vehicles on the road surface was strongly correlated with PM production.

Clearly, some evidence suggests that asphalt composition and application contributes to road wear, but more work is required to determine the correspondence with roadside PM concentrations.

Product	Asphalt type	Binder	Laying temp, C	Target Binder content	Target Bitumen content
Fibrovia	Fibrovia 14 surf 65psv 40/60	Binder 40/60 Bitumen	160-190	6.0% (5.5%-6.5%)	3.6%
Fibrovia	Fibrovia 10 surf 40/60 psv	Binder 40/60 Bitumen	160-190	6.3% (5.8%-6.8%)	3.8%
Hot Rolled Asphalt	HRA 30/14 surf des 40/60	Binder 40/60 Bitumen	170-190	6.5% (5.9%-7.1%)	3.9%
Asphalt Concrete	AC 20 HDM bin 40/60	Binder 40/60 Bitumen	160-190	4.4% (3.8%-5.0%)	2.6%

***Asphalt Exhibit 1 Typical composition of UK road asphalts**, courtesy of Jan Helmsley, Jean Lefevre (UK) Ltd.*

Concrete Types

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Auxiliary Power Units for Diesel Locomotives

Summary

To reduce PM and NOx emissions in railway stations, some locomotives can be fitted with generators to provide lighting and air conditioning power to carriages when the train is in the terminal, so the locomotive can be switched off. The generators are significantly cleaner than the locomotive engines, and emissions would be reduced by 7t of NOx and 210kg of PM over 10 years. The costs of £50,000 per locomotive outweigh the socio-economic benefits per decade of £34,725. A more economic alternative might be to work with Network Rail to reinstall Shore Supply of electricity for carriages.

Introduction

Diesel and diesel-electric railway locomotives are thought to emit some 8% of NOx emission in London [MAQS 2011a] and contribute to PM pollution and to noise and air pollution nuisance in and around the major diesel stations at Paddington, Marylebone and Kings Cross. Endeavouring to mitigate local nuisance effects, Chiltern Railways is installing Auxiliary Power Units (APUs) in five of their Class 67 locomotives serving the London Marylebone-Birmingham Snow Hill Route. A preliminary assessment of the costs and impacts of this measure is presented.

Relevant Regulations

Emissions from railway locomotives are regulated at two levels. Since January 2009, the Office of Rail Regulation checks new locomotives to ensure that they are compliant with Stage III of European Parliament Directive 2004/26/EC [EUR LEX], requiring rail engines greater than 2Mw to emit less than 7.4g NOx per kWh and 0.2g PM per kWh. Once in service, it falls to local authority Environmental Health Officers to control local emissions from locomotives.

Air quality improvement measures involved

Until rail privatisation, lighting and heating power for stationary trains was provided at terminii by Shore Supply, a powered umbilical that connected to the train. After rail privatisation, Shore Supply was phased out due to billing difficulties and now TOCs must run their diesel trains engines for power.

At Marylebone Chiltern Train's Class 67 locomotive engines are a General Motors/EMD 710 V12 139.5 litre turbo charged two stroke, providing up to 2.8 MW of power. When idling and stationary in station the EMD 710 generation capacity greatly exceeds the requirements of the carriages for power, as a result of which fuel is wasted and unnecessary air and noise pollution are generated.

To address this problem, Chiltern Railways is installing Volvo TAD1352GE 356kW generators in a free compartment on one carriage on each of five train-locomotive sets. These generators will be used when the train is stationary, operating at 250kW allowing the EMD710s to be used only when the train needs to move. The fuel consumption of the generators will be lower than that of the EMD710 as will the air pollution, CO2 and noise emissions.

Costs and Benefits

The current EMD 710 is recognised as a particularly clean engine, and is compliant with US EPA Tier 2 NOx and PM limits without exhaust treatment [EPA Loco 2008]. In-service Class 67s were built using a 1998 EMD710, which does not comply with EU Stage III or US EPA Tier 0 emissions standards. In the absence of data from manufacturers on the actual emissions, we have used the limits of the highest available relevant standard to which the engine is known to not comply, this being US EPA Tier 0, being 11.61 g NOx/kWh and 0.43 PM_{10}/kWh (8.6g NOx/bhp-hr and 0.32 g PM_{10}/bhp-hr - ibid). Fuel consumption in current EMD710s at 250kW is 62l/h, or £31.50 per hour. The

Locomotive APUs

Volvo generators are each compliant with EU Stage IIIA and consume 60l/h while operating at 250kW output, with emissions no greater than 4g/kWh NOx and 0.2g/kWh PM10. Purchase and installation of the generators costs £50,000 per locomotive.

