Air quality improvement initiatives in other cities

A brief review of evidence to inform the Westminster City Council Air Quality Task Group

Report prepared in partnership with Westminster City Council

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City of Westminster

The Policy Institute at King's

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Foreword

Located at the centre of the UK's capital city, Westminster is a vibrant and successful London borough. This attribute brings with it many environmental challenges for residents, business and visitors. The combination of high density development, land use and volumes of vehicle/pedestrian movement mix to create a complex, yet finely balanced urban environment. Aware that poor air quality is a significant problem, Westminster City Council designated the whole borough an Air Quality Management Area in 1999. Since then interventions, both locally and city wide, have improved air quality in Westminster but not yet to an extent that the impact on public health has been removed.

To assess the current situation, Westminster City Council established an Air Quality Task Group in summer 2016. The Task Group was chaired by Councillor Ian Adams and later Councillor Andrew Smith and comprises members of the then Environment and Customer Services Policy and Scrutiny Committee, the Chairman of the Adults, Health and Public Protection Policy and Scrutiny Committee and a member from the then Children Sports and Leisure Policy and Scrutiny Committee.

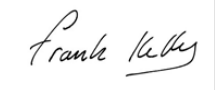
From the outset, the Task Group recognised that many initiatives to improve air quality in Westminster are already underway. Furthermore, London is already taking action to tackle air pollution on a number of fronts, for example through investments in the bus fleet and other forms of public transport, restrictions on older taxis and regulations to address emissions from construction sites and new developments.

Despite this range of initiatives, an early decision of the Task Group was to commission the Policy Institute at King's to review air quality and pollution in Westminster and compare its ongoing and planned initiatives with those elsewhere. The focus of this work was therefore to identify air quality improvement initiatives in a selection of cities: Copenhagen, Los Angeles, Paris, New York, San Francisco, and Singapore. These were selected as potential comparators to central London on the basis of their common source of air pollutants and large exposed populations. Evidence for initiatives to improve air quality identified interventions in four main areas: (i) reducing private car use, (ii) reducing emissions from all vehicles, (iii) reducing energy usage by buildings and (iv) reducing emissions from energy usage by buildings.

Importantly, this review identifies and discusses the difficulties, not least a lack of good quality data on air quality and health outcomes, in conducting research that provides definitive evaluations of the effectiveness of actions to improve air quality. As a result, it is often difficult to follow the pathway from air quality interventions to health outcomes because such a causal link or 'accountability chain' does not tend to originate from a single, stand-alone study.

In terms of the air quality challenges faced by Westminster it is clear that the most relevant and appropriate thresholds to aspire to are not the legally binding EU limit values but rather the stricter, health based WHO guidelines. The WHO outdoor air quality guidelines are based on the expert evaluation of scientific evidence, and are set to indicate "pollutant concentrations below which lifetime exposure or exposure for a given averaging time does not constitute a public health risk".

In summary, this report offers some insights on the feasibility of a range of interventions designed to improve air quality in cities around the world and when possible, describes whether the intervention was successful within the originating city. This report has informed the final report of the Air Quality Task Group and the recommendations that it makes to its cabinet members responsible for the environment, health, parking and planning and development. It provides the evidence base for the council to be even more ambitious in its own actions and communications and in its lobbying of other stakeholders to move faster to improve the air quality of this great city.



Professor Frank Kelly

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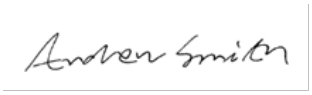

Councillor Andrew Smith

Chairman of the Air Quality Task Group
Chairman of the Children, Environment and Leisure Policy and Scrutiny Committee

Executive Summary

The thick smogs of the 1950s may no longer plague London, but the capital's air quality remains problematic, with concentrations of nitrogen dioxide (NO_2) regularly exceeding legal limits and concentrations of particulate matter (PM) often above health-based guidelines. At the same time, health and medical research is building increasingly robust links between exposure to ambient air pollution and a range of health complications, particularly for vulnerable groups. A recent report by a working party of the Royal College of Physicians shows the impact of air pollution on all life stages, including harmful effects on babies in the womb, on children and adults and the elderly. In the face of concerns about the air we breathe, policymakers at all levels are under pressure to find solutions that will reduce emissions of pollutants from vehicles, buildings and other sources.

Aim of this report

This report is based on a short study that reviewed academic and grey literature to identify initiatives to improve air quality in other cities globally, as well as other London boroughs. The study was conducted with a view to exploring whether and what Westminster City Council can learn from other authorities, both close to home and overseas, who are also striving to tackle air pollution. The team at the Policy Institute at King's worked in partnership with analysts from Westminster City Council, who considered initiatives being implemented elsewhere in London (the Royal Borough of Kensington and Chelsea, the London Borough of Camden and the City of London Corporation), while the team at the Policy Institute focused on the international evidence.

The international search for ideas focused on six cities: Copenhagen, Los Angeles, Paris, New York, San Francisco, and Singapore. These locations were selected in consultation with Westminster City Council and with an expert steer from the project's advisor, Professor Frank Kelly. They were considered useful and appropriate case studies not just because of their similarities with central London in terms of their high density of pollution sources and high population density, but also their experiences in leading pollution control initiatives. To identify these initiatives, we used a targeted search of academic and grey literature for interventions in each of the selected cities. Although we have included some insights into whether each intervention appeared to be successful in its context (if such information was available), it is not within the scope of this study to advise on its transferability elsewhere. We comment on the potential for transferability in our concluding reflections based on discussions with colleagues at the Westminster City Council.

London is already taking action to tackle air pollution on a number of fronts

Initiatives already underway in London include investments in the bus fleet and other forms of public transport, restrictions on older taxis, and regulations to address emissions from construction sites and new developments. An Ultra-Low Emission Zone is proposed by the Mayor of London for 2019, covering all vehicles in an as yet-to-be-agreed area of the city.

Westminster City Council is a leading authority on tackling many of the air quality issues faced by inner-London boroughs. This ranges from developing one of the first European district heating networks (Pimlico District Heating), which aimed to tackle air pollution and improve energy efficiency in response to the smogs of the 1950s, to being the first borough to produce an Air Quality Action Plan and introduce on-street charging points for electric vehicles. Westminster City Council's most recent Air Quality Action Plan was released in April 2013, including actions on transport, development/construction, and communication.

Our search for evidence identified interventions for reducing emissions from both transport and buildings using a variety of policy mechanisms, especially investing in infrastructure and providing resources for enforcement.

Our targeted search for evidence on initiatives to improve air quality has uncovered ideas and interventions that can largely be organised into four main themes: (i) reducing private car use, (ii) reducing emissions from all vehicles (making transport cleaner), (iii) reducing energy use by buildings and (iv) reducing emissions from energy use by buildings (making electricity and heat generation cleaner).

We found that a variety of mechanisms are being used to encourage good practice and penalise bad practice across these themes. These include legislative approaches (including enforced regulation, or softer advisory policy), education and engagement activities (including raising awareness about air quality concerns and ways to mitigate risks, and providing advice on reducing energy consumption), financial mechanisms (such as monetary rewards for good practice or fines for bad practice to members of the public and industry), investments in infrastructure (such as new, energy-efficient buildings and cycle-friendly roads), measures to increase the convenience of cleaner transport (such as allowing cyclists to take bicycles on trains), technological innovations to control emissions, and "leading by example", which refers to commitments by a city or region's authorities to reduce their contribution to emissions, with the aim of inspiring others.

Most interventions we found are focused on discouraging private car use and reducing emissions from industrial vehicles, using primarily regulatory/legislative enforcement mechanisms and investing in infrastructure to encourage other forms of transport.

Most of the sources we found pointed to the importance of reducing private car use, either by making it less appealing to the user (for example, by closing roads or restricting city access), making public transport or bicycling more convenient, or using planning legislation to ensure housing and commercial buildings are constructed closer to public transport hubs.

All of the cities we reviewed used some form of charging to disincentivise private car use, including dynamic parking charges in New York and San Francisco that are more expensive at peak times, and road pricing in Singapore. It is also apparent that restricting private car use requires strong investment in public transport infrastructure. Copenhagen is a prime example of a city that has invested heavily in integrating its bus, train and metro systems to enable passengers to move easily between different modes of transport, and has also devoted significant resources to improving its cycling infrastructure.

Reducing the number of vehicles on the road and encouraging greener ways of travel aligns with the deliverables of the Westminster City Council *Greener City Action Plan* (GCAP). Such forms of 'active travel' have benefits not only for air quality, but can also contribute to significantly improved health outcomes by increasing physical activity.

Interventions that target buildings emissions primarily focused on reducing emissions from power and energy production, using mainly regulation/legislative enforcement mechanisms, investing in infrastructure and education/engagement activities.

Efforts to switch to cleaner fuels have been made in most of the cities we reviewed. The Cities of Los Angeles and San Francisco have provided extensive support for solar power in the form of financing options, piloting technology for solar energy storage and introducing feed-in tariff systems to incentivise property owners and developers to generate solar power on rooftop space. New York has also introduced a financial incentive that helps eligible owners offset the costs of their photovoltaic and green-roof installations.

As well as measures to encourage the powering of buildings with cleaner fuels, the cities we studied have also tried to reduce the total amount of energy consumed by buildings. Changes to building design and construction practices are one such measure; San Francisco has the Green Building Program, which ensures that all new buildings are built and operated according to third-party verified energy standards, while new buildings in Copenhagen must comply with the Danish building code, which now stipulates that the energy needs of new buildings must be 'nearly zero' by 2020, with energy needs covered primarily by renewables or district heating. The City of New York is also leading by example in this area, trialling an approach to house building termed 'passive building design', which uses high levels of insulation and other design features to moderate a building's heat loss and gain and improve air quality. As well as making new builds more energy-efficient, city authorities have devoted resources to the retrofitting of existing buildings. In Los Angeles, financial incentives are on offer for building owners to improve the energy efficiency of their properties via an initiative termed the Better Buildings Challenge.

Cities have also looked for less direct ways to reduce the energy consumption of buildings, such as installing cool roofing and paving, and planting rooftop vegetation to mitigate urban heat island effects, as in San Francisco. Finally, we also came across a range of engagement and educational activities aimed at encouraging businesses to be more energy-efficient, including providing awards for best practice and training and education workshops to businesses on how to cut emissions.

Both academic and grey literature show a lack of rigorous evaluation of interventions, and little information specifically on the resulting health outcomes or indirect effects.

Overall, we found evaluations to be quite sparse in this area. This may be due to the difficulty of attributing outcomes to a specific intervention. Studies that seek to quantify the impact of an individual intervention (such as adding a pollutant filter to a vehicle) on air quality are typically unable to control for the full range of variables that also affect air quality, confounding their results. Many of these studies (primarily from the academic literature) therefore tend to model the effects of the intervention on emissions, rather than the overall effect on air quality. Articles that show wider policy interventions (such as changing the cycling infrastructure of a city), are mainly from grey literature, and only provide before-and-after measures of air quality or emission concentrations, if any evaluation was conducted at all. Finally, trade-offs between interventions were not discussed in detail in the literature and are not within the scope of this report, but are important to take into consideration if any of these interventions are to be adopted in practice.

Ideas that could provide learning for Westminster City Council include dynamic car parking schemes, enabling energy-efficient buildings, and greater community engagement.

We are mindful that many initiatives are already underway in Westminster, some of which are highlighted in this report. However, initiatives in international cities and neighbouring boroughs can still provide areas for learning and potential collaboration. For example, the dynamically priced parking scheme in Los Angeles uses in-ground sensors to notify drivers in real time where parking is available and adjusts parking prices based on demand. Singapore's electronic road pricing system is an example of an innovative form of dynamic road pricing within a charging zone.

Interventions that specifically target building emissions, however, may be more within the control of a borough. Local authorities can lead by example, as other cities reviewed here have done, by ensuring new buildings comply with strict energy efficiency standards or by retrofitting existing stock. A council could also influence private sector-owned buildings through the environmental standards it stipulates for new developments and by linking building owners to sources of finance and technical advice for making energy efficiency improvements. More direct measures that local authorities could take may include providing commercial buildings and households with energy meters to allow them

to monitor their energy consumption and conducting outreach programmes that educate building owners on energy efficiency.

Finally, intense community engagement and raising awareness have been key to initiatives, especially in Singapore and New York, and may also be applicable in the Westminster context. The London boroughs we included in this report also have notable examples, such as the Community Kitchen Garden Scheme and the training of 'Green Champions' in the Royal Borough of Kensington and Chelsea, the Schools and Nurseries Cleaner Air Fund in Camden, and the Science in the City Programme involving residents' engagement schemes in Barbican. Finally, the CityAir App launched by the City of London Corporation is a great example of a simple technological innovation that also enables user participation and engagement.

While many of the ideas may already be under consideration in Westminster, the literature indicates the importance of using more ambitious targets for existing initiatives.

Many of the cities we looked at have been comprehensive in their approaches and set ambitious targets for improving air quality. For example, while the other cities have tried to 'green' their fleet to some extent, Copenhagen has committed to having 100% of their passenger cars on electric or hydrogen powered by 2025. The anti-air pollution plan in Paris includes a total ban on diesel cars and a completely electric or hybrid city fleet by 2020. Camden introduced a borough-wide 20mph speed limit in December 2013 which could be worth exploring further.

In terms of emission concentration targets, Westminster has significantly higher mean average concentrations for $PM_{2.5}$, PM_{10} and NO_2 than the London averages, and all three concentrations exceed the WHO's annual mean guidelines, despite improvements. There is therefore still work to be done to comply with WHO guidelines and align initiatives explicitly with the aim of achieving these targets.

Concluding thoughts

We conclude with a final thought about the transferability of the interventions identified in this study. Interventions identified in the literature tended to be implemented at the city level, rather than in a single district or borough. Collaborations and partnerships with other districts may therefore be necessary to make some interventions work effectively, and we have observed in some of these initiatives that involving stakeholders from different sectors in both design and delivery of interventions can lead to better compliance with initiatives. It may also be necessary to combine a range of approaches, including top-down enforcement policies, financial incentives and community engagement, to generate meaningful improvements.

We hope that this synthesis of initiatives from other cities and boroughs will help to both support and intensify the initiatives that are already in place in Westminster, and to generate new ideas for improving practice.

Table of Contents

1| Background

Although trends in air quality have improved since the turn of the century, London's concentrations of some pollutants regularly exceed legal limits for nitrogen dioxide (NO_2) and health-based guidelines for particulate matter (PM) [1]. At the same time, health and medical research is building increasingly robust links between exposure to ambient air pollution and a range of health complications. A recent report by a working party of the Royal College of Physicians shows the impact of air pollution on all life stages, including harmful effects on babies in the womb, on children and adults and the elderly.[2]

Different emission sources produce pollutants that can affect air quality, impacting on health and the environment (Table 1). Research by King's College London estimated that air pollution was responsible for up to 141,000 life years lost or the equivalent of up to 9,400 deaths in London in 2010, as well as over 3,400 hospital admissions (figures relate to health impacts of NO_2 and PM in 2010).[3] The estimated economic costs of these health impacts, for example from hospital admissions and early deaths, ranges from £1.4 billion to £3.7 billion[a]. [3] The official Department for Environment, Food and Rural Affaris (DEFRA) figure for the cost of air pollution to the NHS between £9-18 billion per year which relates only to the life-years lost costs[4].

Table 1 Air pollutant sources, health and environmental effects, and current London concentrations (adapted from [5])

Pollutant	Key sources of emissions	Health/environmental effects
Particulate matter (PM) Typically referred to as particles under 10µm in diameter (PM_{10}) and fine particles less than 2.5µm in diameter ($PM_{2.5}$)	Transport (exhaust, tyre and brake wear), combustion, industrial processes, construction and demolition, natural sources. Also created by interaction of other pollutants.	Linked to asthma, lung cancer, respiratory and cardiovascular diseases, infant mortality and low birth weight. The smallest particles are of greatest health concern (e.g. $PM_{2.5}$). PM exposure can lead to growth stunting or mortality in plants. Black carbon (a component of PM) contributes to global warming.
Nitrogen oxides (NOx), including nitric oxide (NO) and nitrogen dioxide (NO_2)	Transport, combustion.	Exposure to NO_2 can cause lung irritation, decrease lung function, and increase chance of respiratory infections. Long term exposure is associated with low birth weight babies and excess deaths. NO and NO_2 are precursors to formation of Ozone, and acid rain. NOx can be deposited into fresh water and land, harming biodiversity in sensitive sites.
Sulphur dioxide (SO_2)	Combustion (particularly coal) and road transport.	Causes irritation of lungs, nose and throat, and exacerbates asthma. Precursor to formation of smog. Forms acid rain, which damages freshwater environments, soils and vegetation.
Carbon monoxide (CO)	Road transport (particularly petrol), combustion, industry. CO arises from incomplete combustion.	Headaches, nausea, dizziness, affects lung performance. Precursor to formation of Ozone.
Ozone (O_3)	Formed by reaction of hydrocarbons, NOx, and Volatile Organic Compounds in sunlight.	Harms lung function and irritates respiratory system. Can increase incidence and severity of asthma and bronchitis. Long term exposure can lead to cardiorespiratory mortality. Acts as a powerful greenhouse gas. Stunts plant growth.

[a] The estimated economic cost of £1.4 billion is based on long-term exposure to $PM_{2.5}$ and mortality, short-term exposure to PM2.5 and hospital admissions, short-term exposure to NO_2 and both deaths brought forward and hospital admissions. The estimated £3.7 billion is from replacing short-term exposure to NO_2 and deaths brought forward with long-term exposure to NO2 and mortality.

In the face of concerns about the air we breathe, policymakers at all levels are under pressure to find solutions that will reduce emissions of pollutants from vehicles, buildings and other sources. The Westminster City Council's Air Quality Task Group in 2016 was interested in identifying examples of good practice in tackling air quality improvement in other cities, and comparing these to current practice in Westminster, to better understand if there is more that the Council or its partners can do to improve the air quality in the borough.

1.1 Approach to this study

This report is based on a short study that reviewed literature to identify initiatives to improve air quality in other cities globally, as well as other London boroughs, with a view to exploring whether there is learning that can be applied for Westminster City Council. We worked in partnership with analysts from Westminster City Council who considered existing initiatives in the area (including initiatives in the Royal Borough of Kensington and Chelsea, London Borough of Camden and the City of London Corporation), while the team at the Policy Institute focused on the international evidence.

Specifically, we concentrated on finding initiatives in a selection of cities: Copenhagen, Los Angeles, Paris, New York, San Francisco, and Singapore. These locations were selected in consultation with Westminster City Council for their potential for comparison to central London, due to their characteristics (a high density of air pollutant sources, as well as people), and the expert steer from our advisor Professor Kelly on these cities' experiences in leading pollution control initiatives.

To identify these initiatives we used a targeted search of academic and grey literature for interventions in each of the selected cities. Details of our search strategy for finding these initiatives are provided in Annex A. Through this literature search we identified 103[b] articles that we included in our full text review, available in Annex B. Our intention is not to provide a direct comparison of interventions in these cities with either London or Westminster, but to highlight initiatives that have been proposed, modeled or implemented to tackle air quality concerns in these municipal areas.

1.2 Caveats and limitations

Given the nature of this report (a targeted search within a limited time available for the study) we note the following caveats and limitations both for the methods and the availability of evidence.

While we used principles of systematic searching, we stress that this is not a comprehensive review of evidence in the field. There is currently a full Cochrane review in progress whose objective is to assess the effectiveness of interventions to reduce ambient PM air pollution concentrations, and to reduce their impact on health.[6] The interventions we identified from academic literature tend to be very well described, but most of the interventions tend to be found in the grey literature such as policy reports or city council planning documentation. Those documents, however, while providing a good set of ideas, did not have details on how the specific intervention could be implemented without further research. The analysts based in Westminster City Council were able to conduct some searches on these interventions to find out more, and we have included further detail wherever possible.

Neither set of academic nor grey literature sources offer much information on the effectiveness of interventions. One of the reasons for the lack of many rigorous evaluations may be due to the difficulty of attributing outcomes to a specific intervention. Studies that try to demonstrate the attribution of

[b] This number includes grey literature such as City Council reports for cities, where each annual report would be counted as a separate reference. Many of these reports and academic articles refer to the same initiatives, so the number of articles does not reflect the number of initiatives.

individual interventions (such as adding a pollutant filter to a vehicle) to overall emissions could not also include in their measurements the wider confounding factors affecting air quality. Many of these studies (primarily from the academic literature) therefore tend to model effects on the level of the specific emissions that are or could be reduced, rather than the overall effect on air quality. Articles that do show wider policy interventions (such as changing the cycling infrastructure of a city, mainly from grey literature) could only provide before and after measures of air quality or emission concentrations, if they mentioned evaluations at all. The difficulty of detecting significant air quality improvements related to an intervention against the backdrop of broader regional and meteorological changes has been previously acknowledged. [7, 8]

Related to the evaluation and attribution question, we found that the knock-on effects of interventions were seldom described. For example, building in a congestion charge in one high-emission zone could simply displace poor air quality from one zone to another. Trade-offs between interventions were therefore not discussed in detail and are not within the scope of this report, but are important to take into account if any of these interventions are to be adopted in practice. A good example of this in the London context is that of the congestion charge. Despite a huge drop in vehicle journeys within the congestion zone, many people have simply avoided this zone, displacing pollutants elsewhere and increasing journey times in the areas to which traffic was displaced. [8]

Finally, we note that any of these interventions may not be directly transferable to a London or Westminster context. We offer some insights on feasibility and whether the intervention was successful within the city described (if such information was available), but it was not within the scope of this study to report on its transferability elsewhere. Much of this will depend on individual topographies, existing policies and population trends. Furthermore, some of the interventions we found tend to be city-wide and not limited to one district or borough. Collaborations and partnerships with other districts may be necessary to make interventions work.

1.3 This report

In the next section (Chapter 2) we provide a brief overview of the current state of air quality in central London and Westminster, and an overview of existing initiatives there and in other London boroughs, conducted by the team of analysts from Westminster City Council. This is followed by the initiatives identified in international comparator cities, which was the focus of the team at the Policy Institute (Chapter 3). We end with our reflections and headline findings (Chapter 4).

2 | Across London

In 2010, the mortality burden in Westminster due to $PM_{2.5}$ was estimated to be between 88 and 92 deaths equating to between 1,403 and 1,570 life years lost [3]. King's College London's study of 2010 air quality data estimated that 5,879 deaths in London and 184 deaths in Westminster can be attributed to NO_2, although this estimate is far less certain[3].

Before presenting the data from other cities it is worth bearing in mind the many initiatives that have already started in Westminster. London is taking action to tackle air pollution on a number of fronts, for example through the Low Emission Zone and Congestion Charge Zone, investments in the bus fleet, restrictions on older taxis, investment in public transport, and regulations to address emissions from construction sites and new developments. Recently, the Mayor of London has also proposed the introduction of an Ultra-Low Emission Zone (ULEZ) in 2019 covering all vehicles in Central London.[1]

In this chapter we present the current state of air quality in terms of pollutant concentrations, and existing initiatives in both Westminster and select other London boroughs.

2.1 Current state of air quality in Westminster

London also has a comprehensive monitoring network, funded by London boroughs, the Greater London Authority (GLA), Transport for London (TfL) and Heathrow Airport. Many of these sites are part of the London Air Quality Network (LAQN), managed by King's College London's Environmental Research Group, enabling the region to understand trends in air quality. Removing the weather effects from trends in concentrations of the main pollutants monitored in the LAQN, the group has identified a reduction of NOx and PM from 2008 to 2013[c]. This is encouraging as it shows that overall air quality is improving in London, but the dynamic nature of air pollution means concentrations at some sites may be going up while the overall trend is improving.[9]

The whole of Westminster was designated an 'Air Quality Management Area' (AQMA) in 1999 due to exceedances in NO_2 and PM_{10}. Since the turn of the century air quality has improved in Westminster but pollution remains a significant problem, with EU limit concentrations for NO_2 still being breached on a regular basis. Westminster has significantly higher average mean concentrations for $PM_{2.5}$, PM_{10} and NO_2 compared to the London average (Table 2). NO_2 concentration exceeds the EU Limit values, whilst particulate matter (PM_{10} and $PM_{2.5}$) both meet the EU objectives. However, all three concentrations exceed the WHO's annual mean guidelines.

[c] NOx roadside sites show a downward trend of 1.25% per year, equating to a total reduction over the six year period of 7.5%. NO_2 roadside sites show a downward trend of 2.1% per year, equating to a total reduction over the six year period of 12.6%. PM_{10} roadside sites show a downward trend of 1.4% per year, equating to a total reduction over the six year period of 8.4%. PM_{10} background sites show a downward trend of 0.65% per year, equating to a total reduction over the six year period of 3.9%. $PM_{2.5}$ roadside and background sites show a downward trend of 2.2% per year equating to a total reduction over the six year period of 13.2%

Table 2 Summary table comparing Westminster's average annual concentration levels for $PM_{2.5}$, PM_{10} and NO_2 compared to the London average, the EU Limit Values and the WHO's guideline limit

Pollutant	EU limit values	WHO limit values	Current Westminster values[d]	Current London values
PM_{25}	25 µg/m^3 annual mean	10 µg/m^3 annual mean 25 µg/m^3 24-hour mean	17.7 µg/m^3 annual mean	15.3 µg/m^3 annual mean
PM_{10}	40 µg/m^3 annual mean 50 µg/m^3 24-hr mean	20 µg/m^3 annual mean 50 µg/m^3 24-hr mean	28.0 µg/m^3 annual mean	24.0 µg/m^3 annual mean
NO_2	40 µg/m^3 annual mean 200 µg/m^3 1-hr mean	40 µg/m^3 annual mean 200 µg/m^3 1-hr mean	50.2 µg/m^3 annual mean	30.6 µg/m^3 annual mean

The concentrations of these pollutants vary across the borough. NO_2 concentrations are particularly high to the central and eastern parts of the borough where there is a greater density of businesses, visitor attractions and subsequently transport infrastructure. The residential areas to the north of Westminster and substantial areas of green space such as Hyde Park and Regent's Park have the lowest NO_2 concentrations in the borough. Ward level concentration data shows that nineteen out of twenty wards had an average concentration level that is greater than the EU annual mean limit value of 40 ug/m^{-3} in 2013 (Maida Vale is the exception, see Annex C). Road transport (58%) and domestic and commercial gas (32%) produce the majority of oxides of nitrogen (NO_x) emissions [10]. TfL Buses (17.7%), taxis (8.5%) and diesel cars (7.2%) are the largest contributors of road transport emissions [9](Figure 1).

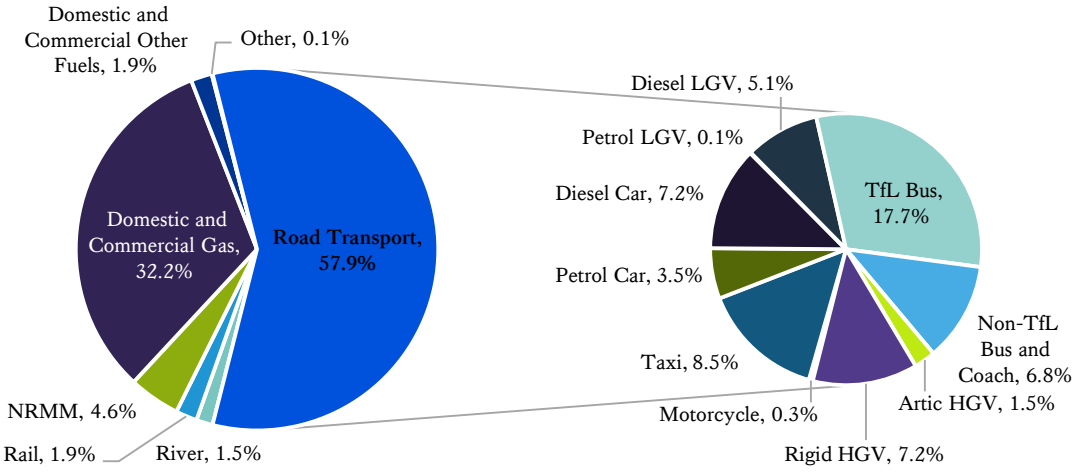

Figure 1 Source composition of NOx for Westminster (LAEI, 2016)

[d] Data taken from LAEI 2013. Air quality in Westminster is monitored through the London Atmospheric Emissions Inventory (LAEI) data and five automatic monitoring sites: Victoria Palace Theatre, Strand, Oxford Road, Marylebone Road and Horseferry Road. The latest release of the LAEI provides concentration data for the year 2013, the reason for this time lag is that the dataset is vast and it takes time to be calibrated.

Concentrations of PM_{10} have reduced significantly and now rarely exceed the EU's annual average limit value of 40 ug/m^3. In 2013 there were only a handful of areas that were greater than 40 ug/^{3} and these fell on major transport routes where heavy road transport influences the extent of the pollution. Similar to NO_2, particulate matter concentrations are higher on major transport routes and business areas; in Westminster this includes much of the West End, St James, Marylebone High Street and Bryanston and Dorset Square. Over half of PM_{10} emissions come from road transport sources (55.2%); taxis (12.2%), petrol cars (10.3%), diesel cars (9.4%) and diesel LGVs (8.6%) make up over 40% of PM_{10} emissions. [10] Re-suspension contributes a quarter of all PM_{10} emissions [10]. The other 20% of emission sources predominantly consists of domestic and commercial gas (6.0%) and Non-Road Mechanical Machinery (5.5%) [10] (Figure 2).

Nearly two-thirds of $PM_{2.5}$ emissions come from road transport (64.9%); once again taxis, petrol cars, diesel cars and diesel LGVS contribute the largest portion of this (49.1%)[10]. Domestic and commercial gas (11.5%) and NRMM (10.0%) also have large contributions to $PM_{2.5}$ emissions [10]. (Figure 3)

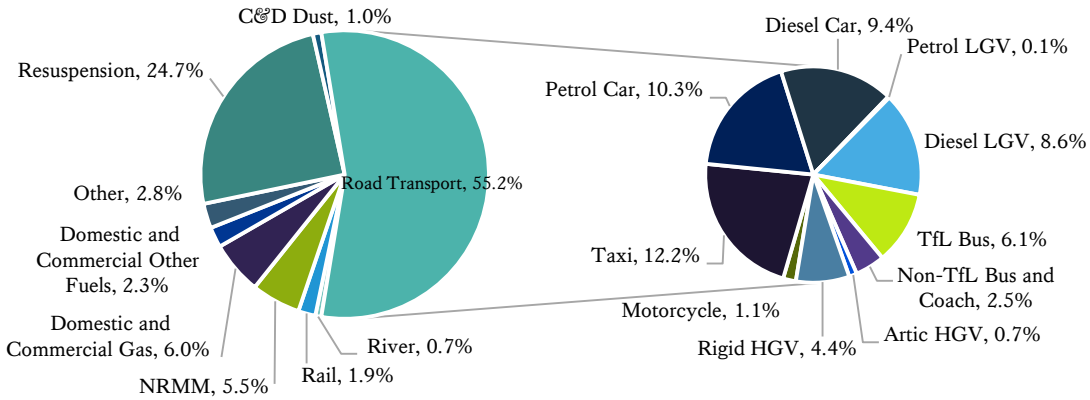

Figure 2 Source composition of PM_{10} for Westminster [11]

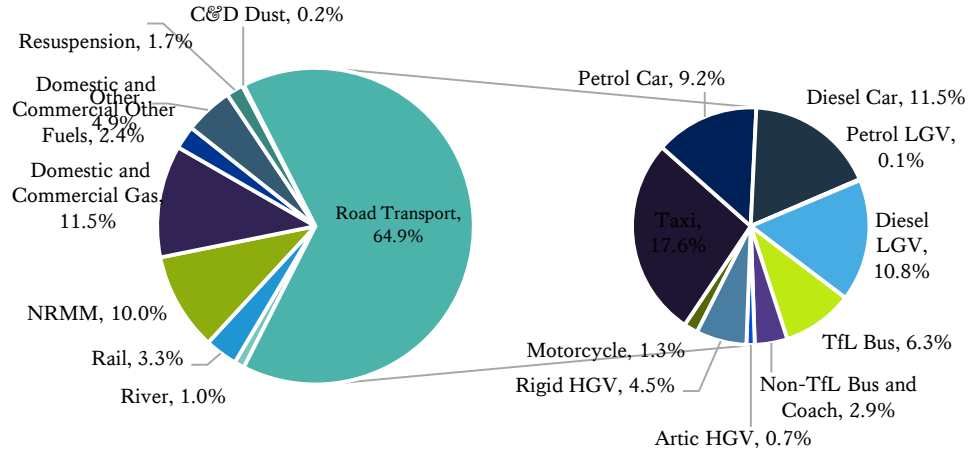

Figure 3 Source composition of $PM_{2.5}$ for Westminster [11]

2.2 Current initiatives in Westminster

Westminster City Council is a leading authority on tackling many of the air quality issues faced by inner-London boroughs. This ranges from developing one of the first European district heating networks (Pimlico District Heating) to tackle air quality and improve energy efficiency in response to the smogs of the 1950s, to being the first borough to produce an Air Quality Action Plan or introduce on-street electric re-charging points [12].

Westminster City Council's most recent Air Quality Action Plan was released in April 2013. The action plan highlights everything that Westminster is currently doing to tackle air pollution; split into three main categories: transport, development and communication (Table 4). Road transport is responsible for a large proportion of emissions in Westminster, and the Plan includes nineteen transport objectives relating to reducing emissions from road transport. 'Development' is also an important focus for the region; Westminster has over 12,000 new planning applications every year and has a significant amount of major development. [12]. Emissions from current buildings through gas and oil consumption and emissions through the construction of new developments have a significant impact on air quality. Central heating and boilers account for a large amount of air emissions in Westminster. Careful and sustainable building development and Westminster's spatial planning policies have a central role to play in mitigating air quality impacts from development. Finally, raising awareness about the health risks of air pollution is essential in helping the public and businesses act more responsibly and take action to reduce pollution. These actions are captured under 'communication' initiatives.

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Table 3 Actions from Westminster Air Quality Plan, 2013 [13] Transport actions indicated by 'TRAN x', Development actions by 'DEV x' and communications actions by 'COMM x'

Transport, Development and Communication plans and actions	Progress
TRAN 1 and TRAN 2: work with TfL to investigate options for reducing through-traffic and reducing air pollution and hotspots (Tran 1). Examine options to minimise pedestrian exposure to pollution (Tran 2) - Reduction in vehicle speeds - Improvements in pedestrian and cycling environment - Enhanced surfaces - Widening footways	The Major Schemes Programme has been developed in consultation with a wide range of stakeholders including; TfL, land owners, developers and Business Improvement Districts (BIDs). An assessment of air quality impact was undertaken for Baker Street Two Way in 2015.
TRAN 3: support car clubs with particular emphasis on including low emission vehicles in the fleet - Promote car clubs - Help to provide car club bays in Westminster - Provide electric vehicle charging infrastructure at car club bays - Introduce electric vehicles into Westminster's on street car club fleet	Westminster has over 10,000 car club members using 194 car club vehicles. Each vehicle aims to remove between fifteen and twenty private vehicles from the road From May 2016, Westminster's on street car club fleet included 11 Plug-in Hybrid Electric Vehicles (PHEVs) with on street charging infrastructure installed at each of the bays from which they operate
TRAN 4: promote and provide infrastructure for electric and low emission vehicles Work with more partners to improve service	Working with Thurlestone & Streetcharge to implement a residential parking scheme Working with delivery vehicles (UPS) to convert their diesel vehicles into EVs Working with UPS on converting one diesel vehicle into three EV assisted cargo bikes using government funding Reviewing the practicality of using lighting columns
TRAN 5: Investigate ways that freight consolidation can be developed to reduce congestion Use planning policy to control freight deliveries Kerbside management Procurement policy Communication and partnership working	When necessary Westminster seeks a Servicing Management Plan (SMP) from a new development; this seeks to control the size of delivery vehicles and the spread of vehicles (for example, developing a booking system so vehicles do not all arrive at once) Site specific construction logistics plans and considerate building schemes are in operation Pioneered various schemes including; doubling the time allowed for HGVs to load/unload on yellow lines, writing a 'loading' code of practise and introducing a more flexible approach to enforcement. Westminster's Green Fleet Policy, sets procurement fuel hierarchy prioritising zero emission vehicles. This encourages contractors to choose fuel efficient transport options The West End Partnership will/have produced a freight and consolidation plan A review of freight issues and movements has taken place as part of the Oxford Street West project.

	Westminster work closely with CRP to research and link any international projects such as 'Last Mile Logistics' or 'Freight Electric Vehicles in Urban Europe (FREVUE) with Westminster
TRAN 6: Raise awareness of the benefits of fuel efficient driving Support and undertake local communication campaigns	CRP have provided fuel efficiency driver training; 77 private hire drivers completed the training on average reducing their fuel use by 17%.
TRAN 7: support sustainable travel such as walking and cycling Adopted a cycling strategy and a walking strategy Work with TfL to create safer and more legible routes Run or support cycling events Raise awareness of the relationship between HGV drivers and cyclists	The council provides free cycle training. Ran the Westminster Festival of Cycling Bike Loan Scheme to encourage bike ownership Trialling bike hangars by removing and replacing an underutilised car parking bay Code of Practise has been updated requiring HGVs used in construction to have a rear warning for cyclists, amongst other measures Bike stations across the borough to offer free advice to cyclists Investigating measures to increase walking, including; 20 mph speed limits and keeping pavements clear.
TRAN 8: support and promote travel plans for schools and businesses Supporting TfL's STAR scheme to implement school travel plans across schools in Westminster Deliver projects to reduce air emissions around schools or raise awareness	Cycle training, walking trips, child pedestrian training, travel training, participating in TfL's Travel Party Scheme, sponsored walks/runs, promotion of school travel plans, car free days and Cleaner Air 4 Schools Project in 2012. Making air quality improvements around schools, including; pedestrian crossings and promotional events to encourage walking and cycling. Develop lesson plans to increase knowledge and understanding of air quality and its impacts on health.
TRAN 9 and 10: ensure low emission vehicles within the council's fleet (Tran 9). Compel contractors and associates to have low emission fleets.	Westminster's 'Green Fleet' policy sets a procurement fuel hierarchy prioritising zero emission vehicles and vehicle emissions standards requirements.
TRAN 11: Commit to Safe and Fuel Efficient Driving (SAFED) training for fleet drivers	Training for all council drivers is carried out.
TRAN 12, TRAN 13 and TRAN 14: 'no idling' legislation, review options to decrease idling (TRAN 12). Communicate the no idling message to parked coach drivers (TRAN 13). Improve public communications about car idling (TRAN 14). Awareness campaigns City Marshals and Air Force Marshals Enforce against idling coach drivers	In April 2015, the council started enforcing against engine idling. City Marshals have spoken to over 6,000 drivers and asked them to switch their engine off Air force marshals were introduced in April 2016 to spread awareness about engine idling Volunteer campaign days have taken place where volunteers go to hotspot areas and advise drivers to switch their engines off. Idling days focused in the Marylebone Low Emissions Neighbourhood Signs have been installed in coach stations to remind drivers not to idle No idling message has been promoted on the council website and other publications

TRAN 16: Lobby the Minister for Transport with responsibility for rail services and to local MPs about the possibility of electrification of rail services from Marylebone.	This has been completed
TRAN 17 and TRAN 18: maintain dialogue with train operating companies to review opportunities for improvements in reducing emissions (TRAN 17). Communicate with Ministers to make the case for stronger control of the environmental effects of rail services through existing mechanisms	ongoing
TRAN 19: Raise with TfL and the GLA the importance of appropriate environmental impact assessments within consultation exercises when changes in the rail services are proposed	This has been completed
DEV 1: require developers to undertake an Air Quality Assessment where a development may affect local air quality and require developers to submit an air pollution abatement and mitigation plan where an air quality assessment shows that a new development will have adverse effects on the environment Use planning policy in accordance with the London Plan to limit emissions	Planning permission is being refused where a development will cause harm to the environment and there is no mitigation plan in place. Detailed planning policy is currently being revised and will safe-guard air quality in Westminster
DEV 2: strengthen and develop further air quality policies in the emerging local planning documents to develop a transparent air quality assessment methodology for planning applications	Planning policies are currently being revised to manage and mitigate air, noise and light pollution, as well as construction impacts, construction waste and contaminated land
DEV 3: Include air quality requirements in Sustainable Design SPD to help reduce unwanted emissions from boilers through improved building efficiency, boiler efficiency, using renewable energy and supplying energy efficiently.	This is currently on hold whilst there is ongoing consultation and local plan development
DEV 4: Protect decentralised energy networks in order to provide efficient energy production and to minimise emissions from combustion Ensure major developments link to and extend existing heat and energy networks in their vicinity	The council has received part funding from the Department of Business Energy and Industrial Strategy for a feasibility study looking at using zero emission heat pumps to abstract energy from the River Thames into the district heating network in Pimlico. Church Street Regeneration project has developed a business case for a district heating network
DEV 5: Adopt policy ensuring biofuel combustion does not negatively impact on local air quality	Strong air quality planning policy exists to ensure there is no biomass development in Westminster
DEV 6: prioritising low polluting transport options in development	Planning policy exists to promote the use of car clubs, electric and alternative fuel vehicles and cycling.

DEV 7: require developers to comply with the Code of Construction Practice Code of Construction Practice applies to all major developments and basement excavations.	Developers must engage with residents, submit information, and adhere to the best practice contained in the document. The GLA's 'Control of Dust and Emissions from Construction and Demolition' must be adhered to A dedicated team of staff have been recruited funded by the new fees that form part of the code
COMM 1: publish high quality air quality information via the Westminster City Council website Website is regularly updated	Information is regularly provided on the council website; including any updated air quality action plans and progress reports. Information about the Marylebone LEN was publicised on the council's webpages Twitter is another medium used to provide information; for example free cycle training and no idling volunteer days
COMM 2: continue to monitor air quality across the city and periodically review Automatic Monitoring sites provide real time data The LAEI is reviewed with each new edition	Concentration mapping is carried out Monitoring site data is analysed
COMM 3: Monitor $PM_{2.5}$ emissions	PM2.5¬ is now monitored at one site in Westminster, Marylebone Road PM2.5 is monitored through the LAEI
COMM 4: undertake communication campaigns to raise awareness of air pollution	Health campaigns have been undertaken, for example 'Close the front door' designed at educating shops to shut their front doors to reduce emissions released from air conditioning units and to protect employees and customers from ambient air pollution
COMM 5: foster links with clinical commissioning groups and health departments to air public communication and understanding of how air pollution affects health	Work on health communications will be co-delivered by both the Built Environment and Public Health Units within the council
COMM 6: support airTEXT and promote its service via the website	airTEXT is being supported via the council website
COMM 7: business engagement to raise awareness about air quality Westminster's partner the CRP are supporting business through their Clean Air Better Business programme Working with BIDs on this work	Twenty-two businesses are taking action via Victoria BID's 'Air Quality Champions' Programme
COMM 8: Raise air quality awareness within Westminster's schools	Work closely with schools to encourage more sustainable modes of travel Have run numerous activities including cycle training, walking trips, lesson planning, sponsored walks and runs, car free days and bus days run in partnership with TfL. Green walls have been installed at two primary schools.