As a results with engine idling at 250kW replaced by the generator for 15 minutes at the beginning of each of four journeys per day, the emissions change per year resulting is as shown in the table. The motors have similar fuel efficiency, so there would be no fuel savings or CO_2 reduction.

Emissions	NO_x/kWh-locomotive	PM_{10}/kWh-locomotive	NO_x / year-locomotive	PM_{10} / year-locomotive
EMD710	11.6g	0.43g	1.06t	39kg
Volvo TAD	4g	0.2g	0.365t	18kg
Reduction	7.6g	0.23g	0.695t	21kg
Emissions reduction over 10 years			6.95t	0.21t
Cost per tonne year 1			£ 71,942 /t	£2.38M /t
Cost per tonne years 1-10			£7,192 / t	£0.24M / t

Table 13.1 Emissions of NOx and PM10 from the EMD and Volvo motors, g/kWh and mass/year/locomotive, emissions reduction per year-locomotive and estimated cost per tonne of the emissions reduction for the first year and first decade.

Monetised Benefits of PM_{10}, NO_x and CO_2 Emissions Reductions

Using the IGCB Damage Cost methodology, the estimated socio-economic benefits of the emissions reductions over 1 and 10 years was calculated and this is shown in Table 13.1. As there is no change in CO_2 emissions the social cost of carbon impact is negligible.

	PM_{10} DC, per loco.	NOx DC, per loco.	Total Costs or Benefits per loco.	Total Costs or Benefits for 5 locos.
Benefit Year 1	£ 2,864	£ 608	£ 3,472	£ 17,360
Benefit Yrs 1-10	£ 28,644	£ 6,081	£ 34,725	£ 173,625
Total Cost			£ 50,000	£ 250,000

Table 13.2 Socio-economic impacts of emissions reductions for PM10, NOx, CO2 and the total benefits. Benefits are shown per locomotive and for all five locomotives to be run by Chiltern Railways, and for one and 10 year periods.

These socio-economic benefits suggest that the £50,000 cost of installation of each generator is not outweighed by the health and greenhouse-gas reduction benefits over a 1 or 10 year period, but would be over a longer period.

Shore Supply

Shore Supply was provided for trains and carriages at terminals in the past, but was phased out due to difficulties with billing. An alternative approach to fitting generators to carriages would be to reintroduce Shore Supply, either using high wattage power points or generators at the platform. These would have the same environmental benefits per locomotive, but as the installation cost would be shared with a large number of locomotives, the cost per locomotive would be an order of magnitude lower. The approach used could readily be developed from that for all electric locomotives.

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Low emissions RCVs

The use of Compressed Biomethane Gas (CBG) as a heating, energy generation and transport fuel is increasingly advocated. CBG offers several advantages:

- By consuming food waste that would otherwise go to landfill, it reduces the cost of the landfill tax to the service operator;
- By capturing methane from sewage it reduces local methane emissions;
- It reduces the global warming impact of the waste as the methane that would otherwise be released in landfill is converted to CO2 (a molecule of methane has a Global Warming Potential 21 time greater than one of CO2, even though it's lifetime is only 0.5% of that of the CO2 molecule).
- It can be lower in cost than fossil fuels;
- When used in transport, it has very low emissions of NOx and PM10, usually better than the Euro VI requirements.

As a result, production of CBG by anaerobic digestion has been prioritised by HM Government, both in Defra's Water Strategy and DECCs energy supply and generation strategies. Research has suggested that the most effective use of CBG by councils for transport would be in Refuse Collection Vehicles.

Summary

CBG powered RCVs, projected over 2012-2017

Benefits £s (NPV, 2012)	Cost £ (NPV 2012)	Annualised cost to council	Benefit-Cost Ratio	Timescale
£1.6M	£0.95M	£ 178,284	1.68	Years
2t	0.018t	13,028t	0.65M km	38
NOx change, annualised	**PM change, annualised**	**1159t**	**Mileage pa**	**RCVs replaced**

Air quality improvements and Cost-Benefit assumptions

Greenwich council commissioned a study to investigate the effects of installing a biomethane generation facility and using it to generate heat and electricity and fuel fleet vehicles. The CENEX study [Carrol, 2009] indicated this was financially viable and that the most suitable fleet for conversion to CBG would be the refuse collection vehicles. The study indicated that conversion of the RCVs to CBG would yield an annual reduction in NOx of 2t, PM of 0.018t and CO2 of 1159t. The CENEX study did not monetise the cost of the air pollutant emissions over the vehicle lifetime.