Since its release in 2013, Westminster City Council has been working hard to tackle air quality. The following initiatives how now taken place [14]:

Marylebone Low Emission Neighbourhood: In July 2016, Westminster City Council won £1 million funding from the Mayor of London for a Marylebone area 'Low Emission Neighbourhood'. The low emission neighbourhood will be a three year programme that looks at changing behaviour and making public realm improvements to create an environment that encourages improvements in air quality. Measures will include:

- The Green Club Building Energy Efficiency Scheme: Improves emissions from businesses by making improvements to the operation and by retrofitting energy efficiency measures.
- Area wide Delivery & Service Programme: Business Improvement Districts are working to join up businesses delivery and waste schemes to reduce the number of vehicles on the road.
- Electric vehicle delivery scheme with UPS: Taking diesel vehicles off the road and replacing them with EV delivery vehicles.
- Off Street EV charging bays with Q Parks: Q Parks installing more off street EV charging bays in car parks including rapid charging facilities.
- Residents EV charging pilot: Working with Thurlestone and Streetcharge to implement a residential EV charging scheme pilot. Residents will sign up and up share the use of the bay.
- Emission based charging scheme for on street parking
- No idling enforcement: Expanding engine idling work to run promotional campaign days using volunteers from residents and businesses; working with the Princess Grace hospital to reduce the vehicle idling of Ambulances and encourage the use of low emission taxi fleets to drop off and pick up patients.
- Play Streets: The closure of certain residential streets from vehicles to allow children to play and learn to cycle (particularly needed in Marylebone).
- Smart taxi rank: Using bay sensors to manage the use of taxi ranks by providing taxi drivers with real time information as to when a feeder rank had available space. This helps to combat over-ranking and prevent vehicle emissions from having a particular effect in residential areas.
- Street Scape: Improvements made to the public realm to create vibrant, green areas that reduce air pollution. These include a green spine down George Street using green walls, planters and park lets; pavement widening, green benches and raised table junctions to reduce traffic speeds and create a better pedestrian experience; further installation of green roofs, casual EV charging bays and more cycle stands.

Air Quality Task Group: In August 2016, Westminster City Council launched a new Air Quality Task Group. Councillors from the Environment, Health and Children's Scrutiny Committees formed the task group, and with input from experts will seek to focus on three main areas: pollution caused by transport, pollution caused by building emissions and the health impacts of poor air quality.

The group is seeking views and evidence from residents and workers in Westminster and will evaluate the health impacts of air pollution on adults and children. The group will also seek expert witnesses to give evidence at its meetings and learn from best practice.

Greener City Action Plan: The Greener City Action Plan was launched in October 2015. It is a ten-year strategy set around eleven policy priorities: addressing noise pollution, delivering secure and low carbon supplies, improving local air quality, supporting a sustainable transport system, making the best use of our open and green spaces, ensuring sustainability through economic development, supporting sustainable growth, managing water use, addressing flood risk and communication and encouraging people into environmental action.

In the past year, the Council has worked with several stakeholders to encourage the switch to low polluting vehicles, promote smarter transport decisions and spread awareness across both businesses and residents of their environmental footprint.

Smarter Transport: The Council provides real time information to drivers in the West End through a parking app that allows drivers to see where the free parking spaces are. This reduces congestion and stops unnecessary pollution. Westminster is also working with the Department for Transport to provide this information to businesses.

Green Spaces: The Council will shortly be launching the Open Space & Biodiversity Strategy which sets out how to make the most of the Council's green spaces.

Cross River Partnership: Westminster City Council has a close working relationship with the Cross River Partnership, which carries out a large number of projects to improve air quality in Westminster.

2.3 Learning from other London boroughs

Local authorities have a statutory requirement to produce an Air Quality Action Plan (AQAP) outlining how they plan to reduce emissions within their borough. AQAPs are publically available and so this chapter assesses how three inner-London boroughs are tackling air pollution in their local authority areas: the Royal Borough of Kensington and Chelsea, the London Borough of Camden and the City of London Corporation. On the whole, the three boroughs have similar approaches to reducing emissions. They focus on similar issues, such as tackling air quality through reducing transport emissions, building development emissions and changing behaviour. We outline the main initiatives identified in these boroughs in the next sections.

Royal Borough of Kensington and Chelsea

The Royal Borough of Kensington and Chelsea has a holistic approach to tackling air quality in the borough, producing a joint air quality and climate change action plan released in 2016 (see Box A for six focus areas).

Box A Initiatives to tackle air quality in Royal Borough of Kensington and Chelsea[15]

1. Public health o Increase community awareness of the local impacts of air quality and climate change and support vulnerable groups through appropriate adaption measures. o Address fuel poverty by improving heating and energy efficiency in residents' homes. o Keep residents with heart and lung conditions in their homes and not in hospitals.
2. Building usage and development o Lead by example to reduce pollution and improve energy efficiency within the Council's estate and operations. o Improve energy efficiency in the borough's housing stock. o Strive for energy efficiency measures, renewable energy and water efficiency to developers for new builds and retrofit in residential and commercial properties. o Use the planning system to minimise local emissions and exposure to poor air quality.
3. Transport: cycling, car and goods vehicle usage o Reduce levels of motor traffic in the borough by increasing sustainable transport levels. o Use the Council's policies to reduce local emissions. o Increase take-up of less polluting vehicles. o Lead by example by reducing the Council's fleet of vehicles and procuring a greener fleet.

4. Business and community o Reduce greenhouse gas emissions from the borough. o Form partnerships to engage with and empower communities to take more action. o Enable the community to improve energy efficiency in their homes and reduce energy bills. o Reduce general waste and increase recycling rates.
5. Greening measures and local improvements o Ensure that the Council's operations are resilient to climate change impacts. o Develop local measures that reduce the impacts of poor air quality, heatwaves and flooding. o Use the Council's policies to increase the installation of greening measures and local improvements. o Create healthy outdoor spaces and green infrastructure to improve health and well-being.
6. Lobbying and partnership o Ensure that funding is available to implement this local action plan. o Ensure that policies and legislation holistically tackle poor air quality and climate change. o Share expertise and knowledge on climate change and air quality within the Council and with external and local partners. o Work in partnership and lobby external bodies to advance solutions that target the causes and effects of climate change and poor air quality.

The borough's objectives largely focus on reducing the extent and impacts of climate change and hence a series of their policies are centred on reducing carbon emissions in the borough. The following projects have not yet been tried in Westminster[15]:

- **Develop a Community Kitchen Garden Scheme:** This scheme encourages residents and community groups to grow and maintain fruit and vegetable gardens. The objective of this scheme is to promote a healthy environment where food production has zero food miles and residents are encouraged to lead healthy lifestyles to tackle issues such as obesity. The initiative started in 2009/10 and focuses on transforming neglected or under-used areas of the borough into allotment style gardens. According to the Royal Borough of Kensington and Chelsea's 'Environment Project Update Report 2015/16' there are now over seventy community kitchen gardens currently in operation, being used by 1,500 residents[16]. There is a target to produce up to ten more community gardens each year to increase residential exposure to the initiative.

- **Publicity drive over smokeless fireplaces:** The Royal Borough of Kensington and Chelsea is a smoke control area, which means that it is an offence to emit smoke from a chimney of a building, or from a furnace or any fixed boiler. the borough committed to launchinies an initial publicity drive and an annual campaign to make residents aware of the pollution caused by non-smokeless fuels in household fireplaces. Whilst Westminster is also a 'smoke control' zone, to date there have been no communication campaigns to discourage smoke from fireplaces or raise awareness of the importance of this.

- **Roadside operations to test vehicle exhausts:** The Royal Borough of Kensington and Chelsea carries out at least one roadside operation to test vehicle exhaust emissions each year. Westminster City Council has done this in the past but no longer carries this out. Rather than penalise the driver, the overall objective is to raise awareness of the importance of cleaner emissions.

- **Identify and train 'Green Champions':** The Royal Borough of Kensington and Chelsea identifies and signs up green champions within the borough to help support energy reduction and energy generation projects and educate other members of the community into becoming more energy efficient and reducing pollution.

The London Borough of Camden

The London Borough of Camden released their 'Camden Clean Air Action Plan' in 2016. The plan comprises five main sections: monitoring air quality in Camden, reducing emissions from buildings and new development, reducing emissions from transport, raising awareness of air quality, and lobbying and partnership working [17].

There are several schemes taking place in Camden that Westminster are not currently doing, some of which are highlighted below [17]:

- **Diffusion tubes:** Like Westminster, the London Borough of Camden has a series of automatic monitoring sites across the borough to monitor pollutants. However, diffusion tubes are also used to monitor NO_2 pollution across the borough. These portable air quality monitors are used to evaluate public realm schemes and help build an understanding of the impact of pollution.

- **Borough-wide 20mph speed limit:** A borough-wide 20mph speed limit was introduced in Camden in December 2013. This may have a number of benefits, including a reduction in the number of people killed or seriously injured through traffic collisions, a higher uptake of people walking or cycling to reach their destination and a reduction in air pollution. This is a measure that Westminster City Council is currently considering.

- **Schools and Nurseries Cleaner Air Fund:** The London Borough of Camden is currently working in partnership with Imperial College London on an air pollution monitoring scheme with schools across the borough. A one off £55,000 air quality fund was opened for schools, nurseries and children's centres to apply for funding in Camden. The London Borough of Camden has been able to support projects in one secondary school, one children's centre, eight primary schools and nine nurseries. The projects included a pollution free playground, energy efficiency improvements, creation of an awareness film, turning a car park into a cleaner air community space, and a pram and scooter store to encourage parents to walk their children to school. The scheme encourages sustainable transport use, educates children and parents about the dangers of pollution and introduces greening measures to reduce air pollution.

- **Original research:** Between 2008 and 2012, the London Borough of Camden carried out one of the first international studies to investigate whether photocatalytic paint can reduce NO_x and NO_2 concentrations. This work was funded by TfL and carried out in partnership with Kings College London. The study showed that there was no change in NO_2 concentrations but that there were reductions in NO_x, however it is thought that this change may have come from a change in wind direction which dispersed pollution [18].

The City of London Corporation

The City of London Corporation (CLC) has some of the most concentrated levels of pollution in the UK. Their most recent air quality strategy was released in 2015 (see Box B for main policy areas).

Box B Initiatives to tackle air quality in The City of London Corporation[18]

1. Air Quality Monitoring: The City Corporation will monitor air pollutants to assess compliance with air quality objectives, to evaluate the effectiveness of policies and to provide alerts when pollution levels are high

2. Political influence and commitment: The City Corporation will seek opportunities to influence air quality policy across London to secure lower levels of air pollution in the Square Mile

3. Working with the Mayor of London: The City Corporation will work with the Mayor of London on air quality policy and action in order to improve air quality in both the Square Mile and across London

4. Working with other external organisations: The City Corporation will work with a range of external organisations to encourage action to reduce emissions across the Square Mile and raise awareness of air quality and its potential impact on health

5. Reducing emissions from transport: The City Corporation will seek opportunities for a significant reduction in emissions associated with road traffic in the Square Mile

6. Reducing emissions from new development: The City Corporation will ensure that new developments have a minimal impact on local air quality both during the development phase and when occupied

7. Leading by example: The City Corporation will assess the impact of its activities on local levels of air pollution in the Square Mile and take steps to minimise it whenever possible

8. Recognising and rewarding good practice: The City will promote, reward and disseminate best practice for tackling poor air quality through its award schemes

9. Raising Awareness: The City Corporation will take action to raise awareness amongst City residents and workers about air pollution and provide information on how to reduce exposure on days of high levels of pollution

10. Air Quality and Public Health: Improving air quality and reducing public exposure will remain a key public health priority for the City Corporation until concentrations are at a level not considered to be harmful to health

There are a number of initiatives that are being carried out by CLC that Westminster are not currently doing. These include [18]:

- **Science in the City programme [19]:** Using money generated from the Mayor's Air Quality Fund, the CLC worked with UCL's 'Mapping for Change' programme on two resident-focused air quality projects. The main aim of the 'Science in the City' programme was to engage communities and businesses regarding air quality issues in Mansell Street and the Barbican area. The Barbican Project (Oct 2013 – Oct 2014) began by meeting a number of residents from the Barbican Estate to discuss air pollution, including where residents felt that air pollution was particularly high in the surrounding area and how they felt they could tackle it. NO_2 was then monitored at sixty-nine sites in the surrounding area at residents' home addresses and hotspot areas. $PM_{2.5}$ was also measured by twenty-one residents using a SlidePak Aerosol monitor. Survey data was collected at the start and end of the project to help evaluate the impact the project has had on residents' perception of air quality; it was found that over the lifetime of the project there was an increase of 19% in residents who felt that air quality was 'a big problem'. A final meeting took place to discuss possible future actions to improve air quality in the City of London Corporation. Similarly, the Mansell Street Project (Nov 2014 - Oct 2015) was undertaken to monitor NO_2 levels in the surrounding area. The monitoring locations and data were also plotted on an interactive map.

- **Environmental awards:** The City of London Corporation runs a series of awards that are given to businesses that can demonstrate excellence in green technology and sustainable development. The Considerate Contractors scheme encourages best practice for building/civil engineers and includes an 'Environmental Award' which rewards innovation in protecting the environment. CLC also runs the national Sustainable City Awards scheme that

aims to make more businesses aware of environmental issues and encourage best practice to reduce air pollution.

- **Beech Street tunnel cleaning:** The Beech Street tunnel is an enclosed space that is often used by commuters. The tunnel reduces the dispersion of pollutants and as such exposure to pollution here is high. The City of London Corporation introduced additional street washing in the hope of reducing pollution exposure in the tunnel.

- **Additional taxi ranks:** The City of London Corporation is attempting to reduce pollution caused by taxis by installing new taxi ranks and encouraging taxi drivers to use them. This is in an effort to reduce the amount of time that taxis are driving in the city 'plying for hire'. Taxi rest bays are provided which are free of charge to taxi drivers but have a maximum stay of 30 minutes and cannot be used for plying for hire [20].

- **CityAir app:** In partnership with Kings College London, the City of London Corporation launched their CityAir app which users can sign up to for pollution alerts and find alternative routes which have less pollution exposure. The app allows users to sign up as a particular user group, for example, 'joggers' 'pedestrian' or 'vulnerable person', and receive bespoke messages which make the user aware of current pollution levels and advise on how to reduce exposure. There are now almost 10,000 users using the app.

- **Bart's Health Trust work:** The City of London Corporation was awarded £280,000 from the Mayor's Air Quality Fund to reduce air pollution in the city between 2013/14 and 2015/16. A further £100,000 was awarded over the three years as part of a joint project with Bart's Health NHS Trust. The project has a twofold approach; improve local air quality in the area and raise awareness amongst the most vulnerable patients. Work is currently still taking place and includes engaging with patients and staff to raise awareness of how to reduce air quality exposure, training staff to give out air quality advice to help vulnerable patients reduce their exposure to pollution, installing green infrastructure and reduce emissions from transport at the hospital.

3 | International comparisons

In this section, we report on interventions identified in six cities around the world: Copenhagen, Singapore, Paris, New York, San Francisco and Los Angeles. These cities vary in population size, topography and geography, as well as culture, but they all share the characteristics of major cities, including a dense urban population and the air quality problems associated with heavy traffic and closely located buildings. Vehicles tend to be the main contributors to air pollution in cities, and transport-related pollutants nitrogen dioxide and particulate matter are strong oxidants which, when in contact with the delicate respiratory airways, can lead to damage.[21] There are of course significant challenges to maintaining good air quality in cities; working and living space are needed for large populations, and adequate transport facilities are required for frequent movement of workers. We describe how these cities have kept functioning while trying to tackle air quality concerns.

3.1 Selected cities

New York City

In the USA, the 1963 Clean Air Act (and subsequent amendments) and the establishment of the National Ambient Air Quality Standards (NAAQS) have helped to significantly reduce concentrations of air pollutants nationally.[22] They also appear to have resulted in air quality improvements in New York State.[23] It has been estimated that up to 70% of PM in New York City comes from external sources, while local pollution sources include busy roads and energy generation in the densely packed buildings.[24] In addition to national standards and regulation at the state level, local air quality improvements in the last ten years have been delivered via the previous Mayor's flagship sustainability plan, PlaNYC (2007), and by its successor, OneNYC (2015). [24] Both plans integrate environmental goals into the city's economic development, focusing on measurable, time-bound targets subject to frequent reporting.[25] For example, in 2008 the city launched the New York Community Air Survey, which measures street-level concentrations of pollutants year-round at more than 100 locations. This data was used to identify the use of residual (or heavy) fuel oil in buildings as one of the main drivers of street level pollution, which led to policies to reduce the sulphur content of heating oil. In general, New York's approach has been centred on encouraging the use of cleaner fuels by both buildings and vehicles via financial incentives (mainly targeted at the private sector) and legislation. Transportation initiatives have been less prominent than in other cities (NYC only introduced a bike sharing service in 2013[26]) and there has been less emphasis on reducing private car use, at least partly due to State legislature's refusal to vote on legislation authorising a congestion pricing plan in 2008.[24] However, the city has expanded its bike infrastructure and invested in bike and car sharing schemes.

Although improvements in air quality cannot be directly attributed to the approaches outlined above in NYC, it is worth noting that a 2013 air quality report found that between 2008 and 2013 overall sulphur dioxide (SO_2) concentrations declined by 69%, while concentrations of nickel in fine particulate matter declined by 35%. State regulatory monitors found that average city-wide $PM_{2.5}$ concentrations in 2009-2011 were down 23% compared to 2005-7. The city estimates that these improvements contributed to 780 fewer deaths and over 2,000 fewer emergency department visits and hospitalisations for respiratory and cardiovascular causes each year. [27] Despite these overall improvements, some areas of the City continues to experience concentrations of $PM_{2.5}$ that violate WHO standards [28] and NAAQS standards. [22]

California (San Francisco and Los Angeles)

The San Francisco Bay Area, consisting of the nine counties that surround San Francisco Bay, is the second largest metropolitan area in California, with 7.44 million people (most of our sources refer to this wider area, rather than San Francisco specifically). [29] In the summer the main sources of ozone-

forming pollutants in the Bay Area are on-road motor vehicles and other mobile sources, in the winter the main source of fine particle pollution is wood smoke.

Since 1967 Air Quality in California has been moderated by the California Air Resource Board (CARB) and 35 regional air quality districts that ensure compliance with local, state and federal air regulations. [30] At the state level California has led the way in enforcing policies requiring catalytic converters in cars, cleaner unleaded fuels, and zero emission vehicle fleets [31], and the air quality standards set by CARB go beyond national legislation. From 1992 to 2011 ambient annual average $PM_{2.5}$ values in non-desert areas fell by 32%, and state-wide maximum 8 hour ozone values decreased 38%. Over the same period the state population increased by 21% and average daily vehicle miles travelled increased by 41%. NO_x emissions from on road motor vehicles declined by 42% between 2000 and 2010, and overall NOx emissions fell by 38% over that period[32]. Although compliance has improved, the Bay Area continues to experience days where ozone concentrations exceed national and (stricter) state standards for ozone and PM [33]. Central to the Bay Area strategy is the use of various grant and incentive programs which fund public agencies and private companies to reduce pollutants from mobile sources. The Mobile Source Incentive Fund, for example, uses a $2 surcharge levied on vehicle registration to fund the purchase of clean air school buses and accelerate vehicle repair or retirement. [33-39]

Los Angeles is the largest city in California and the second largest in the United States. It is also one of the most heavily polluted areas, with a large percentage of pollutants coming from automobiles and the heavy goods trucks serving the Long Beach-Los Angeles port complex, through which 40% of all goods transported into the United States move. However, NOx emissions in the South Coast air basin have declined substantially since 1970 despite an increase in traffic and commerce, and the Los Angeles basin is compliant with the NAAQ standards for nitrogen dioxide, carbon monoxide, sulphur dioxide, and lead, although it violates standards for ozone and $PM_{2.5}$.[31] According to Parish et al. (2016) it has gone from being one of the most polluted cities in the world 50 years ago to "one of the least 'polluted' cities of its size."[40]

Los Angeles is the only one of our three American cities to have implemented any form of low emission zone. Its Clean Trucks Program progressively banned the oldest and most polluting drayage trucks from serving the San Pedro Bay Port and put in place a funding mechanism to help truck owners replace older trucks with new, lower-emission vehicles, successfully reducing NO_x and PM emissions. [23-25] According to a review article by Parrish et al., improvement in air quality has been accomplished despite several unfavorable conditions that make the region particularly susceptible to high air pollution concentrations [31]. Most of the emissions in the urban area are due to private automobiles on the freeway systems, but the technological solutions involving the development of catalytic converters and more efficient car engines along with the implementation of better traffic management systems have been central to the success of air pollution control strategies.

Copenhagen

As in other locations, air pollution in Copenhagen is the product of both local sources and sources outside of the city. While NO_x emissions are largely locally-generated, predominantly by road vehicles, particle pollution is dominated by regional sources, from wider Denmark and elsewhere in Europe. Within Copenhagen, the main sources of particulate matter pollution ($PM_{2.5}$ and PM_{10}) are household wood burning and vehicles [41]. As a member of the European Union, Denmark is subject to EU air quality regulations, such as the Euro standards for road vehicle emissions and the Air Quality Directive, which sets limit values for a wide range of air pollutants [42]. Denmark, and Copenhagen in particular, has struggled to keep emissions within these limits in the past, and Copenhagen has exceeded the limit value plus the margin of tolerance for nitrogen dioxide since it was introduced in 2002.[42]

Pressure from NGOs has been important in motivating government action to address emissions and comply with air quality guidelines in Denmark, and has been identified as the force behind the introduction of Copenhagen's low emission zone.[42] A central element of Copenhagen's strategy to address air pollution is the promotion of cycling over private car use. The municipality has the explicit goal of becoming the world's best cycling city, a target that sits closely with its intention to be carbon-neutral by 2025.[43] Measures to make cycling easier, faster and safer have therefore featured heavily in municipal policy making and appear to have been successful, with the proportion of trips to work or study made by bike rising from 30% in 1998 to 36% in 2012 and 45% in 2014.[44] To support their investments into their predominantly cycling infrastructure, they have also discouraged private car use altogether, with sales taxes of up to 180% on new cars [45], and encouragement to purchase smaller, more fuel-efficient cars. They have also set ambitious goals for the city; it is planned that 100% of passenger cars will be electric or hydrogen by 2025 [46], and The City will install 30,000 sqm of solar cells on new build and existing buildings [46].

Singapore

Singapore faces its own unique air pollution issues, most notably the transboundary haze caused by slash-and-burn agricultural practices in neighboring Indonesia.[47] The city has a long history of using legislation and financial mechanisms to address air pollution issues. Its first Anti-Pollution Unit was established in 1970 and a Clean Air Act setting emissions standards was passed in 1971.[48] Due to its small size and associated congestion, Singapore has had a form of road pricing since 1975; the area licensing scheme charged cars with less than four passengers to enter the city centre. This was replaced with the electronic road pricing system (ERP) system in 1998, an innovative variable road pricing scheme in which an electronic cash card displayed on the car's window screen is debited when they drive into the charge zone. There are a number of other financial mechanisms (e.g. the vehicle quota system) [49] and legislation (such as strict vehicle emission standards) that have focused on reducing private car use and reducing emissions from private car use.

Singapore's most recent approach to air pollution is notable for its emphasis on public engagement to foster a sense of environmental ownership e.g. holding annual Community and Youth for the Environment days, and developing partnerships with the private sector e.g. via an Energy Efficiency network.[50-56]

Paris

Although Paris has had some success in reducing the number of days on which PM_{10} concentrations exceed those permissible since 2009, they continue to be at a very high level.[57] According to Airparif's 2014 air quality report, 400,000 residents in Greater Paris are exposed daily to NOx and PM above acceptable standards. As a member of the EU, Paris' air quality legislation is bound by EU standards, and it has been fined by the European court for failure to comply with PM limits.[26]

Historically Paris's strategy has been to promote public transport and to encourage the use of hybrid and electric vehicles through infrastructure improvement - Paris was one of the first cities to develop bicycle and electric car sharing programs.[26] More recently the experience of severe air pollution episodes have led to Paris experimenting with ad-hoc emergency approaches, such as allowing only cars with odd license plates to use the roads.[58, 59] Mayor Hidalgo's new anti-air-pollution plan is notable for its ambitious targets, such as a total ban on diesel cars and a completely electric or hybrid city fleet by 2020. These initiatives combine legislation with consumer focused financial mechanisms e.g. free parking and charging for electric vehicles. On high pollution days, public transport and residential parking are offered free. [58, 59]

3.2 Overview of types of interventions from international comparison cities

We provide details of the interventions we identified in tables provided in Annex B. These tables include information about the types of emissions the intervention seeks to address, the mechanism used to enact it, and whether any evaluation or modeling of the intervention's effects has been conducted. The type of information listed under each of these columns is described below.

Emissions source being addressed: In this column we describe the source of the emission in general terms, covering emissions from power generation, transport, buildings and construction. Some interventions, particularly legislative ones, address emissions from multiple sources. We included articles that specifically describe initiatives to reduce emissions of air pollutants, and improve air quality, such as those listed in Table 1. However, not all policies have been designed to reduce air pollution per se - some are to address CO_2 emissions to tackle global warming, and we have included these as well if they relate to measures to reduce energy consumption.

Mechanism: There are a variety of approaches and mechanisms used to deliver air quality improvements in these cities. We have categorised each intervention in terms of the approach it takes, which may include any combination of the following:

- Regulation/legislative enforcement (including regulation, and other enforced top-down approaches)
- Education and engagement activities (including raising awareness about air quality concerns and ways to mitigate risks, training schemes for fuel-efficient driving)
- Financial incentives (specifically incentive-based mechanisms for users or industry such as monetary rewards for good practice)
- Financial tax or charging based mechanisms (such as taxing or fines for bad practice or high parking charges)
- Infrastructure investment (including new energy-efficient buildings and new cycle-friendly roads, energy efficient transport, or even planting more trees in the city)

Aim of intervention: In addition to the mechanism, we also indicate the primary aim of some of the interventions. For example, some interventions enabled the city to 'lead by example' by committing to certain standards, with the aim of inspiring its population to follow good practice. There are also measures to increase 'user convenience', for example by investing in cycling infrastructure, more people will be encouraged to cycle.

In general, we found that that most sources described interventions or ideas, but provided little detailed information about how the idea was implemented or the outcomes of its implementation. Many of the interventions outlined below were mentioned in policy documents that gave little more than a brief mention of the initiative, and it was not always clear to what extent each had been implemented. For studies that included intervention evaluations, these tended to be relatively simplistic, describing before and after changes in air quality. Inevitably, this meant the outcome results were described in terms of large-scale changes that could not be attributed to individual interventions. Newer interventions or ideas (that were either in planning phases or currently being implemented) were often modeled to show *potential* air quality improvement results. However, the outcomes of these modeling exercises depend heavily on the parameters used and the assumptions made, and these were not always detailed clearly, especially in policy documents. Although this information is not included in the tables, in our descriptions below we refer to evaluations of these initiatives where appropriate.

Any individual intervention listed in Annex B could involve a number of mechanisms and address more than one emission source (resulting in a total that is greater than the number of interventions we selected to describe in this report). Most of the interventions are targeted at addressing emissions from transport (private car use or commercial vehicles), using primarily regulation/legislative enforced mechanisms and investing in infrastructure. However, some of the policy and intervention mechanisms used could also provide useful learning for addressing buildings emissions.

3.3 Examples of interventions

Most emissions discussed in the studies or documents we found are emitted from vehicles or buildings. The interventions we identified, whether modelled or implemented fully and/or evaluated, are centred on the following four main sources of pollution in urban areas:

- Reducing private car use
- Reducing emissions from all vehicles (making transport cleaner)
- Reducing energy usage by buildings
- Reducing emissions from energy usage by buildings (making electricity and heat generation cleaner)

It may be helpful to view these interventions in two broad categories; those that seek to change behaviour (reducing private car use and energy use) and those that seek to make existing behaviours less polluting (reducing emissions of air pollutants from vehicles and buildings).

Details of the interventions are described in Annex B, and we provide brief overviews of some illustrative examples below.

Reducing private car use

Most of the sources we found pointed to the importance of reducing private car use, either by making private car use less appealing to the user (by closing roads or restricting city access, for example), making public transport or bicycling more convenient, or using planning legislation to build housing and commercial buildings closer to public transport hubs. The mechanisms used include financial mechanisms and incentives, investing in public transport infrastructure and public engagement initiatives.

The cities we surveyed have generally sought to **lead by example**, reducing the number of vehicles in their municipal fleet. The Copenhagen city administration uses bikes for street cleaning, leaf and garbage removal and for park maintenance – they have 20 bikes used regularly by their staff. **[60]** New York introduced a car sharing to its municipal fleet, running a pilot scheme to replace 50 city cars with ZipCars (a private car sharing company) [61], and is reducing the number of miles travelled by Department of Sanitation vehicles via a Solid Waste Management Plan which shifts waste management operations from trucks to barge and rail transport. [25]

All the cities we surveyed used some form of **taxing/charging** to provide disincentives to private cars use. Perhaps most interesting from a local authority perspective was the use of dynamic parking charges. New York City's *Park Smart* [61, 62] and San Francisco's *SF Park* [63] schemes use metering systems to charge more for parking at peak times. The schemes are designed to increase vehicle turnover and reduce congestion caused by vehicles looking for parking spaces, but no results of their early pilot studies were identified our search. In Los Angeles, a similar *LA Express Park* system uses ground sensors to notify drivers in real time where car parking is available, and adjusts parking prices based on demand. [64-66]

Some cities use road-pricing systems to discourage driving into certain zones altogether. Singapore's electronic road pricing system (ERP) system requires that all vehicles that enter restricted zones be fitted with an electronic unit ('CashCard'). Cameras with sensors on gantries on the roads communicate with this unit and deduct an amount displayed to the driver on the unit's screen. The amount debited depends on the location and time. [48, 49, 67, 68] Although long term effects on pollution concentrations were not found in our search, one study by Ang and Tan found that the number of vehicles entering the restricted zone during the restricted hours fell by over 33% and the number of passenger cars fell by 61%. Motorists either carpooled or adjusted their schedule to avoid the restricted period. [68].

Some cities use **financial incentives** to reward their citizens when they decrease their car use. In Singapore, road users are offered discounts on road tax and vehicle registration if car owners drive only at off peak times.[49] In San Francisco, legislation requires employers to provide a commuter benefits programme to support and encourage employees to cycle, carpool and take public transport into work either via employee funded transport, pre-tax deductions of transit expenses or an employer subsidy. [35, 38, 69-72]

At times, Paris, New York and Los Angeles have gone beyond disincentives to outright prevention by introducing temporary road closure programmes **enforced by legislation**. In Paris all private non-electric cars were banned from the city centre for seven hours on one day in 2015 [73] and the *Champs-Elysees* is now closed to cars on the first Sunday of every month.[74] The city also plans to close the first four government districts ('arrondissements') to all but residents' vehicles, deliveries and emergency services by 2020. [75] As well as these routine road closures Paris has also recently resorted to emergency measures during extreme pollution episodes, banning all cars with even or odd license plates from the road on consecutive days and reducing the speed limit. [58, 59] While no papers evaluating the effect of these closures were available in Paris, studies have been conducted in the two American cities. In New York, the 'Summer Streets' campaign closed Park Avenue in New York to traffic for three consecutive Saturdays. Whitlow et al. found that on the mornings without traffic the concentration of ultrafine PM particles was substantially reduced, but $PM_{2.5}$ concentrations were non-responsive, peaking in the morning irrespective of traffic flow.[76]

Los Angeles has introduced a series of programmes, titled *CicLAvia,* in which tens of kilometres of streets are closed to motorised vehicles. [77]. There were two CicLAvia events in 2014, four in 2015 and eight scheduled for 2016, with an aspiration to host monthly CicLAvias by 2017. Shu et al [77] evaluated CicLAvia and found that $PM_{2.5}$ reduction was 49%, and the community-wide $PM_{2.}5$ reduction was 12%. Two other studies evaluating the effects of a planned freeway closure in LA found reduced concentrations of $PM_{2.5}$ [78, 79] and ozone [79] relative to control days (although daily maximum NO2 concentration was higher at some sites) providing further support for road closure programmes. We note the limitations of some of these evaluations (as observed in our caveats) as the knock-on effects on surround areas and roads were not available. The authors also note the limitation of their own evaluations as measurements were made over a three-day period which may be insufficient to lead to general conclusions about improvements in air quality.

Restricting private car use requires strong **investment in infrastructure** for public transport. Copenhagen is a prime example of a city that has heavily invested in integrating the bus, train and metro systems to make public transport more attractive by enabling passengers to move easily between different modes of transport [80, 81]. They have also invested in cycling infrastructure, and introduced a range of smaller measures to make cycling and bicycle maintenance as user-friendly and convenient as possible.[43, 46, 80, 82] Investments in the city's urban infrastructure include building more cycle routes, cycle 'superhighways', widening cycle lanes, and installing footrests at traffic lights. The 'green wave' system on designated routes co-ordinates the traffic lights to minimise stoppages for cyclists at red lights when travelling at 20km/h. Commercial buildings and developments are required to have 0.5 bicycle parking spaces per employee, and residential developments should have 2.5 bicycle parking spaces per 100 m^2. An idea (not yet implemented to our knowledge at the time of writing), is the use of LED lights in tarmac to indicate which mode of transport has priority and when, enabling

the flexible sharing of road space.[60] Other cities have encouraged car sharing - New York has made use of zoning amendments to allow shared vehicles to be stationed in off-street parking lots and garages [61], and Paris has expanded the infrastructure necessary for the Autolib electric car sharing scheme, building a network of charging stations and setting aside dedicated parking spaces. [57]

In Copenhagen, Singapore and San Francisco urban planning policies have been designed to reduce the need for private cars usage in the long term. In Copenhagen, building regulations allow for a higher density of buildings close to stations and ensure that large offices can only be located within 500 metres of a station. The growth of Copenhagen has been set along five designated 'fingers' leading to the main city centre within which there are major train and road routes, with green, open spaces in between.[80] Similarly in San Francisco, land use policies encourage development near transit corridors[39, 63] and in Singapore policy aims to decentralise commercial activities to four regional centres.[83]

Finally, cities have used **public engagement** to encourage their residents to reduce the use of private cars. In Copenhagen, citywide campaigns were introduced to create the perception that cycling is fun, faster, comfortable and safe, and associated with personal and societal benefits. [60] In San Francisco, the 'Spare the Air' programme uses public announcements to ask residents to reduce car use on days when ground-level ozone is predicted to exceed National Ambient Air Quality Standards. [34, 36, 84]

Reducing emissions from vehicles (making transport cleaner)

Certain transport use is inevitable in big cities, and the aim of many initiatives is to reduce the emissions from transport via retrofitting, fleet renewal and the promotion of low emission alternatives such electric or hybrid vehicles. Mechanisms include legislation, financial (dis)incentives, public engagement and infrastructure investment.

This is another area in which many cities aim to '**lead by example**' by greening their city fleet, with Paris and Copenhagen notable for their ambitious targets. For example, the local Parisian transport company has agreed with the Mayor of Paris that 100% of its buses will meet Euro VI emissions standards by 2025, with 80% of its buses powered by electric and 20% powered by biogas. By 2020 Paris aims to have a municipal fleet that is completely electric or hybrid fleet.[57] Copenhagen's target is for 100% of its passenger cars to be electric or hydrogen by 2025.[46] Similarly New York had greened its Department of Sanitation fleet by retiring old vehicles and retrofitting others, measures which it estimates have reduced the PM emissions of its fleet by 80% and NOx emissions by 50% since 2005. [27]

In some of our cities low emissions zones have been introduced, banning older or more polluting vehicles using legislative enforcements. Copenhagen has had a low emission zone since 2008, and since 2010 all vehicles heavier than 3.5 tonnes (buses and lorries) have been required to comply with at least the Euro IV standards, or to be equipped with a certified particulate filter. The zone covers almost the whole city area. A before-and-after comparison of quality in the restricted areas by the Danish Ecological Council reported a fall in ultrafine particle concentration.[42] Paris has the most ambitious low emission zone of any of our cities. Introduced in 2015, the LEZ covers the whole city inside the orbital road and envisages a complete ban on diesel cars by 2020. [57] In Los Angeles, the *Clean Trucks Program,* beginning in 2008*,* progressively banned the oldest and most polluting drayage trucks from serving the San Pedro Bay Port and put in place a funding mechanism to help truck owners replace older trucks with new, lower-emission vehicles. Strict deadlines were given to all trucks with heavy fines for non-compliance. [29, 85, 86] Lee et al. [85] analysed vehicular emissions before and after the implementation of the programme and found that by 2012, total vehicular emissions were down substantially for both NOx (48%) and PM (55%) compared to 2005 due to a sharp decrease in emissions from drayage trucks. Singapore has combined progressively stricter

vehicle emissions standards with strict enforcement measures, including a compulsory biannual inspection for vehicles in their third year of ownership and older. [49, 67]

In Copenhagen, **legislation** to reduce the sulphur content of fuel in in 1999 [87] and 2005 [88] has been effective. Wåhlin et al. [87] and Wåhlin [88] used the measurement of pollutants at a single monitoring site before and after the legislation change to evaluate its effect, and found a drop in ultrafine particle concentrations that was attributed to the reduction and subsequent elimination of sulphur in diesel fuel. [87, 88]

Cities have also used **financial incentive mechanisms** to try and encourage the retirement of older and more polluting vehicles and the adoption of lower emission vehicles. In New York, these have mainly taken the form of grants to private and non-profit companies. The Citywide Private Fleet Alternative Fuel Programs, for example, offers rebates up to 80% of the increased cost of choosing an electric or alternative fuel over a conventional one. According to NY State Energy and Research and Development Authority, the program contributes to the reduction of 2.2 tons of PM over the vehicles' useful lives. [89] San Francisco also has an extensive programme of grants to accelerate repair or retirement, including a $1000 incentive for residents to retire vehicles built before 1994. [33, 35, 38] Paris and Singapore operate more punitive measures, levying **financial penalties**. Paris operates a diesel tax and higher motorway tolls for polluting vehicles, and in Singapore road tax relates to engine size to encourage the purchase of smaller cars. Road taxes also increase at the rate of 10% p.a. when the car is above 10 years old, peaking at 150% when the car is 15 years old. [49, 67]

Most of the cities in this review are investing in infrastructure to encourage the adoption of low-emission vehicles. As mentioned above, Paris has rolled out the Autolib electric car sharing scheme, and San Francisco, New York, L.A. and Copenhagen are all expanding their charging infrastructures. [25, 46, 57, 63, 64]

Reducing emissions from energy usage by buildings (making electricity and heat generation cleaner)

We found initiatives to reduce the emissions of harmful air pollutants from buildings in New York, California and Copenhagen.

A 2009 analysis revealed that almost 10,000 buildings in NYC were burning No. 6 and No. 4 heating oils, fuels that have significantly higher levels of sulphur and nickel compared to other heating oils. Although these buildings made up only 1% of the city's buildings, those buildings emitted more $PM_{2.5}$ than all the car and trucks in the streets combined. [24] To combat this, New York City passed a local law in 2010 to cut the allowed sulphur content in heating oil (numbers 2 and 4), require all heating oil to contain 2% renewable biodiesel by October 2012, and to phase out the use of the most heavily polluting heating oils (numbers 4 and 6) by requiring all boilers to burn no 4 or cleaner by 2015, and natural gas or ultra-low sulphur no.2 by 2030. This legislation was accompanied by the 'Clean Heat' programme that encouraged the voluntary early adoption of cleaner fuels by providing technical and financial assistance to building owners. [90, 91]

Studies have investigated changes in air quality at the time that this policy was being enacted and explored whether improvements in air quality and better health outcomes can be attributed to it. For example, New York City Community Air Survey (NYCCAS) data indicates that during this period as of winter 2012-2013 SO_2 concentrations (generated from burning sulphur-containing fuels) fell by 69%, while concentrations of nickel in fine particulate matter (an indicator of residual oil combustion) had declined by 35 percent compared with December 2008 values [92]. There is some degree of confidence that these results can be attributed to the boiler initiatives as neighbourhoods with the greatest reductions in emissions from boiler conversions and fuel Sulphur restrictions saw the greatest improvement in air quality.[92] A 2014 study by Kheirbek et al. modelled the impact on public health of reductions in fine particulate matter ($PM_{2.5}$) associated with the part and full implementation of this initiative. They estimated that the partial phase out of high-sulphur heating oil would translate into 210 avoided premature deaths, 140 avoided hospitalisations for cardiovascular and respiratory

disease, and 400 fewer emergency department visits for asthma, annually across NYC (compared to 2008) though these benefits were unevenly distributed through the city [93]. The full phase-out of high-sulphur fuel was calculated to lead to 290 avoided premature deaths, 180 avoided hospitalisations for cardiovascular and respiratory disease, and 550 fewer emergency department visits for asthma annually (again compared to 2008 and again unevenly distributed throughout the city). The part-implementation of the programme accounts for the bulk of emissions reductions (and therefore health benefits). [93]

Efforts to switch to cleaner fuels have also been made in other cities. The cities of Los Angeles and San Francisco have provided extensive support for solar power in the form of **financing options**, piloting technology for solar energy storage and introducing feed-in tariff systems to incentivise property owners and developers to generate solar power on rooftop space. [38, 64, 65, 69] New York has also introduced a **financial incentive** in the form of a Solar Property Tax Abatement, a measure that helps eligible owners offset the costs of their photovoltaic and green-roof installations. [27, 89]

Copenhagen meanwhile has focused its resources on support for wind power, building twenty wind turbines in Copenhagen harbour and creating a cooperative to own ten of these. The City of Copenhagen estimates that this windfarm eliminates 208 tonnes of NO_2 emissions annually, alongside 232 tonnes of SO_2 emissions and 4,400 tonnes of dust and clinker. [80] There are plans by the city-owned utility company to build a further 100 turbines by 2025. [80]

More dramatic legislative steps have also been taken in some instances. In 2008 San Francisco introduced a law that prohibits the use of wood-burning devices from November to February at times when air quality is forecast to be unhealthy and Paris has gone further, implementing a full ban on wood fires from January 2015. Prior to this, wood fires were responsible for 23% of the city's particulate pollution. [39, 75]

We also saw a few examples of initiatives to capture pollutants. In New York, the *Million Tree Initiative* was introduced as a public-private initiative to plant and maintain one million new trees to reclaim underused parks and space. [61, 89, 94, 95] As of 2013, a total of 730,000 trees had been planted; with priority given to areas with fewer trees and high levels of child asthma. Morani et al. modelled the effect of planting a million trees on the city's air quality and found that the trees would remove 10,000 tons of air pollutants (O_3, PM_{10}, SO_2, NO_2) over the next 100 years (assuming 4% tree mortality rate), or remove 3000 tons of air pollutants over the next 100 years (assuming 8% tree mortality rate).[95] However, other studies have pointed out that a simple 'more trees are better' approach is unlikely to be adequate. Tong et al. measured the effect of trees on the dispersion of particulates in Queens, NY, and found that it was highly dependent on wind direction. In some conditions trees actually slowed the dispersion of particulates and increased local pollution concentrations.[96]

Finally, there are examples of making energy generation less polluting, some of which have been modelled in the academic literature. For example, in New York, Gilmore et al. modelled the effects of integrating batteries into the national grid that charge at off-peak times using cleaner energy generation, and discharge at peak times, replacing dirtier generators installed to meet peak demand. The authors conclude that the impact on air quality depends on the type of energy generation used to charge batteries compared to the types displaced by the use of batteries. [97]

Reducing energy usage by buildings

As well as efforts to encourage the powering of buildings with cleaner fuels, the cities we studied have made efforts to reduce the total amount of energy consumed by buildings.