To do this the lifetime of the vehicles which was taken as six years, based on data from the CENEX study (fleet age 3rd-quartile 6.3 years). Additional savings from biomethane fuel costs are indicated by the CENEX study of £0.25M pa (allowing for the premium in the capital cost of the RCVs), and these figures are also included in the calculation.

The setup cost for the council was taken as the premium of the cost of the CBG RCVs, being £25,000 x 38.

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Street sweeping and washing

There have been a number of significant reviews of the impact of street washing on PM resuspension in recent years [Boulter, 2006; Johansson, 2006; AQC, 2010a]. These reviews have shown a very large variation in the impacts of street washing and sweeping and the consensus view [Boulter, 2006; Johansson, 2006; AQC, 2010a] is that street washing and sweeping are not effective in reducing PM resuspension and subsequent air pollutant concentrations.

Therefore no further analysis of this measure has been conducted.

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Green Walls and Trees

Trees and vegetation have formed a key element of London's public realm since the 18th century and are increasingly managed as a resource with many benefits. Recent research suggests that large areas of vegetation can have a significant impact on air pollution concentrations in street canyons. Researchers have studied the air quality impacts of green walls, horizontal vegetation and trees, as well as the broader economic and amenity benefits of urban vegetation. Modelling indicates that green walls could remove around half the air pollution emitted in a street canyon but at very considerable expense, while trees could remove a few percent at a lower net cost.

Two scenarios were examined, one for Green Walls the other for trees. Even assuming a very high 50% removal rate of pollutants, green walls were found to be a very expensive method of reducing air pollution. Trees are two orders of magnitude less expensive, but still a net cost to public authorities even assuming a high removal rate of 5%. In both cases, significant noise benefits arise from reduced noise reflection and noise screening. Other benefits include improvements to urban drainage, aesthetics, urban biodiversity, climate amelioration, enhanced recreation, conservation and health and well-being [Tallis, 2011]. Horizontal vegetation, such as green roofs, grassy verges or flower beds were not considered as few London street canyons have suitable large verges and green roofs primarily influence urban background pollution.

Overall, Benefit-Cost Ratios were found to be 0.02 for Green Walls and 0.15 for trees. The results suggest that while vegetation will remove air pollution this should only be considered a secondary benefit of vegetation, and that trees are more beneficial for air pollution than green walls. If air quality is the main outcome sought, the money would be better spend in another way.

Summary of results

Scenario	(a) Green Walls		(b) Trees	
Installation and maintenance cost to Authority	Nil		£0.2M	
Installation and maintenance cost to private sector	£9.5M		Nil	
NOx baseline emissions, pa	2.14t			
PM10 baseline emissions, pa	0.15t			
CO2 baseline emissions, pa	935t			
NOx reduction, pa	**0.54t**		**0.007t**	
PM10 reduction, pa	**0.07t**		**0.009t**	
CO2 reduction, pa	**46t**		**13.2t**	
PV of NOx Damage Cost	*£*	*5,267*	*£*	*68*
PV of PM Damage Cost	*£*	*150,943*	*£*	*19,645*
PV of Shadow Carbon Price	*£*	*11,875*	*£*	*3,425*
NPV 2012 £	*-£9M*		*-£0.2M*	
Benefits-Costs ratio	*0.02*		*0.15*	

Vegetation Exhibit 1: Estimated Costs and Benefits of vegetation *over 10 years for (a) a 252m x 24m green wall along the Euston Road LAEI Link 33269, and (b) maintenance and replanting of 50 London Plane trees at the same location.*