Changes to building design and construction practices have featured in the energy efficiency efforts of several cities. San Francisco has the Green Building Program, which ensures that all new buildings are built and operated according to third-party verified energy standards, which means buildings must

conform to set standards for sustainability in terms of the site and location, water efficiency, energy consumption and atmosphere, materials and resources, and indoor climate. [69, 70] New builds in Copenhagen must comply with the Danish building code, which has been gradually tightened since 1961 and now stipulates that the energy needs of new buildings must be 'nearly zero' by 2020, with energy needs covered primarily by renewables or district heating.[46, 80, 98] The City of Copenhagen had lead the way in more energy-efficient construction, developing so-called 'lighthouse projects' that provide examples for other developers to emulate. [46] The first such building constructed as a public-private partnership at the University of Copenhagen is Denmark's first public CO_2 neutral building relying on district heating and solar power and seasonal storage. [99] The City of New York is also leading by example in this area, trialling an approach to house building termed 'passive building design'. This utilises high levels of insulation and other design features to moderate a building's heat loss and gain and improve air quality. According to the City of New York, these standards have the capacity to reduce a building's heating and cooling energy demands by 90 percent. [25] New York has also introduced the Enterprise Green Communities Guidelines, which ensure that affordable housing is energy efficient and constructed in an environmentally-friendly way.

As well as making new builds more energy-efficient, city authorities have also devoted resources to the retrofitting of existing buildings. Copenhagen's 2025 Climate Plan commits to raising the rate of retrofitting by 0.5 percentage points per annum such that 33% of the housing stock and 46% of commercial properties will be retrofitted in the period up to 2025. It is anticipated that this policy could lead to a 10% decrease in electricity consumption and 20% in heat consumption when comparing 2025 with 2010. [46] Retrofitting is also being promoted in New York City via initiatives such as Community Retrofit NYC, a free programme to assist owners of small and mid-sized multi-family buildings to improve energy efficiency by connecting them with finance programmes and technical advice. [25] Similarly in Los Angeles, **financial incentives** are on offer for building owners to improve the energy efficiency of their properties via an initiative termed the Better Buildings Challenge.[65] The City of New York is also making its own resources available for retrofitting via its 30x17 commitment, which pledges to reduce municipal greenhouse gas emissions by 30% by 2017 (compared to 2006). As part of this commitment, 10% of the municipality's annual energy budget is being devoted to projects to reduce energy use and promote renewables, including via the retrofitting of buildings. [27, 61, 89]

Singapore has gone beyond the regulation of the energy performance of the building itself to also stipulating the performance of the appliances within it. Minimum Energy Performance Standards prevent inefficient home appliances from being sold on the local market and these standards are regularly reviewed to keep in line with technological advancements. [51, 56]

Cities have also looked for other ways to reduce the energy consumption of buildings less directly. Cool roofing and paving, which are more reflective than conventional varieties, are ideas considered by San Francisco as ways of mitigating the urban heat island effect. This is where an urban area is heated through human activity, and cooling this area increases energy consumption and therefore emissions. [63] Vegetation is also being utilised to mitigate warming due to the heat island effect; San Francisco is planting trees and preserving vegetation to provide shade, [63] while Singapore has tried 'green roofs'; the planting of greenery on rooftops to reduce surface temperatures and energy consumption. Nyuk Hien, Puay Yok and Yu investigated the effect of green roofs on surface temperatures, observing that the surface temperatures of green roofs could be up to 18 degrees centigrade lower than the original uncovered roof surfaces. [100] Modelling by Wong et al. [101] found that an extensive green roof could reduce the energy consumption of a building, but significant savings were only found for roofs in exposed areas that were fully covered in greenery. Those in built up areas and with partial greenery cover showed much lower energy savings.

We also found ideas to reduce energy consumption that have yet to be put into practice. Ommen, Markussen and Elmegaard modelled the effect of lowering district heating temperatures in Copenhagen on energy consumption. They found that while reducing temperatures initially reduced energy consumption, at a certain point the effect was reversed as hot tap water requires electricity to

reach the required temperatures.[102] Energy tariffs that vary in response to demand was an proposal modelled for New York City, with the idea being that if higher rates were charged on peak demand days (when the most polluting forms of energy generation are employed), energy consumption and therefore emissions would be reduced. Gilbraith and Powers found that while tariffs of this sort could reduce the use of more polluting peak energy generation and thus emissions, this would be unlikely to significantly affect air quality at a city-wide level.[103]

Finally, we also came across a range of **engagement and educational activities** aimed at encouraging businesses to be more energy-efficient. In Singapore, the 'Green Office' award recognises corporate commitment to the environment, while Energy Efficiency Network awards are focused on celebrating best practice in energy management. Guidance is provided to businesses via the Energy Efficiency National Partnership, an industry outreach program offering training workshops and energy benchmarking studies.[50, 52, 55, 56] Similarly, training and information on how to reduce emissions from buildings is offered in New York and San Francisco for groups including businesses, building owners and managers, schools and industrial facilities [27, 63, 70, 71, 89], while Copenhagen plans to provide businesses with information on how to identify, finance and implement cost-effective energy savings.[46] A more targeted approach is taken by the City of Los Angeles; they are collaborating with the Building Owners and Managers Association of LA to provide energy efficiency training to janitors.[65]

Looking more specifically at engagement with the public, Singapore has a range of initiatives to promote lower energy usage. The 'Save Energy Save Money' campaign was launched in 2016 to encourage households to save energy, with posters displayed in public spaces and resources made available online. The 'Reduce@NorthWest' energy audit educational programme and challenge trains student volunteers to teach residents about energy efficiency, while the 'S.W.I.T.C.H. (Simple Ways I Take to Change my Habit) campaign also focuses on training volunteers, who then pass on their knowledge about how to reduce energy consumption to households. [50]

4 | Reflections

Through our targeted search for available evidence on initiatives to improve air quality in Copenhagen, Los Angeles, Paris, New York, San Francisco and Singapore, we have come across ideas and interventions in four main areas: (i) reducing private car use, (ii) reducing emissions from all vehicles (making transport cleaner), (iii) reducing energy usage by buildings and (iv) reducing emissions from energy usage by buildings (making electricity and heat generation cleaner). Our intention is not to provide a direct comparison of interventions in these cities with either London or Westminster, but to highlight initiatives that have been proposed, modeled or implemented to tackle air quality concerns in these municipal areas.

A variety of mechanisms are being used to both encourage good practice and penalise bad practice across these areas. These include legislative approaches (including enforced regulation, or softer advisory policy), education and engagement activities (including raising awareness about air quality concerns and ways to mitigate risks, and providing advice on reducing energy consumption), financial mechanisms (such as monetary rewards for good practice or fines for bad practice to members of the public and industry), investments in infrastructure (such as new, energy-efficient buildings and cycle-friendly roads), measures to increase the convenience of cleaner transport (such as allowing cyclists to take bicycles on trains), technological innovations to control emissions, and "leading by example", which refers to commitments by a city or region's authorities to reduce their contribution to emissions, with the aim of inspiring others. Most interventions we found are focused on reducing emissions from transport (specifically, discouraging private car use and reducing emissions from industrial vehicles), using primarily regulation/legislative mechanisms and investing in infrastructure, such as public transport and cycling lanes and facilities.

Based on what we have learned from our brief study, we offer the following four points of reflection, covering both the types of mechanisms or interventions that show some promise, and the nature of the evidence in this area.

1. Both academic and grey literature show a lack of rigorous evaluation of interventions, and little information specifically on the resulting health outcomes.

Although in no way conclusive, this review supports previous work that has demonstrated that there are limitations in the way this work is conceptualised and in the conclusions that can be drawn from existing interventions [104]. There are difficulties in conducting research that provides an evaluation (sometimes referred to as an 'accountability study') of actions to improve air quality, including a lack of robust data on air quality and health outcomes, and the existence of confounding factors that limit the ability to attribute outcomes to specific interventions with confidence [104]. It is therefore difficult to follow the pathway from air quality interventions to health outcomes, as this causal link or 'accountability chain' [104, 105] is seldom fully described in anyone one article. Often studies describe one element of this chain (illustrated in Figure 4), such as the regulatory action of a policy, its impact on emissions, or its effect on ambient air quality or exposure dose. In this regard, studies that use modelling techniques to predict the effects of an intervention further along the chain could be useful, as these were rare in our search. Modelling results also depend on the parameters of the model or the assumptions made, and these do not always line up from one study to another, making the drawing of connections across studies between the 'intervention to reduce emissions', the 'extent of emissions reduced' and the ultimate 'health effects' very challenging.

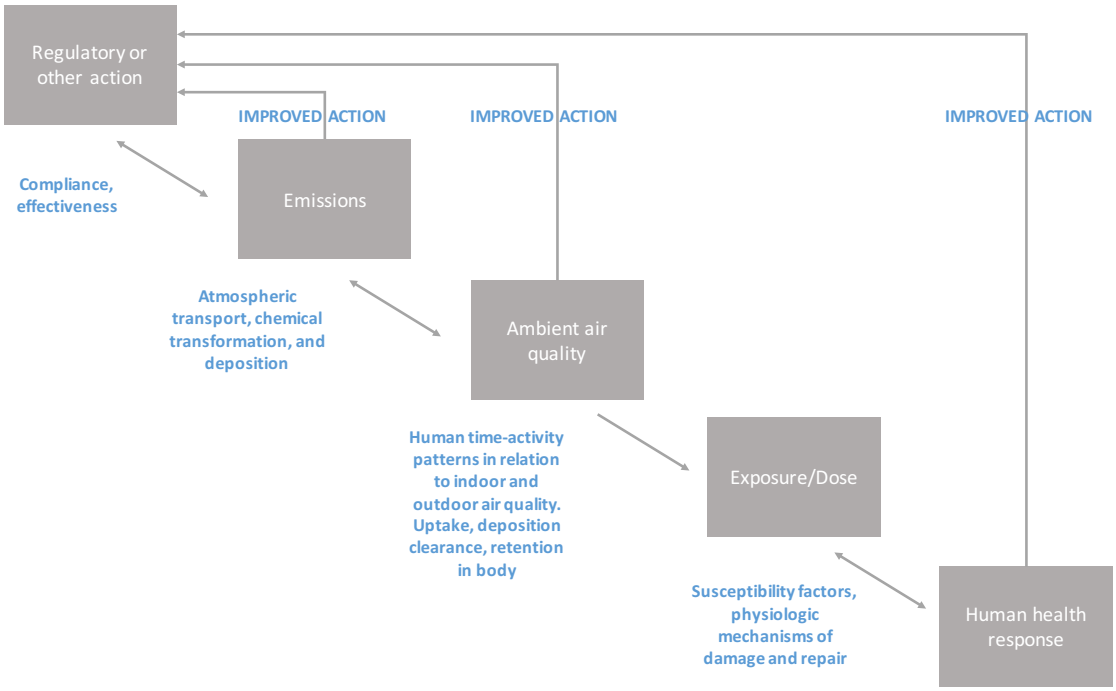

Figure 4 Chain of accountability linking regulatory action and human health outcomes to air pollution (adapted from HEI, 2003) with permission [105]

2. Ideas that could provide learning for Westminster City Council include dynamic car parking schemes, enabling energy-efficient buildings, and greater community engagement.

We are mindful that many initiatives are already underway in Westminster, some of which are highlighted in this report. There are, however, some areas of activity that could provide learning for the borough. For example, the dynamically priced parking scheme in Los Angeles uses in ground sensors to notify drivers in real time where parking is available and adjusts parking prices based on demand [64-66]. Singapore's electronic road pricing system is an example of an innovative form of dynamic road pricing within a charging zone.

An important consideration is that the international case studies employed here are cities or city-regions; a very different unit of analysis to the local authority. This difference is salient in that a local authority such as Westminster City Council is unlikely to have the same degree of policy discretion as a municipality, and therefore faces more limitations on the interventions it can employ directly to respond to air pollution. Broadly speaking, local authorities have more direct control over interventions to address emissions from buildings, with influence over planning and land use in the region, and their close contact with those owning homes and businesses inside the borough.

Regarding emissions from buildings, a local authority could lead by example with its own buildings, either by ensuring its new builds comply to strict energy efficiency standards or through the retrofitting of its existing stock. It could also influence private sector-owned buildings through the environmental standards it stipulates for new developments and by linking building owners to sources of finance and technical advice for making energy efficiency improvements. More direct measures that the local authority could take may include providing commercial buildings and households with energy meters to allow them to monitor their energy consumption and conducting outreach programmes that educate building owners on energy efficiency.

Regarding emissions from vehicles, one way for a local authority to reduce the number of vehicles entering its boundaries is by making parking difficult or expensive. This could be achieved by reducing the number of parking spaces, increasing parking charges (either across the board or at times of peak demand) or utilising technology that alerts drivers to vacant parking spaces in real time to

reduce cruising and idling, for example. Idling could also be targeted by equipping parking wardens with the power to issue tickets to culpable drivers. Local authorities can also encourage the use of cleaner transport by installing facilities such as charging stations for electric cars, and by converting their own fleets to lower-emission vehicles. Encouraging cycling over car use is another approach very much within the power of a local authority. This might be achieved by investing more in cycling infrastructure, such as cycle lanes and parking, as well as other measures to make cycling more accessible and convenient, for example by providing information about the fastest cycling routes via signs and GPS.

Beyond these more targeted interventions, local authorities might also have an important role to play in raising awareness of air pollution, and the contribution residents make to it through their transport habits and residential and domestic energy usage. Providing alerts to residents on days when air pollution is particularly high may be one feasible measure, as well as broader outreach to schools and communities to provide information on energy efficiency and cleaner travel. Such intense community engagement and raising awareness have been key to initiatives especially in Singapore and New York, as well as the London boroughs we included in this report. Notable examples include the Community Kitchen Garden Scheme and the training of 'Green Champions' in the Royal Borough of Kensington and Chelsea, the Schools and Nurseries Cleaner Air Fund in Camden and the Science in the City Programme that uses residents' engagement schemes in Barbican. Finally, the CityAir app launched by the City of London Corporation is a great example of a simple technological innovation that also enables great user participation and engagement.

3. While many of the ideas may already be under consideration in Westminster, the literature indicates the importance of using more ambitious targets for existing initiatives.

Many of the cities we looked have set ambitious targets for improving air quality. For example, Copenhagen has committed to having 100% of their passenger cars on electric or hydrogen powered by 2025. The anti-air pollution plan in Paris includes a total ban on diesel cars and a completely electric or hybrid city fleet by 2020. Camden introduced a borough-wide 20mph speed limit in December 2013 which could be worth exploring further.

In terms of pollutant concentration targets, Westminster has significantly higher mean average concentrations for $PM_{2.5}$, PM_{10} and NO_2 than the London averages, and all three concentrations exceed the WHO's annual mean guidelines, despite improvements. There is therefore still work to be done to comply with WHO guidelines and align initiatives explicitly with the aim of achieving these targets.

4. Multi-faceted approaches that include the use of top-down enforcing policies or financial incentives can be effective ways to enable larger scale improvements.

Part of the reason for the lack of rigorous policy evaluations is because of the existence of comprehensive programmes that use a combination of approaches to achieve improvements. As noted in our caveats, studies of wider policy interventions could only provide before and after measures of air quality or emissions following the introduction of a new piece of legislation or a set of policy interventions. Copenhagen's cycling strategy included significant investment in their city's infrastructure, as well as public engagement and awareness campaigns. In New York City, it was the combination of legislation on boilers with public clean heat campaigns and funding of retrofitting to buildings that together contributed to a reduction in emissions. It is important to note that enforcement measures tend to be accompanied by significant investment in infrastructure, such as retrofitting of buildings or road infrastructure. They may also simply involve investing in subsidy schemes; for example investments in electric vehicle subsidy schemes to encourage users through a financial incentive.

5. Involving stakeholders from different sectors in both design and delivery of interventions can lead to better compliance with initiatives.

To complement enforcement and regulatory activity, some of these interventions sought input from stakeholder groups. Before introducing the legislation on replacing heavy polluting oils in New York, commercial building associations, interest groups and oil suppliers were consulted, as such an intervention would require changing practices in large corporations. Involving schools and universities were also a large part of Singapore's strategy; rewarding good practice and working with them to cut emissions from buildings. In Copenhagen, part of the success of the cycling campaign was the branding of the city as a 'cycling city', which helped to engage the public in the initiatives. While we do not know the counterfactual (i.e. what would have happened if key stakeholders were not involved in the process), the examples we highlight in this report are illustrations of how communication, collaboration and engagement can help with compliance.

*

We conclude with a final thought about the transferability of these interventions identified in this study. Although we have included some insights on whether each intervention appeared to be successful in its context (if such information was available), it is not within the scope of this study to report on its transferability elsewhere. Interventions tended to be described at city level and were not limited to one district or borough. Collaborations and partnerships with other districts may be necessary to make them work effectively. We hope that this synthesis of initiatives identified from other cities and boroughs helps to both encourage the initiatives that are already in place in Westminster, and may help generate new ideas for improving practice.

5 | References

1. Howard, R., S. Beevers, and D. Dajnak, Up in the air: How to solve London's air quality crisis: Part 1. King's College London and Policy Exchange, 2016.

2. Holgate, S., et al. Every breath we take: The lifelong impact of air pollution, Report of a working party. 2016. Royal College of Physicians.

3. Walton, H., et al., Understanding the health impacts of air pollution in London. London: Kings College London, Transport for London and the Greater London Authority, 2015.

4. DEFRA. Air Quality: Economic Analysis. 2013; Available from: https://www.gov.uk/guidance/air-quality-economic-analysis (accessed 1 June 2017)

5. DEFRA. National Atmospheric Emissions Inventory. Overview of air pollutants. Web source. Available at: http://naei.defra.gov.uk/overview/ap-overview (accessed 1 June 2017)

6. Burns, J., et al., Interventions to reduce ambient particulate matter air pollution and their effect on health. The Cochrane Library, 2014.

7. Rich, D.Q., Accountability studies of air pollution and health effects: lessons learned and recommendations for future natural experiment opportunities. Environment International, 2017.

8. Kelly, F., et al., The impact of the congestion charging scheme on air quality in London. Part 1. Emissions modeling and analysis of air pollution measurements. Research Report (Health Effects Institute), 2011(155): p. 5-71.

9. Greater London Authority, Cleaner Air for London: Progress report on the delivery of the Mayor's Air Quality Strategy 2015. Available at: https://www.london.gov.uk/sites/default/files/maqs_2015_progress_report_final_for_publication.pdf. (accessed 1 June 2017)

10. Greater London Authority, Cleaner Air for London: Progress report on the delivery of the Mayor's Air Quality Strategy 2013. Available at: http://www.london.gov.uk/sites/default/files/MAQS%20Progress%20Report%20-%20July%202013.pdf. (accessed 1 June 2017)

11. Greater London Authority, London Atmospheric Emissions Inventory (LAEI) 2013. 2016: London.

12. Westminster City Council, Westminster City Plan Consolidated with all changes since November 2013. 2016.

13. Westminster City Council, Air Quality Action Plan 2013-2018.

14. Westminster City Council, Air Quality Annual Status Report for 2015 (2016).

15. Royal Borough of Kensington and Chelsea, RBKC Air Quality and Climate Change Action Plan 2016-2021 (2016)

16. Royal Borough of Kensington and Chelsea, The Royal Borough Environmental Project Update Report 2015/16.

17. London Borough of Camden, Camden's Clean Air Action Plan 2016-2018.

18. City of London Corporation, City of London Air Quality Strategy 2015-2020.

19. Mapping for Change, Monitoring air quality in the Barbican. 2015.

20. City of London Corporation. Taxis. Available from: https://www.cityoflondon.gov.uk/services/transport-and-streets/parking/where-to-park/Pages/taxis.aspx. (accessed 1 June 2017)

21. Kelly, F.J., Oxidative stress: its role in air pollution and adverse health effects. Occupational and environmental medicine, 2003. 60(8): p. 612-616.

22. Buckley, S.M. and M.J. Mitchell, Improvements in urban air quality: Case studies from New York state, USA. Water, Air, and Soil Pollution, 2011. 214(1-4): p. 93-106.

23. Butler, T.J., G.E. Likens, and B.J.B. Stunder, Regional-scale impacts of Phase I of the Clean Air Act Amendments in the USA: The relation between emissions and concentrations, both wet and dry. Atmospheric Environment, 2001. 35(6): p. 1015-1028.

24. Charles-Guzman, K., Air Pollution Control Strategies in New York City: A Case Study of the Role of Environmental Monitoring, Data Analysis, and Stakeholder Networks in Comprehensive Government Policy Development, in School of Natural Resources and Environment 2012, University of Michigan.

25. The City of New York, OneNYC Progress Report 2016. 2016: New York.

26. Slovic, A.D., Air pollution policies from an urban-oriented perspective: comparing implemented strategies to control vehicular emissions and mobility in São Paulo, New York City and Paris. 2016.

27. The City of New York, PlaNYC Progress Report 2014. 2014: New York.

28. Hinsdale, J. By the Numbers: Air Quality in New York City. 2016; Available from: http://blogs.ei.columbia.edu/2016/06/06/air-quality-pollution-new-york-city/. (accessed 1 June 2017)

29. Su, J.G., et al., Identification of Effects of Regulatory Actions on Air Quality in Goods Movement Corridors in California. Environmental Science and Technology, 2016. 50(16): p. 8687-8696.

30. Bay Area Air Quality Management District. History of the Air District. Available from: http://www.baaqmd.gov/about-the-air-district/history-of-air-district (accessed 1 June 2017)

31. Parrish, D.D., et al., Air quality progress in North American megacities: A review. Atmospheric Environment, 2011. 45(39): p. 7015-7025.

32. Cox, P., et al., The California almanac of emissions and air quality. California Air Resources Board, Sacramento, CA, 2013. 30.

33. Bay Area Air Quality Management District, Bay Area Air Quality Management District Annual Report. 2015: San Francisco.

34. Bay Area Air Quality Management District, Bay Area Air Quality Management District Annual Report. 2010: San Francisco.

35. Bay Area Air Quality Management District, Bay Area Air Quality Management District Annual Report. 2014: San Francisco.

36. Bay Area Air Quality Management District, Bay Area Air Quality Management District Annual Report. 2011: San Francisco.

37. Bay Area Air Quality Management District, Bay Area Air Quality Management District Annual Report. 2012: San Francisco.

38. Bay Area Air Quality Management District, Bay Area Air Quality Management District Annual Report. 2013: San Francisco.

39. Bay Area Air Quality Management District, Improving Air Quality & Health in Bay Area Communities. 2014: San Francisco.

40. Parrish, D.D., et al., Air quality improvement in Los Angeles—perspectives for developing cities. Frontiers of Environmental Science and Engineering, 2016. 10(5).

41. Jensen, S.S., et al., Source Contribution to harmful air pollution in Copenhagen. 2013, DCE –Nationalt Center for Miljø og Energi, 85 s.: Copenhagen.

42. Danish Ecological Council, Clean Air Copenhagen - Air quality challenges and solutions. 2014.

43. City of Copenhagen, The City of Copenhagen's Bicycle Strategy 2011-2025. 2011: Copenhagen.

44. Cycling Embassy of Denmark. Bicyle Account from Copenhagen. 2015; Available from: http://www.cycling-embassy.dk/2015/05/06/new-bicycle-account-from-copenhagen/. (accessed 1 June 2017)

45. The Danish Ecological Council, Clean Air Copenhagen – Air quality challenges and solutions. 2014: Copenhagen.

46. Municipality of Copenhagen, CPH 2025 Climate Plan. 2012, Copenhagen Municipality: Copenhagen, Denmark.: Copenhagen.

47. Lee, J.S.H., et al., Toward clearer skies: Challenges in regulating transboundary haze in Southeast Asia. Environmental Science and Policy, 2016. 55: p. 87-95.

48. Tan, Y.S., T.J. Lee, and K. Tan, Clean, Green and Blue: Singapore's Journey Towards Environmental and Water Sustainability. 2009: Institute of Southeast Asian Studies. 442.

49. Heng, L.L., Transport-based air pollution management: The Singapore experience. Asia Pacific Journal of Environmental Law, 2001. 6(3-4): p. 333-348.

50. National Environment Agency, Annual Report 2010/2011. 2011: Singapore.

51. National Environment Agency, Annual Report 2015/16. 2016: Singapore.

52. National Environment Agency, Annual Report 2011/2012. 2012: Singapore.

53. National Environment Agency, Annual Report 2012/13. 2013: Singapore.

54. National Environment Agency, Annual Report 2014/2015. 2015: Singapore.

55. National Environment Agency Annual Report 2009/10. 2010: Singapore.

56. National Environment Agency, Annual Report 2013/2014. 2014: Singapore.

57. Soot Free Cities. Soot Free Cities: Paris. Available from: http://sootfreecities.eu/city/paris.

58. Willsher, K., Paris emergency measures to combat smog hailed as a success, in The Guardian. 2015.

59. Forster, K., Paris bans cars with even plates in third day of transport restrictions to ease air pollution, in The Independent. 2016.

60. Soot Free Cities, Soot Free Cities, Guidelines: Cargo Bikes. 2015: Copenhagen.

61. The City of New York, PlaNYC Progress Report 2011: New York.

62. The City of New York. PARK Smart. Available from: http://www.nyc.gov/html/dot/html/motorist/parksmart.shtml. (accessed 1 June 2017)

63. Bay Area Air Quality Management District, Clean Air Plan - Volume 2. 2010: San Francisco.

64. City of Los Angeles, pLAn Transforming Los Angeles. 2015.

65. City of Los Angeles, Sustainable City pLAn: First Annual Report 2015-16. 2016: Los Angeles.

66. City of Los Angeles Department of Transport, Great Streets for Los Angeles: Strategic Plan. Los Angeles.

67. Chin, A.T.H., Sustainable urban transportation: abatement and control of traffic congestion and vehicular emissions from land transportation in Singapore. Environmental Economics and Policy Studies, 2000. 3(4): p. 355-380.

68. Ang, B.W. and K.C. Tan, Why Singapore's land transportation energy consumption is relatively low. Natural Resources Forum, 2001. 25(2): p. 135-146.

69. San Francisco Department of the Environment, Annual Report. 2012: San Francisco.

70. San Francisco Department of the Environment, Annual Report. 2014: San Francisco.

71. San Francisco Department of the Environment, Annual Report. 2013: San Francisco.

72. Christopher E. Cobey, A.S.J., San Francisco Bay Area Employers Must Comply with Commuter Benefits Program by September 30, 2014. 2014.

73. Toor, A., Paris imagines a world without cars. The Verge, 2015.

74. Toor, A., Older cars will be banned from Paris as of July. The Verge, 2016.

75. O'Sullivan, F., Paris Aims to End Its Pollution Misery by Cutting Out Cars. CityLab.

76. Whitlow, T.H., et al., Impact of local traffic exclusion on near-road air quality: Findings from the New York City "summer Streets" campaign. Environmental Pollution, 2011. 159(8-9): p. 2016-2027.

77. Shu, S., et al., Air quality impacts of a CicLAvia event in Downtown Los Angeles, CA. Environmental Pollution, 2016. 208: p. 170-175.

78. Quiros, D.C., et al., Air quality impacts of a scheduled 36-h closure of a major highway. Atmospheric Environment, 2013. 67: p. 404-414.

79. Hong, A., et al., Impact of temporary freeway closure on regional air quality: A lesson from Carmageddon in Los Angeles, United States. Environmental Science and Technology, 2015. 49(5): p. 3211-3218.

80. City of Copenhagen, Copenhagen: Solutions for Sustainable Cities. 2014: Copenhagen.

81. Andersen, A.V. Copenhagen No. 2 in Europe for Air Quality 2015 14/12/16]; Available from: https://stateofgreen.com/en/news/copenhagen-no-2-in-europe-for-air-quality. (accessed 1 June 2017)

82. Gössling, S., Urban transport transitions: Copenhagen, city of cyclists. Journal of Transport Geography, 2013. 33: p. 196-206.

83. Yuan, L.L., A Case Study on Urban Transportation Development and Management in Singapore in National University of Singapore / Habitat II Global Workshop. 1997.

84. Cutter, W.B. and M. Neidell, Voluntary information programs and environmental regulation: Evidence from 'Spare the Air'. Journal of Environmental Economics and Management, 2009. 58(3): p. 253-265.

85. Lee, G., et al., Assessing air quality and health benefits of the Clean Truck Program in the Alameda corridor, CA. Transportation Research Part A: Policy and Practice, 2012. 46(8): p. 1177-1193.

86. Bishop, G.A., et al., Emission changes resulting from the san Pedro bay, California ports truck retirement program. Environmental Science and Technology, 2012. 46(1): p. 551-558.

87. Wåhlin, P., et al., Pronounced decrease of ambient particle number emissions from diesel traffic in Denmark after reduction of the sulphur content in diesel fuel. Atmospheric Environment, 2001. 35(21): p. 3549-3552.

88. Wåhlin, P., Measured reduction of kerbside ultrafine particle number concentrations in Copenhagen. Atmospheric Environment, 2009. 43(22-23): p. 3645-3647.

89. The City of New York, PlaNYC Progress Report 2013. 2013: New York.

90. Diabartolomeo, L. A Seat at the Table: How Academics Can Help Inform Policy Decisions When Their Work is Timely and They Engage Stakeholders Involved in the Policymaking Process. 2014; Available from: http://marroninstitute.nyu.edu/uploads/content/A_Seat_at_the_Table_-_Version_3.pdf.

91. International Gas Union, Case Studies in Improving Urban Air Quality. 2015, International Gas Union.

92. City of New York. New York City Trends in Air Pollution and its Health Consequences. 2013; Available from: https://www1.nyc.gov/assets/doh/downloads/pdf/environmental/air-quality-report-2013.pdf.

93. Kheirbek, I., et al., The public health benefits of reducing fine particulate matter through conversion to cleaner heating fuels in New York city. Environmental Science and Technology, 2014. 48(23): p. 13573-13582.

94. The City of New York, The Process Behind PlaNYC. 2010: New York.

95. Morani, A., et al., How to select the best tree planting locations to enhance air pollution removal in the MillionTreesNYC initiative. Environmental Pollution, 2011. 159(5): p. 1040-1047.

96. Tong, Z., et al., Quantifying the effect of vegetation on near-road air quality using brief campaigns. Environmental Pollution, 2015. 201: p. 141-149.

97. Gilmore, E.A., et al., The air quality and human health effects of integrating utility-scale batteries into the New York State electricity grid. Journal of Power Sources, 2010. 195(8): p. 2405-2413.

98. Danish Energy Agency, Ministry of Housing, and Urban and Rural Affairs, Low Carbon & New Energy Cities in Denmark. 2014: Copenhagen.

99. Build Up: The European Portal for Energy Efficiency in Buildings. Green Lighthouse: Denmark's first public carbon-neutral building. 2015; Available from: http://www.buildup.eu/en/practices/cases/green-lighthouse-denmarks-first-public-carbon-neutral-building (accessed 1 June 2017)

100. Nyuk Hien, W., T. Puay Yok, and C. Yu, Study of thermal performance of extensive rooftop greenery systems in the tropical climate. Building and Environment, 2007. 42(1): p. 25-54.

101. Wong, N.H., et al., Life cycle cost analysis of rooftop gardens in Singapore. Building and Environment, 2003. 38(3): p. 499-509.

102. Ommen, T., W.B. Markussen, and B. Elmegaard, Lowering district heating temperatures - Impact to system performance in current and future Danish energy scenarios. Energy, 2016. 94: p. 273-291.

103. Gilbraith, N. and S.E. Powers, Residential demand response reduces air pollutant emissions on peak electricity demand days in New York City. Energy Policy, 2013. 59: p. 459-469.

104. Van Erp, A.M., et al., Progress in research to assess the effectiveness of air quality interventions towards improving public health. Air Quality, Atmosphere & Health, 2012. 5(2): p. 217-230.

105. Group, H.A.W., Assessing health impacts of air quality regulations: concepts and methods for accountability research. Health Effects Institute, Boston, 2003.

106. Godin, K., Stapleton, J., Kirkpatrick, S.I., Hanning, R.M. and Leatherdale, S.T, Applying systematic review search methods to the grey literature: a case study examining guidelines for school-based breakfast programs in Canada. Systematic Reviews, 2015. 4(1): p. 1.

107. Ballini, F. and R. Bozzo, Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology. Research in Transportation Business and Management, 2015. 17: p. 92-98.

108. Soot Free Cities. Copenhagen 14/12/16]; Available from: http://www.sootfreecities.eu/city/copenhagen. (accessed 1 June 2017)

109. Floater G. et al, Copenhagen Green Economy Leader Report. 2014, LSE.

110. Dowling, S. Five of the most radical car-free city experiments. 2014; Available from: http://www.bbc.com/future/story/20140318-five-car-free-city-experiments. (accessed 1 June 2017)

111. Soot Free Cities. Guideline: Sustainable Parking Management. Available from: http://www.sootfreecities.eu/download/best-practice/parking-management.pdf. (accessed 1 June 2017)

112. City of Los Angeles Department of Public Works, Making Air Quality Progress via Alternative Fuel Vehicles and Fuel Economy Programs. 2011.

113. South Coast Air Quality Management, D., Clean Fuels Program 2012 Annual Report and 2013 Plan Update. 2013.

114. Technology Advancement Office, Clean Fuels Program 2010 Annual Report and 2011 Plan Update, L. Angeles, Editor. 2011.

115. Technology Advancement Office, Clean Fuels Program 2011 Annual Report and 2012 Plan Update. 2012: Los Angeles.

116. South Coast Air Quality Management, D., Final Program Environmental Impact Report for the 2012 Air Quality Management Plan. 2012.

117. Tingey, D.T., et al., Stricter ozone ambient air quality standard has beneficial effect on ponderosa pine in California. Environmental Management, 2004. 34(3): p. 397-405.

118. Cheung, K., et al., Spatial and temporal variation of chemical composition and mass closure of ambient coarse particulate matter (PM10-2.5) in the Los Angeles area. Atmospheric Environment, 2011. 45(16): p. 2651-2662.

119. Winner, D.A. and G.R. Cass, Effect of emissions control on the long-term frequency distribution of regional ozone concentrations. Environmental Science and Technology, 2000. 34(12): p. 2612-2617.

120. Hasheminassab, S., et al., Long-term source apportionment of ambient fine particulate matter (PM 2.5) in the Los Angeles Basin: A focus on emissions reduction from vehicular sources. Environmental Pollution, 2014. 193: p. 54-64.

121. Harrison, D., Ex post evaluation of the RECLAIM emissions trading programmes for the Los Angeles air basin, in Tradeable Permits: Policy Evaluation, Design And Reform. 2004. p. 45-69.

122. Giuliano, G. and T. O'Brien, Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach. Transportation Research Part D: Transport and Environment, 2007. 12(7): p. 460-473.

123. Lee, E.S., C.C.D. Fung, and Y. Zhu, Evaluation of a high efficiency cabin air (HECA) filtration system for reducing particulate pollutants inside school buses. Environmental Science and Technology, 2015. 49(6): p. 3358-3365.

124. Sathaye, N., R. Harley, and S. Madanat, Unintended environmental impacts of nighttime freight logistics activities. Transportation Research Part A: Policy and Practice, 2010. 44(8): p. 642-659.

125. McPherson, E.G., et al., Million trees Los Angeles canopy cover and benefit assessment. Landscape and Urban Planning, 2011. 99(1): p. 40-50.

126. The City of New York, PlaNYC Progress Report 2012. 2012: New York.

127. Environmental Defense Fund. Clean heat for New York City. Available from: https://www.edf.org/clean-heat-new-york-city. (accessed 1 June 2017)

128. Christian, R. Three reasons New York made environmental history in 2013. 2014; Available from: https://www.edf.org/blog/2014/01/21/three-reasons-new-york-made-environmental-history-2013. (accessed 1 June 2017)

129. Aleksic, N., J.Y. Ku, and L. Sedefian, Effects of the NOx SIP Call program on ozone levels in New York. Journal of the Air and Waste Management Association, 2013. 63(11): p. 1335-1342.

130. Kado, N.Y., et al., Emissions of toxic pollutants from compressed natural gas and low sulfur diesel-fueled heavy-duty transit buses tested over multiple driving cycles. Environmental Science and Technology, 2005. 39(19): p. 7638-7649.

131. Lee, D.Y., V.M. Thomas, and M.A. Brown, Electric urban delivery trucks: Energy use, greenhouse gas emissions, and cost-effectiveness. Environmental Science and Technology, 2013. 47(14): p. 8022-8030.

132. Lin, S., et al., Impact of NO x emissions reduction policy on hospitalizations for respiratory disease in New York State. Journal of Exposure Science and Environmental Epidemiology, 2013. 23(1): p. 73-80.

133. Ngo, N.S., Analyzing the Relationship Between Bus Pollution Policies and Morbidity Using a Quasi-Experiment. Medicine, 2015. 94(37): p. e1499.

134. Roustan, Y., M. Pausader, and C. Seigneur, Estimating the effect of on-road vehicle emission controls on future air quality in Paris, France. Atmospheric Environment, 2011. 45(37): p. 6828-6836.

135. Jan, C., Mayor of Paris to battle traffic and air pollution (France) | Eltis.

136. Farrell, A.E., J.J. Corbett, and J.J. Winebrake, Controlling air pollution from passenger ferries: Cost-effectiveness of seven technological options. Journal of the Air and Waste Management Association, 2002. 52(12): p. 1399-1410.

137. Tao, L., et al., Effects of switching to lower sulfur marine fuel oil on air quality in the San Francisco Bay area. Environmental Science and Technology, 2013. 47(18): p. 10171-10178.

138. Weinzimmer, D., et al., Evaluation of the safe routes to transit program in California, in Transportation Research Record. 2015. p. 92-100.

139. Cho, H., et al., Evaluation of CCHP systems performance based on operational cost, primary energy consumption, and carbon dioxide emission by utilizing an optimal operation scheme. Applied Energy, 2009. 86(12): p. 2540-2549.

140. Bhatia, R., Case study: San Francisco's use of neighborhood indicators to encourage healthy urban development. Health Affairs, 2014. 33(11): p. 1914-1922.

141. Kua, H.W., Attributional and consequential life cycle inventory assessment of recycling copper slag as building material in Singapore. Transactions of the Institute of Measurement and Control, 2013. 35(4): p. 510-520.

142. National Environment Agency, Factsheet on More Measures to Improve Singapore's Air Quality. 2015: Singapore.

Annex A: Literature search method for international city comparison

Search methods

This project included a brief review of academic and grey literature, involving the following steps:

1. Academic literature was identified through a search of Scopus, a database of peer-reviewed literature from the fields of science, technology, medicine and the social sciences, among others[e]. The search was restricted to the title, abstract and keyword of studies published from the year 2000 onwards and used the following search terms:

   (Air W/2(pollut* OR quality OR ambient)) OR ((atmospher* W/2 pollut*)) OR ((particulate matter OR ambient particulate OR PM* OR ultrafine particulate OR ultrafine particle)) OR ((coarse particle* OR soot OR black smoke OR black carbon OR elemental carbon OR wood smoke)) OR ((nitrogen dioxide OR nitrogen oxide* OR NO2 OR NOX))

   AND

   (control* OR regulation* OR policy OR policies OR strategy OR strategies OR intervention* OR guideline OR act OR directive OR ban OR bans OR clean* OR low* OR congestion* OR efficien* OR zone)

   AND

   City name (Singapore/Copenhagen/New York/Paris/Los Angeles/San Francisco)

   The choice of search terms was informed by correspondence with Jacob Burns, lead author on the Cochrane Review *Interventions to reduce ambient particulate matter air pollution and their effect on health* (forthcoming).[6] The first group of search terms was intended to capture the problem, the second group the intervention and the third group the city in which the intervention had been proposed or implemented. No search terms were added to capture the outcomes of the intervention so as not to restrict the range of outcomes identified (we considered effects on emissions, air quality and health outcomes to all be relevant) and so as not to exclude interventions that had not been evaluated at the time of searching.

2. Grey literature was identified using a method adapted from Godin et al.[106], and made use of three different searching strategies. First a search was done of the Opengrey.eu database using the search string outlined above. Next, searches using the Google search engine were conducted using the terms: "policy AND City name AND 'air pollution'" and the first 100 results were checked for each city. Finally searches in Google were used to identify relevant websites which were hand searched for relevant documents.

3. In addition, we used keyword searches in Google to search for further information about a particular intervention or idea that required further information.

A total of 103 studies were included in our analysis (see Figure 5). Given that these studies include grey literature such as City Council reports for cities, each annual report was counted as a separate

[e] Overview of Scopus literature coverage: https://www.elsevier.com/solutions/scopus

reference. Many of these reports and academic articles refer to the same initiatives, so the number of articles does not reflect the number of initiatives.

For the academic literature search (point 1 above), we used the following inclusion/exclusion criteria to determine which of the papers identified in our search were eligible for review:

- Primary (empirical) research studies published in English were considered eligible for review, while editorials, opinion or descriptive pieces, commentaries and news articles were excluded.
- Studies looking at policies/regulations/interventions and reporting outcomes including emissions of air pollutants, air quality and energy consumption were all considered eligible for inclusion. It was assumed that in reducing energy consumption, emissions of air pollutants generated by energy production would also be reduced.
- Health outcomes were also considered to be of interest when it could be demonstrated that the health effect resulted from a change in air quality and that this change in air quality was brought about by an intervention.
- Interventions or initiatives were only included if they addressed ambient (outdoor) air pollution, as this was the focus of this study. For example, interventions to mitigate indoor exposure to air pollutants via air filtration were excluded.