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Introduction

Recent modelling studies suggest that green walls can reduce in-canyon air pollution by as much as 60% for PM and 40% for NO2 [Pugh, 2011, in press] and that overall the urban canopy removes 0.7%-1.4% of PM10 from London's air [Tallis, 2011]. Research in the USA using the same UFORE model as Tallis indicates that the 89,425 London Plane trees in New York remove 14 tonnes of NOx and 16.6 tonnes of PM10 through deposition each year and cause a net reduction of 24,638 tonnes in CO2 emissions, equivalent to 150g of NOx and 185g of PM, and 275kg of CO2 per year [Peper, 2007]. Trees and green walls are a well established amenity and a key element of architectural and urban planning. Beyond air pollution, Peper et al. (2007) identify additional benefits from trees due to reduced air conditioning and heating (£54 or $81 per London Plane), reduced costs due to to capture of storm water (£76 or $115 per London Plane), and an increase in property value (£61 or $92 per London Plane), with total benefits per tree in the region of $208 per year (averaged over all tree types), and total costs per tree of $37 per year. It is notable that the costs of planting and maintaining a tree differ greatly between the New York and London cases - annual maintenance in London is costed at £300 ($450). Planting in New York is costed at £9 ($14) per tree while in London it is costed at £3,000 per tree. It is probable that these differences can be accounted for in different approaches to cost estimation for public sector staff time.

Relevant Regulations

Afforestation and vegetation is controlled directly by local authorities through the environment department, public realm and development controls, as laid out in various Supplementary Planning Documents and within various borough strategies. In addition, the GLA operates an afforestation programme (RE:LEAF) and a Forestry Commission London Tree and Woodland Framework informs the GLA's environment strategy.

Air quality benefits

Vegetation affects air pollutant concentrations primarily through wet and dry deposition on leaf surfaces. The rates of deposition vary strongly by species and by location [Pugh 2011] and so any strategy that is intended to optimise vegetation for air pollution impacts must take care with the species and geometries specified. Pugh et al. (2011) suggests that targeting green walls and horizontal vegetation (e.g. grass or flower beds) at street canyons will deliver the best results for emissions reduction as the air in street canyons is recirculated thus being repeatedly exposed to the vegetation surfaces before being advected away. This recirculation is essential to the theory and suggests that trees in the street canyon will reduce the impact of green walls, in other words they should not be used together. Similarly, green walls will be expected to have little effect in a street surrounded by low buildings as no recirculation will occur. Research also points out very strong differences in air pollutant impact between vegetation types. This effect depends strongly on the leaf surface area and the surface stickiness, and the overall effect is to modify the rate of deposition by up to three orders of magnitude so tree varieties need to be chosen carefully.

Who should lead?

There is an strong case for leadership by Local Authorities with evidence from Environmental Health Departments supporting and informing considerations for Supplementary Planning Guidance and Tree Strategies.

Costs and Benefits

Two scenarios were modelled, one each for Green Walls and Trees. Both use emissions data from the 2008 LAEI, for Road Link 33269, a 252m stretch of the Euston Road. For green walls, data was gathered from manufacturers and installers as to costs of installation and maintenance. The cost of installation of a large green wall is roughly £350-£500/m^2, with annual operation and maintenance costs of 10% of this. After discussion with experts we used the figure of £400/m^2. The expected lifetime of the installation is 10 years and impacts are immediate upon installation. The Euston Rd, which is 24m wide and has adequate tall buildings onto which a 252m x 24m green wall could be erected on both sides of the road, and assumed a 40% reduction in NOx, 60% in PM and 5% CO2 removal based on Pugh et al. For trees, the same road link was modelled, but reductions in air pollution were considered to be a fixed amount per tree, in line with the estimates of Peper et al. (2007) described earlier. Installation and maintenance costs were obtained from Southwark council (£3000 and £300 per annum respectively) and wider discussion suggests these are representative.

For mature trees, the installation and maintenance model assumed that trees are already in place 10m apart along the stretch and that two trees per year would need to be replaced. In neither case were the additional monetised benefits described in Peper et al included in the calculation. Calculations were performed over a 10 year period. A sensitivity analysis suggested that longer study periods did not significantly change the results, although declining pollutant emissions in the 2020s and 2030s would affect the NPV of pollution removal somewhat.

Monetised Benefits of PM10, NOx & CO2 Reductions

The annualised installation and maintenance costs, air pollution reduction and resulting Damage Cost reduction due the removal of air pollution by Green Walls and Trees is shown in Exhibit 1. This shows that Benefits-Costs ratios for vegetation in terms of air pollution alone can be expected to be of the order of 0.1-0.02, in other words installation of vegetation on the ground of air quality alone is not cost-effective.

While the cost of Green Walls is likely to remain prohibitive, during consultations is was suggested that the installation and maintenance cost for tree could be reduced by about 66% through suitable planning, London wide procurement and mechanisation. If this proved to be the case the BCR for trees in terms of air quality would improve by about a factor of 3.

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