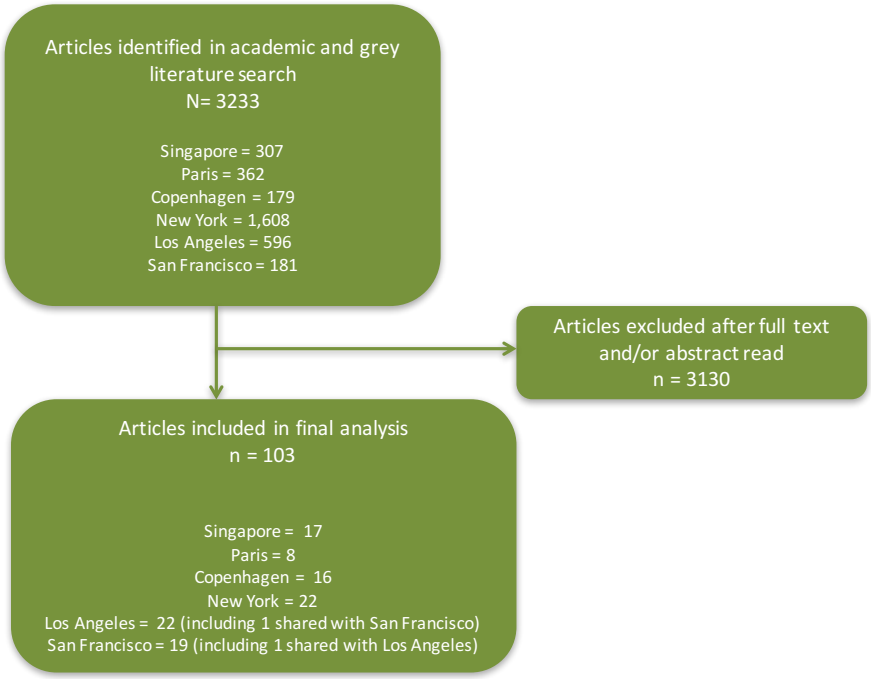

Figure 5 Steps in identifying selected articles for international city comparison

Annex B: Details of initiatives from international comparison cities

Table 4 Initiatives in Copenhagen

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Cold ironing technology for ships in port [46, 107]	A technology that allows ships at berth to use shore power rather than rely on electricity generated by their auxiliary engines. In the 2025 Climate Plan, the City committed to improving the infrastructure for supplying the cruise liners with onshore electricity.	Power & energy production	lower emissions (n/a)	Piloting/testing/New technology
Initiatives to increase cycling [43, 46, 80, 82]	Investment in cycling infrastructure on roads, eg filling in gaps in the network, green cycle routes, cycle superhighways, widening bike lanes, multiple bike lanes (all forming part of the cycling 'Plusnet') lowering curbs, footrests at traffic lights, skewed rubbish bins, changing layout of cycle tracks, bridges and tunnels for cyclists, 200-400 new small short-cuts for cyclists, cycle lanes that run right up to intersections with pulled back stop lines for cars.	Transport	User convenience	Infrastructure investment
	'Green wave' system on designated routes co-ordinates the traffic lights to minimise stoppages for cyclists travelling at 20km/h.	Transport	User convenience	Piloting/testing/New technology
	Bike butlers at five metro stations that lubricate chains, pump up tires (ran for a limited period of time, no longer maintained).	Transport	User convenience	Infrastructure investment
	Options to take bikes on board s-trains (free of charge), local and regional trains, InterCity trains, harbour buses and the Metro (outside of rush hours only).	Transport	User convenience	Infrastructure investment
	LED sensors that warn lorry drivers of approaching cyclists at high-risk intersections (experimental).	Transport	User convenience	Piloting/testing/New technology

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
	Reducing car parking spaces within the city by small % every year to discourage car use.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
	Norms for bicycle parking: commercial developments should have 0.5 bicycle parking spaces per employee, residential developments should have 2.5 bicycle parking spaces per 100 m^2.	Transport	User convenience	Regulation/legislative enforcement
	Campaigns to create the perception that cycling is fun, faster, comfortable and safe, and associated with personal and societal benefits.	Transport	User convenience	Education/engagement
	'Tip us off' website for cyclists to alert the city about potholes.	Transport	User convenience	Piloting/testing/New technology
	LED lights in tarmac to indicate which mode of transport has priority and when, enabling the flexible sharing of road space.	Transport	User convenience	Infrastructure investment
	Intelligent bike share scheme making it possible for passengers of public transport to transfer onto a bike to complete their journey.	Transport	User convenience	Infrastructure investment
	Development of new products such as valet parking for cyclists and treatments for cobblestones to make them easier to cycle on.	Transport	User convenience	Infrastructure investment
	Plans to collaborate with 300-600 businesses in Copenhagen on pilot loan scheme for electric bicycles.	Transport	User convenience	Partnership/collaboration
	Information about the fastest cycle routes via signage and GPS.	Transport	User convenience	Piloting/testing/New technology

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
	Partnerships with workplaces and educational institutions regarding bicycle facilities and information. Better facilities for city employees, such as parking, changing rooms and bike repair.	Transport	User convenience	Partnership/collaboration
Investment to integrate the bus, train and metro systems to make public transport more attractive: [80, 81]	Physical and online integration between bus, train and metro to enable passengers to move easily between different modes.	Transport	User convenience	Infrastructure investment
	Bike parking facilities in each metro and train station.	Transport	User convenience	Infrastructure investment
	Real time bus information.	Transport	User convenience	Piloting/testing/New technology
	Text ticketing, allows passengers to text where they're going and receive a text message as a ticket.	Transport	User convenience	Piloting/testing/New technology
	Currently, Copenhagen is investing in a new metro city ring scheduled to be finished in 2018, with a total of 17 stations in the city centre.	Transport	User convenience	Infrastructure investment
Lowering district heating temperatures [102]	Reducing the temperature to which water is heated in district heating systems	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Policy changes in 1999 [87] and 2005[88] to reduce the sulphur content in fuel.	In July 1999 the sulphur content in diesel fuel was reduced from approximately 500 ppm to slightly less than 50 ppm. At New Year 2005 a new reduction of the sulphur content in diesel fuel from approximately 30–50 ppm to less than 10 ppm (6–7 ppm). The sulphur content in petrol was reduced at the same time from up to 150 ppm to less than 10 ppm	Transport	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Encouraging fuel-efficient driving [46]	Plans by the City to arrange courses to inform drivers of how correct driving will save up to 10% of fuel consumption.	Transport	lower emissions (n/a)	Education/engagement
Retrofitting existing buildings [46, 80]	Goal in the 2025 Climate Plan to increase the rate of retrofitting by 0.5 percentage point per annum such that 33% of the housing stock and 46% of commercial properties will be retrofitted in the period up to 2025.[2]	Power & energy production	lower emissions (n/a)	Infrastructure investment
	The City itself plans to lead the way by carrying out 'lighthouse projects', constructing energy-efficient buildings and to retrofitting existing ones.	Power & energy production	Leading by example	Infrastructure investment
Low energy new building regulations [46, 80, 98]	The energy performance of new buildings is regulated by the Danish building code which has been gradually tightened since 1961. The most recent stipulates that by 2020 new buildings must be 'nearly zero' with energy needs covered primarily by renewables or district heating.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Initiatives to improve energy efficiency[46]	Plans to provide businesses with information on how to identify, finance and implement cost-effective energy savings.	Power & energy production	lower emissions (n/a)	Education/engagement
	Plans to monitor energy usage in City of Copenhagen buildings via remote meter reading.	Power & energy production	Leading by example	Piloting/testing/New technology
Decarbonisation of the district heating grid (combined heat and power generation). [46, 80, 98]	2025 Carbon Plan commits to making the district heating supply carbon-neutral by 2025 by basing it on biomass, waste and geothermal energy.	Power & energy production	Leading by example	Infrastructure investment
District cooling networks[98]	Low-carbon cooling from seawater abstraction: District Cooling is the centralised production and distribution of chilled water – partly cooled with cold	Power & energy production	lower emissions (n/a)	Piloting/testing/New technology

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
	seawater. It is distributed via underground insulated pipelines to commercial and industrial buildings to cool the indoor air.			
Support by the City for wind power [80]	Building of 20 wind turbines in Copenhagen habour, with the creation of a co-operative to own 10 (community ownership of facilities)	Power & energy production	Leading by example	Partnership/collaboration
	The city-owned utility company has plans to build 100 new turbines by 2025.	Power & energy production	Leading by example	Infrastructure investment
	Tours of windfarms to help convince members of the community that they do not have a significant effect on noise levels.	Power & energy production	lower emissions (n/a)	Education/engagement
Support by the City for solar power[46]	The City will install 30,000 sqm of solar cells on new build and existing buildings, respectively –60,000 sqm in total.	Power & energy production	Leading by example	Infrastructure investment
Conversion of the City's fleet of cars to electric or hydrogen power [46]	With a goal that 100% of passenger cars will be electric or hydrogen by 2025	Transport	Leading by example	Infrastructure investment
Use of bicycles by the city administration[60]	Copenhagen uses bikes for street cleaning, leaf and garbage removal as well as for park maintenance. The city administration has 20 bikes.	Transport	Leading by example	Education/engagement
Encourage the use of electric and hydrogen	Plans to install more charging stands and hydrogen filling stations.	Transport	User convenience	Infrastructure investment

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
cars by citizens [46]	Plans for schemes that allow the public and businesses to test electric cars, car-club schemes and hydrogen-electric cars.	Transport	User convenience	Piloting/testing/New technology
Strategic urban planning to reduce car use: [80]	Regulations allow for higher densities of buildings close to stations and ensure that large offices can only be located within 500 metres of a station.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
	The growth of Copenhagen has been set along five designated 'fingers', following train and major road routes, with open space in between.	Transport	lower emissions (n/a)	Infrastructure investment
Buses powered by electricity or biofuels [46]	The city is conducting operational trials with the public transport agency to experiment with electricity and biofuel buses. All external suppliers will be required to use electricity, hydrogen or biofuels when driving for the City of Copenhagen.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Replacement of fluorescent lamps and sodium fittings. [46]	The City Administration has planned to replace the remaining 20,000 fluorescent lamps and sodium fittings over a 3-4 year period.	Power & energy production	Leading by example	Infrastructure investment
Low emissions zone [45]	Copenhagen has had an LEZ for heavy goods vehicles since 2008. Since 2010, all vehicles heavier than 3.5t (buses and lorries) have been required to comply with at least the Euro IV standards or to be equipped with a certified particulate filter. The zone covers almost the whole city area. The city would like to impose a stricter LEZ but this is not possible for vans or personal cars unless the national government changes the law.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Particle filters are required on contractors'	Eg contractors involved in the construction of the new metro station.	Transport	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
non-road mobile machines [108]	The City of Copenhagen has introduced emissions standards into its contracts with public transport bus operators [109]	Transport	lower emissions (n/a)	Regulation/legislative enforcement
High taxes on motoring (national as opposed to city-level policy) [45, 110]	Sales tax of 180% on new cars	Transport	lower emissions (n/a)	Financial: Tax/Charging
	The Danish registration tax and the annual green car owner's tax are differentiated according to fuel consumption to encourage the purchase of smaller, more fuel-efficient cars.	Transport	lower emissions (n/a)	Financial: Tax/Charging
	In 2010 a tax of 130 euros was levied on vans and diesel cars without particulate filters, but no requirement that this be the more effective closed filter.	Transport	lower emissions (n/a)	Financial: Tax/Charging
Restrictions on parking for cars: [111]	Parking charges have been raised on average 50% since Copenhagen's 2005 parking strategy.	Transport	lower emissions (n/a)	Financial: Tax/Charging
	Regulations on the use of catalytic converters in vehicle exhaust systems [109]	Transport	lower emissions (n/a)	Regulation/legislative enforcement
De-nitrifying units in heat and electricity plants [109]	Regulation on the use of de-nitrifying units in heat and electricity plants [109]	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement

Table 5 Initiatives in Los Angeles

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Support by the City for Solar Power [64, 65]	Expanding local solar development programs including a feed-in-tariff program which allows developers and property owners to harness underutilized rooftop space to generate solar energy and then sell at a profit back into the grid.	Power & energy production	lower emissions (n/a)	Financial: Incentive
	Streamlining the permit process for Solar Photo Voltaic systems for small residential rooftop systems by utilizing the California Solar Permitting Guidebook vetted by an expert taskforce	Power & energy production	User convenience	Infrastructure investment
	Enhancing energy storage by piloting technology for energy storage, and streamlining permitting and interconnection process for residential energy storage projects	Power & energy production	lower emissions (n/a)	Piloting/testing/New technology
	Developing grid-tied backup solar allowing excess solar power to be fed back into the grid.	Power & energy production	lower emissions (n/a)	Infrastructure investment
	Lead by example with solar installations of new and existing City Projects E.g. installing a solar installation on the LA Convention Center roof, and creating minimum photovoltaic solar installation requirement for City built projects.	Power & energy production	lower emissions (n/a)	Infrastructure investment
Expanding and improving public transport infrastructure with $40 billion investment [64, 66]	Expanding bike infrastructure and car sharing, improving bicycle access across the transit system, e.g. equipping buses with bike racks.	Transport	User convenience	Infrastructure investment

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Expansion of Dynamically Priced Parking [64-66]	Including 'LA Express Park' – close to 20% of streets are part of LA express park. Implemented in 2012, the program uses in ground sensors to notify drivers in real time where parking is available and adjusts parking prices based on demand, rates increase when parking demand is high and decrease when demand is low.	Transport	User convenience	Piloting/testing/New technology
A package of policies to covert local goods movement to zero emissions[64]	Including supporting technology development and supporting the gasification and electrification of heavy duty rail.	Transport	lower emissions (n/a)	Infrastructure investment
Developing infrastructure for Electric vehicles[64, 66]	Including developing more EV charging stations on public property and streamlining the permit process for charging stations in homes.	Transport	User convenience	Infrastructure investment
Green the city fleet to reduce fuel [64-66, 112]	Purchasing electric vehicles for the city fleet	Transport	Leading by example	Infrastructure investment
	Piloting an EV program for the LAPD	Transport	Leading by example	Piloting/testing/New technology
	installing GPS telematics in street sweepers to increase efficiency	Transport	Leading by example	Piloting/testing/New technology
	a carshare and vanpool rideshare programme for city employees	Transport	Leading by example	Partnership/collaboration

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Better Buildings Challenge [65]	Allows business owners to access financial incentives to improve the energy and water efficiency of their properties.	Buildings	lower emissions (n/a)	Financial: Incentive
Green Janitor Education Program [65]	A collaboration between the City and the building owners and managers association of LA to provide energy efficiency training to building janitors.	Buildings	lower emissions (n/a)	Education/engagement
Go LA App [65]	A route mapping app that allows residents to filter transportation choice by prices, speed, and environmental impact	Transport	User convenience	Piloting/testing/New technology
	Grants to provide EV car sharing services to low income residents [65]	Transport	lower emissions (n/a)	Financial: Incentive
	LAX converting ground equipment to EV [65]. Over 500 AFVs currently operate at LAZ, the majority are natural gas and electric powered. This has been achieved using funding from state and local government	Transport	lower emissions (n/a)	Infrastructure investment
Clean Fuels Program [113-115]	The vehicle via which the South Coast Air Quality Management District funds the development, demonstration and accelerated deployment of clean technologies e.g. EV technologies, emission control technologies etc	Transport	lower emissions (n/a)	Infrastructure investment
Clean vehicle rebate program [116]	Incentives for the purchase of low emission vehicles. Accelerating retirement of older vehicles via financial incentives	Transport	lower emissions (n/a)	Financial: Incentive
Air quality standards and emissions controls [40, 117-120]	The 1970 Clean Air Act led to the establishment of National Ambient Air Quality Standards, which it is the responsibility of states to achieve. Emissions standards exist for specific pollutants and for specific sources, e.g. vehicles.	Multiple sources (or unspecified)	Leading by example	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Road closure programmes [77]	CicLAvia is LA's open streets event. At each event, tens of kilometres of streets in LA are closed to motorized vehicles. There were two CicLAvia events in 2014, four in 2015, eight scheduled for 2016, with an aspiration to host monthly CicLAvias by 2017	Transport	lower emissions (n/a)	Regulation/legislative enforcement
The Regional Clean Air Incentives Market (RECLAIM) [121]	A cap-and-trade scheme for major stationary source emitters of nitrogen oxides and sulphur dioxide implemented in 1994. The caps were gradually reduced until 2003.	Power & energy production	lower emissions (n/a)	Financial: Incentive
The forced retirement of older diesel trucks [29, 85, 86]	The Clean Trucks Program progressively banned the oldest and most polluting drayage trucks from serving the San Pedro Bay Port	Transport	lower emissions (n/a)	Regulation/legislative enforcement
	The Clean Trucks Program put in place a funding mechanism to help truck owners replace older trucks with new, lower-emission vehicles.	Transport	lower emissions (n/a)	Financial: Incentive
Legislation to reduce idling by freight trucks at ports.[122]	The California Assembly Bill (AB) 2650 was introduced in 2003 and levied a penalty of $250 on marine terminal operators for each truck idling more than 30 min while waiting to enter the terminal gate	Transport	lower emissions (n/a)	Financial: Tax/Charging
	Legislation to reduce trains idling at ports has also been implemented [29]	Transport	lower emissions (n/a)	Regulation/legislative enforcement
	Filtration systems to reduce school bus passengers' exposure to particulate matter [123]	Transport	lower emissions (n/a)	Piloting/testing/New technology
Shifting freight traffic from daytime tonight to	As implemented by the PierPASS program for ports of Los Angeles and Long Beach.	Transport	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
reduce congestion and emissions[124]				
The Million Trees programme [125]	A plan to plant an additional one million trees in Los Angeles.	Multiple sources (or unspecified)	Leading by example	Infrastructure investment

Table 6 Initiatives in New York

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
'The Greener Greater Buildings Plan' (GGBP) [27, 89, 126]	A set of laws enacted in 2009 that require energy efficiency upgrades and energy transparency in the largest existing buildings. Specifically, the GGBP requires annual benchmarking, energy audits, retro-commissioning, lighting upgrades, and sub-metering of commercial tenant space.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
'Amalgamated Green' [61]	A program bringing together a group of 30 stakeholders including unions, the Real Estate Board of New York and City University of New York to decide on training needs and create bespoke training resources for each GGBP law. This training is being delivered by relevant stakeholders to building owners and managers.	Power & energy production	lower emissions (n/a)	Education/engagement
Sulphur and Boiler Replacement Legislation [24, 61, 89, 91, 93, 126]	Legislation to reduce the sulphur content in heating oil and to mandate that all buildings phase out heavily polluting oil by 2015, and switch to a clean oil by 2030.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
'NYC Clean Heat' Campaign and its successor, 'NYC Retrofit Accelerator' [24, 89, 126-128]	Schemes to support the voluntary early adoption of cleaner fuels by providing technical and financial assistance to building owners. $100 million in financing was made available from the City and leading banks to support this.	Power & energy production	lower emissions (n/a)	Financial: Incentive
'Community Retrofit NYC [25]	A free program to assist owners of small and mid-sized multi-family buildings to implement efficient upgrades by connecting with finance programmess and technical advice.	Power & energy production	lower emissions (n/a)	Financial: Incentive

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Solar Property Tax Abatement [27, 89]	A measure to help eligible owners offset the costs of their photovoltaic and green-roof installations.	Power & energy production	lower emissions (n/a)	Financial: Incentive
'Green Light New York' energy efficiency education centre [27, 89]	A building which holds training class on energy efficiency for building professionals.	Power & energy production	lower emissions (n/a)	Education/engagement
NYC Carbon Challenge [25, 27, 61, 89]	A challenge first issued by the mayor in 2007 to the city's largest universities and hospitals to match the City's goal of reducing carbon emissions by 30% in 10 years. It has since been extended to cover hotels, multi-family buildings. Institutions that sign up create GHG inventories and action plans and meet regularly to share information.	Power & energy production	Leading by example	Education/engagement
Govt 30x17 commitment [27, 61, 89]	The City of New York has committed to reducing municipal GHG emissions by 30% by 2017 (compared to 2006 levels). This involves committing 10% of the municipality's annual energy budget to projects to reduce energy use and promote renewables, including via retrofitting buildings, investing in cleaner energy generation and providing financial rewards for agencies with the largest reductions in energy bills.	Power & energy production	Leading by example	Infrastructure investment
New York City Energy Efficiency Corporation [27, 89]	A not-for-profit corporation set up to provide finance for energy efficiency and clean energy projects.	Power & energy production	Leading by example	Financial: Incentive
Million Tree Initiative [61, 89, 94, 95]	A public-private initiative to plant and maintain one million new trees across NYC to reclaim underused parks and space. 730,000 trees had been planted as of 2013. Areas with fewer trees and high levels of child asthma are being prioritised in the planting.	Power & energy production	Leading by example	Infrastructure investment

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Passive Building Design [25]	An approach to house building that can significantly reduce energy consumption and improve air quality. Passive building design standards include a high level of insulation and design features to moderate heat gain. The standards are being trialled in new city funded buildings.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Enterprise Green Communities Guidelines [61]	A set of guidelines for ensuring that affordable housing is environmentally-friendly, minimising construction waste and water consumption and promoting energy efficiency. The City is requiring major publically-financed construction projects to comply with these standards.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Green Physical Needs Assessments [25]	All rehabilitation work carried out by the city must undergo an energy and water audit with finance offered to cover the incremental costs of efficiency measures.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Cleaning up the City of New York Department of Sanitation (DSNY) Fleet [27]	This involved installing particulate filters on collection trucks and replacing older, more heavily polluting models with new, cleaner models.	Transport	lower emissions (n/a)	Infrastructure investment
The Hunts Point Clean Truck Program [25]	Grants to replace, retrofit or retire heavily-polluting diesel trucks.	Transport	lower emissions (n/a)	Financial: Incentive
Legislation on commercial waste truck emissions standards [128]	Legislation to hold commercial trucks to the same diesel standards as NYC's own trucks.	Transport	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
The Department of Sanitation's Solid Waste Management Plan [25]	The plan proposes to shift waste management operations from trucks to barge and rail transport.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
NYC Clean Fleet [25]	A plan to add 2000 electric vehicles to the City's fleet.	Transport	Leading by example	Infrastructure investment
Chargers for new spaces [25]	Legislation requires that 20% of new off-street parking spaces are built charger-ready to accommodate electric cars and chargers in the future.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Expanding bike infrastructure [25, 26, 61, 89]	The City has now installed over 1,000 miles of city bike lanes, 40% of which are protected from traffic, 140 'Citibike' bike sharing stations and 2,000 bikes.	Transport	user convenience	Infrastructure investment
Urban Plazas [61, 89]	The City has created new temporary and permanent pedestrian plazas for public recreation.	Transport	user convenience	Infrastructure investment
The Citywide Private Fleet Alternative Fuel Programs [89]	The program offers rebates up to 80% of the increased cost of choosing an electric or alternative fuel over a conventional one.	Transport	lower emissions (n/a)	Financial: Incentive
Funding for private and non-profit companies to move to	Working in partnership with New York State, NYC is providing funding to help private sector companies and non-profits retrofit their vehicles or switch to alternative fuels.	Transport	lower emissions (n/a)	Financial: Incentive

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
cleaner vehicles [61]				
Measures to promote carsharing [61]	Zoning amendments have been introduced to facilitate the expansion of car sharing by enabling shared vehicles to be stationed in off street parking lots and garages.	Transport	user convenience	Infrastructure investment
Measures to promote carsharing [4]	The introduction of carsharing to the City's fleet of 26,000 vehicles and a pilot scheme to replace 50 City vehicles with ZipCars (a private car sharing company).	Transport	user convenience	Infrastructure investment
ParkSmart programme [61, 62]	A parking meter system that charges more for parking at peak times to encourage cars only to park for as long as they need. It is intended that this will increase vehicle turnover and reduce congestion caused by cruising for parking spaces.	Transport	lower emissions (n/a)	Financial: Tax/Charging
Ticketing for idlers [61]	Legislation has been enacted to enable traffic wardens to issue tickets for idling violations (there is a law limiting idling to 3 minutes in New York City).	Transport	lower emissions (n/a)	Financial: Tax/Charging
Retrofitting city ferries and boats [61, 89]	Using upgrades and energy retrofits to make the Staten island ferry less polluting	Transport	Leading by example	Infrastructure investment
GreeNYC Anti-idling campaign [61]	GreeNYC is the city's branded public education program. The 'Turn it Off' Campaign uses advertising to communicate the financial, environmental, legal and health costs of idling to drivers.	Transport	lower emissions (n/a)	Education/engagement
The NO_x State Implementation Plan [129]	Legislation setting NO_x budgets for 22 states to reduce summer ozone concentrations. New York State regulations became operational in 2003.	Multiple sources (or unspecified)	Leading by example	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Demand response energy tariffs [103]	Residential energy tariffs that charge more for energy on peak demand days, when more polluting forms of energy generation such as small combustion turbines are used.	Power & energy production	lower emissions (n/a)	Financial: Tax/Charging
Using batteries in the New York State grid to meet peak energy demand [97]	Batteries can charge at off-peak times, using cleaner energy generation, and discharge at peak times, replacing dirtier generators installed to meet peak demand.	Power & energy production	lower emissions (n/a)	Piloting/testing/New technology
Switching from diesel to electric delivery trucks [130]	To reduce energy consumption and greenhouse gas emissions.	Transport	lower emissions (n/a)	Piloting/testing/New technology
Switching from diesel to compressed natural gas (CNG) or low-suphur diesel as a fuel for buses [131]		Transport	lower emissions (n/a)	Piloting/testing/New technology
The NO_x Budget Trading Program [132]	A regional pollution control programme implemented by the U.S. Environment Protection Agency.	Multiple sources (or unspecified)	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Emissions standards for transit buses [133]	Emissions standards for transit buses were first implemented in 1988 by the Environmental Protection Agency (EPA) and have been continually updated since.	Multiple sources (or unspecified)	Leading by example	Regulation/legislative enforcement
The Summer Streets campaign [76]	This campaign involves the closure of Park Avenue in New York to traffic for three consecutive Saturdays.	Transport	Leading by example	Regulation/legislative enforcement

Table 7 Initiatives in Paris

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Initiatives to tackle diesel vehicles [134]	The introduction of diesel particle filters	Transport	lower emissions (n/a)	Piloting/testing/New technology
	A tax on diesel to encourage the purchase of new gasoline (petrol) vehicles	Transport	lower emissions (n/a)	Financial: Tax/Charging
	An incentive to accelerate the renewal of vehicle fleets	Transport	lower emissions (n/a)	Financial: Incentive
Low Emission Zone [57]	Since February 2015 there has been a LEZ covering the whole city inside the orbital road. Since July 2015 lorries and buses must meet at least Euro I emissions standards. From January 2016 all vehicles must be Euro I and between 2017 and 2020, Euro II, III and IV and will be phased out. There will be a complete ban on diesel cars by 2020	Transport	lower emissions (n/a)	Regulation/legislative enforcement
A Clean Municipal Fleet [57]	A city fleet of electric cars, car sharing for municipal employees. By 2020 the city aims to have a municipal fleet that is completely electric or hybrid	Transport	Leading by example	Infrastructure investment
Clean buses [57]	100% Euro VI buses by 2025, 80% electric and 20% powered by biogas	Transport	Leading by example	Infrastructure investment
Parking Management Scheme [57]	Continuous reduction of parking spaces due to installing sharing spaces and free parking for electric vehicles and charging during the night from 2015	Transport	user convenience	Infrastructure investment
	Heavier motorway tolls for polluting vehicles	Transport	lower emissions (n/a)	Financial: Tax/Charging

	Autolib electric car sharing scheme operated by town councils in and around Paris	Transport	user convenience	Infrastructure investment
Investment in Public transport [57]	1,100 million euros to be invested between 2015 and 2020	Transport	lower emissions (n/a)	Infrastructure investment
	Velib bike sharing scheme	Transport	user convenience	Infrastructure investment
Speed reduction [135]	On the city motorway from 80 to 70km/h and on the main roads to 30km/h[135]	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Road control measures [75]	Ensuring the more polluted road closed to all but electric and hybrid vehicles by 2020, first four arrondissements barred to all but resident's vehicles[75]	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Investment in cycling infrastructure	Doubling the number of cycle lanes by 2020, investing in an electric bikeshare scheme[75]	Transport	user convenience	Infrastructure investment
No Car days [73, 74]	All private non-electric cars banned from the city center for 7 hours	Transport	lower emissions (n/a)	Regulation/legislative enforcement
	Cars banned from the Champs-Élysées on the first Sunday of every month[74]	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Emergency measures allowing only half of vehicles on the road and offering free public transport on	This has been used as an ad-hoc measure to respond to severe air pollution in Paris. When pollution reaches a certain concentration cars are banned from circulation depending on whether their license plates end in odd or even numbers Public transport and residential parking are offered free when the measures are in place and the speed limit is reduced to 20kph. Hybrid or electric vehicles and those carrying three people or more are also permitted to use the roads, and there are fines for non-compliance.	Transport	lower emissions (n/a)	Regulation/legislative enforcement

highly polluted days. [58, 59]				
Bans on wood fires [75]	As of January 2015, wood fires have been banned in Paris. Prior to this, they were responsible for 23% of the city's particulate pollution	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Bans on older cars in the city centre on weekdays [74]	All cars registered before 1997 (and motorbikes registered before 1999) were subject to the ban as of July 2016, and in 2020 it will be extended to cover all cars registered before 2010. There are fines for those who violate the rules.	Transport	lower emissions (n/a)	Regulation/legislative enforcement

Table 8 Initiatives in San Francisco

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
'Spare the Air' (STA) [34, 36, 84]	A programme in which public announcements are made to citizens/residents to ask them to reduce car use on days when ground-level ozone is predicted to exceed National Ambient Air Quality Standards.	Transport	lower emissions (n/a)	Education/engagement
Retrofit or repowering technologies to reduce emissions from passenger ferries[136]	Technologies evaluated include compressed natural gas engines, catalyst filters, selective catalytic reduction and repowering via installation of Tier 2 engines.	Transport	lower emissions (n/a)	Piloting/testing/New technology
The Emissions Reduction Plan for Ports and Goods Movement [29, 33-39, 63]	An action plan introduced by the California Air Resources Board in 2006 to reduce emissions. The plan included bringing in newer, cleaner engines for trucks, retrofitting, requiring ships to use shore-based electrical power and enforcing idling limits for trucks and trains.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Emissions control area along the California coast and in ports [137]	Required ships to switch from heavy fuel oil to low-sulphur fuels.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
The 'Safe Routes to Transit' programme [63, 70, 71, 138]	Funding for a range of infrastructure investments to encourage walking, cycling and the use of public transport. Measures include: kerb extensions, traffic calming, next bus displays, light rail station improvements, pedestrian bridges, bicycle lanes, electronic bicycle lockers, electronic bicycle sharing schemes, parking removal and lane width reduction, intersection improvements, on/off ramp improvements, crosswalk restriping.	Transport	lower emissions (n/a)	Infrastructure investment

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Combined cooling, heating and power (CCHP) systems [139]	CCHP systems generate electrical power while recovering waste heat for heating and cooling. They therefore have the potential to reduce carbon and air pollutant emissions.	Power & energy production	lower emissions (n/a)	Piloting/testing/New technology
The use of neighbourhood indicators of air pollution to inform planning decisions [140]	The City of San Francisco introduced a set of neighbourhood indicators in 2007, one of which is the % of the population living in areas where the concentration of PM2.5 is greater than 10 micrograms per cubic meter.	Multiple sources (or unspecified)	lower emissions (n/a)	Regulation/legislative enforcement
Public Participation Program [34, 36, 37, 39]	100 air district outreach programmes work with engage community members and other stakeholders in air quality programmes. E.g. share and receive information on studies and pending regulations	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
Land Use Policies to support mixed-use high density infill development near transit corridors [39, 63]		Transport	lower emissions (n/a)	Regulation/legislative enforcement
Compliance and Enforcement [34, 36, 39]	A well trained staff of inspectors conduct inspections of air pollution sources, verify compliance etc and conduct projects such as inspections of diesel trucks at ports	Multiple sources (or unspecified)	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Regulation on wood burning devices [39]	A rule which prevents use of wood-burning devices when air quality is forecast to be unhealthy	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Statewide legislation on drayage trucks [39]	Required that they retrofit or be replaced to meet 2007 emission standards by 2014, combined with financial incentives	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Carl Moyer Program [33-39]	A state funded incentive program to reduce emissions from heavy duty engines, provides grants for installing cleaner engines or emission control devices on heavy equipment	Transport	lower emissions (n/a)	Financial: Incentive
Transportation for Clean Air Fund [33-39]	A $4 surcharge on all motor vehicles registered in the bay area is collected and used for a transportation fund for clean air. Distributed to programs to reduce motor vehicle emissions, trip reduction (e.g. bike sharing), alternative fuel an infrastructure projects.	Transport	lower emissions (n/a)	Financial: Incentive
Mobile Source Incentive Fund [33-39]	A $2 surcharge on vehicle registrations used to fund the purchase of clean air school buses, accelerated vehicle repair or retirement program and projects to reduce emissions from agricultural sources	Transport	lower emissions (n/a)	Financial: Incentive
Lower Emission School Bus Program [33-39]	Provides financial incentives to school districts to replace or retrofit older diesel fueled school buses[4, 11]	Transport	lower emissions (n/a)	Financial: Incentive
Zero Emission airport equipment[33]	Grants given to United airlines to fund the replacement of 87 diesel-powered ground support equipment units with zero emission alternatives	Transport	lower emissions (n/a)	Financial: Incentive
Caltrain Electrification project[33]	The electrification of 51 miles of rail line between SF and San Jose	Transport	lower emissions (n/a)	Infrastructure investment

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Clean air vehicle incentives and infrastructure expansion [33, 36, 63]	$14 million in funding for programmes that promote and accelerate plug-in electric vehicle, or PEV, usage e.g. expansion of charging stations at workplaces, multi-unit dwellings, transportation corridors and at key destinations, leasing for government agencies, and incentives for operators of light-duty vehicle fleets and heavy-duty vehicles and buses to purchase clean air vehicles	Transport	lower emissions (n/a)	Infrastructure investment
James Carey Smith Community Grants [33]	$250,000 for community based projects to increase awareness about air quality issues and initiate activities to reduce air pollution	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
Commuter benefits program[35, 38, 69-72]	Offered to employees who work 20 hours a week or more for an employer with 50 or more employees in the bay area to give employees commuter benefits e.g. tax relief on transit or vanpooling expenses, vanpooling subsidies etc	Transport	lower emissions (n/a)	Financial: Incentive
Wayside power grants[38]	A fund to invest in wayside power projects which enable trains to turn off their diesel generators when parked by connected to electric power from the grid.	Transport	lower emissions (n/a)	Infrastructure investment
Vehicle Buy Back Program [33, 35, 38]	Grants for residents with registered and smog-check certified vehicles are eligible for $1000 to retire cars	Transport	lower emissions (n/a)	Financial: Incentive
Green Fleet Plan [69]	To green the air district's own fleet via retrofitting and purchase of fuel efficient/low emission fleet	Transport	Leading by example	Infrastructure investment
Air District Permit Program[34]	Permits must be issued before a stationary equipment that emits to the atmosphere can be built or operated. There is a requirement to use the best available control technology or provide emission offsets	Buildings	lower emissions (n/a)	Regulation/legislative enforcement
Legislation on average NOx emissions allowable from	Plus retrofitting and replacement of large central furnaces and space heaters.	Buildings	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
refineries and residential heaters [63]				
'Green Fleet Certification' [63]	Encouraging public agencies and the private sector to contract with certified green fleets and providing grants to public agencies in greening their fleets.	Transport	lower emissions (n/a)	Infrastructure investment
Bus service improvement [63]	Replacement of old buses, retrofitting, funding hybrid buses and enhancing bus services	Transport	lower emissions (n/a)	Infrastructure investment
Local and regional rail service improvements[63]	Maintain and extending local and regional rail services	Transport	lower emissions (n/a)	Infrastructure investment
Bay area express lane network [63]	Developing a system that offers a seamless carpool and bus lane network free of charge for qualifying vehicles	Transport	user convenience	Infrastructure investment
Support voluntary efforts by Bay area employers to encourage employees to use alternative modes of transport [63, 69, 71]	e.g. via funding of a carpool incentive programs that reward people for choosing less polluting forms of transport for their commute.	Transport	user convenience	Financial: Incentive

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Encourage 'smart' driving[63]	e.g. driving at slower speeds, avoiding quick starts, via a package of measures including coordinating a curriculum with high school driver's ed, promoting a voluntary certification program with fleet operators, varying speed limits on spare the air days etc	Transport	lower emissions (n/a)	Education/engagement
Value Pricing Strategies[63]	Varying road tolls wherein higher prices are set at congested times	Transport	lower emissions (n/a)	Financial: Tax/Charging
Parking policies to reduce motor travel [63]	e.g. SF Park, a variable rate price parking strategy to manage parking spaces determined by location, time of day and time of week	Transport	lower emissions (n/a)	Financial: Incentive
Transportation Pricing Reform[63]	e.g. higher diesel fuel taxes, pay-as-you drive insurance premiums, emission based vehicle registration fees, incentives for purchasing fuel efficient vehicles.	Transport	lower emissions (n/a)	Financial: Incentive
Energy Efficiency Measures[63, 70, 71]	Education and outreach to improve energy efficiency in residential and commercial buildings and industrial facilities, provide technical assistance to local governments to adopt and enforce energy efficiency building codes, including building inspector training, provide information and incentives to increase energy efficiency at schools.	Buildings	lower emissions (n/a)	Education/engagement
	Promote incorporation of renewable energy into new developments and foster innovative renewable energy products via incentives [63]	Buildings	lower emissions (n/a)	Financial: Incentive
Cool roofing and paving to mitigate urban heat island effect[63]	Promote building code requirements for new buildings upgrading for commercial and residential multi-family housing to meet specific "cool roof" standards.	Buildings	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
	Develop and promote adoption of a model zoning ordinance for "cool paving" standards to be met when existing parking lots undergo re-surfacing.	Buildings	lower emissions (n/a)	Regulation/legislative enforcement
	Provide training for public works staff and private construction/paving companies on benefits of and how to meet new cool paving standards	Buildings	lower emissions (n/a)	Education/engagement
Shade Tree Planting [63]	reduce the urban heat island effect by increasing shading through planting of tree and preservation of natural vegetation and cover	Buildings	lower emissions (n/a)	Infrastructure investment
Green Buildings Program [69, 70]	Ensuring that all new buildings and built and operated according to energy efficiency standards with third party verification of building performance.	Buildings	lower emissions (n/a)	Infrastructure investment
Promotion of solar power [38, 69]	Via adoption of best practices for permitting, interconnection and financing, PACE financing and collaborative purchasing with other cities, employee group purchasing programs	Power & energy production	lower emissions (n/a)	Financial: Incentive
Schoolpool program[69, 71]	Free online matching program that helps families find other families to walk, bike, take transit or carpool with to school	Transport	user convenience	Financial: Incentive
	Residential boiler replacement and retrofits[69]	Buildings	lower emissions (n/a)	Infrastructure investment
'What's-your-Watt' Program[69]	Allow residents to check out a watt meter at the library and learn how to reduce energy use at home	Buildings	lower emissions (n/a)	Education/engagement

Table 9 Initiatives in Singapore

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Vehicle quota system[48, 49, 67, 68, 83]	Requires the car owner to purchase a certificate of entitlement before their car is allowed on the road. Fixed number of certificates issued, with the price of the certificates adjusting accordingly via market mechanism. Initially included just cars, now extended to all major types of road vehicle.	Transport	lower emissions (n/a)	Financial: Tax/Charging
Road pricing [48, 49, 67, 68]	Singapore introduced the area licensing scheme (ALS) in 1975 which charged cars with less than four passengers to enter the city centre. This was replaced with the electronic road pricing system (ERP) system in 1998. Under this system an electronic cash card displayed on the car's windscreen is debited when they drive into the charge zone. The amount debited depends on the location and time.	Transport	lower emissions (n/a)	Financial: Tax/Charging
	Replacing Portland cement with copper slag as a greener building material [141]	Construction	lower emissions (n/a)	Piloting/testing/New technology
The Transboundary Haze Pollution Act [47]	Legislation that allows fines to be levied on any companies that contribute to haze in Singapore, irrespective of where in the world they are located. The haze refers to air pollution caused by forest fires lit as part of slash-and-burn agricultural practices.	Multiple sources (or unspecified)	lower emissions (n/a)	Financial: Tax/Charging
Green roofs [100, 101]	Planting greenery on rooftops to address a number of environmental problems, including improving air and water quality and countering the 'heat island' effect.	Power & energy production	Leading by example	Infrastructure investment
Traffic Management Schemes [67]	Including one-way streets, bus lanes, the GLIDE system of traffic controls to minimise the number of traffic stops using automatic sensors embedded in the road and area traffic control.	Transport	lower emissions (n/a)	Infrastructure investment
Vehicle emissions standards [48-52, 67, 142]	Standards have become progressively stricter. New vehicles must currently meet Euro 5 standards and from 2018 must meet Euro 6 emission standards.	Transport	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Control of smoky vehicles [67]	Spot-checks of vehicles and fines for emitting black smoke in excess of 50 HSU.	Transport	lower emissions (n/a)	Financial: Tax/Charging
Fuel quality [48, 49, 51, 53, 67]	Reduction in the sulphur content of fuel and the banning of unleaded petrol	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Statutory vehicle inspection [49, 67]	Compulsory biannual inspection for vehicles in their third year of ownership and older. Includes a carbon monoxide test for petrol vehicles, and smoke and hydrocarbon tests for diesel vehicles.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Road tax that relates to engine size to encourage the purchase of smaller cars [49, 67]	Road taxes also increase at the rate of 10% p.a. when the car is above 10 years old, peaking at 150% when the car is 15 years old.	Transport	lower emissions (n/a)	Financial: Tax/Charging
Preferential additional registration fee [49, 67]	Owners who scrap their car when it reaches 10 years of age receive a discount on the vehicle registration fee for their new vehicle.	Transport	lower emissions (n/a)	Financial: Incentive
'Early Turnover Scheme' [54, 142]	Relaxes requirement to bid for certificate of entitlement for owners of pre Euro and Euro-I diesel cars who scrap their cars.	Transport	lower emissions (n/a)	Financial: Incentive
High levels of duty on new cars [49]	Duty set at 31% of the vehicle's original market value.	Transport	lower emissions (n/a)	Financial: Tax/Charging

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Off-Peak Car Scheme [49]	Discounts on road tax and vehicle registration if car owner only drives on weekends or between the times of 7pm and 7am on weekdays.	Transport	lower emissions (n/a)	Financial: Incentive
	High parking charges Parking is more expensive in the restricted zones of the central business district to discourage commuters from driving into the city. [49]	Transport	lower emissions (n/a)	Financial: Tax/Charging
Code of Practice for Indoor Air Quality [55]	Sets limits on fine particle requirements in buildings	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Energy Efficiency Labelling for electric appliances [53, 55, 56]	Both a voluntary scheme for participating retailers to promote the use of energy efficiency appliances via a three or four tic energy label and a mandatory scheme for all refrigerators and air conditioners, extended to clothes dryers in 2009 and TVs in 2014.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Mandatory Fuel Economy Labelling Scheme [55]	New passenger cars and light goods vehicles must carry a label indicating amount of fuel needed by vehicle to run 100 km.	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Minimum Energy Performance Standards [51, 56]	Stops inefficient home appliances from being sold on the local market. Regularly reviewed and updated in tandem with technology advancements.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Community Engagement to foster a sense of	National Environment Agency launched a music video 'let's make our world the most beautiful home' and 'go green' album.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
environmental ownership [50, 52, 55, 56]	Community Day (held for first time 2010), exhibits and interaction with NEA officers to foster understanding of NEA work and what individuals can do to sustain green environment.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	School's carnival to engage students in environmental activities.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	Youth for the Environment Day - annual platform for Singapore's youth to champion environmental ownership and renew their commitment to care for the environment.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	GreenSchools module developed and schools that demonstrate a sustained commitment to the environment recognised under annual SW Green Schools Awards.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	Eco Friendly awards recognise the efforts and achievements of environmentally proactive individuals.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	Eco music challenge, a competition for young artists to create music that inspires Singaporeans to take care of the environment.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
Fostering and Celebrating good practice in the private sector [50, 52, 55, 56]	Facilitating sharing of good practice via seminars.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	'Green Office' Awards to recognise corporate commitment to the environment.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
	Energy Efficiency Network awards celebrating best practice in energy management.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
	Energy Efficiency National Partnership, and industry outreach program offering training workshops and energy benchmarking studies to industry.	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
Public Engagement Campaigns [50-56]	Including the 10% energy campaign- a public campaign to encourage reducing energy bills by 10% via energy efficiency measures e.g. switching to fluorescent bulbs. Voluntary partnership with retailers to promote energy efficient products. NEA also trains staff to act as volunteer home energy auditors.	Power & energy production	lower emissions (n/a)	Education/engagement
	The Save Energy Save Money Campaign	Power & energy production	lower emissions (n/a)	Education/engagement
	Launched 2016 to encourage households to carry out energy saving measures, posters and banners displayed in public online and resource guide distributed.	Power & energy production	lower emissions (n/a)	Education/engagement
	'Reduce@North West' energy audit educational programme and challenge trains Student volunteers to educate residents in energy efficiency.	Power & energy production	lower emissions (n/a)	Education/engagement
S.W.I.T.C.H. programme[55]	'Simple Ways I Take to Change My Habit' campaign, trains volunteers to help households reduce energy consumption	Power & energy production	lower emissions (n/a)	Education/engagement
Legislation regulating emission limits from factories [54]	Revised standards set 20 March 2015 on PM, NO_X CO and SO_2	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Code of Practice on Pollution Control, later	Lays out environmental requirements for different types of developments including controls on air pollution.	Construction	lower emissions (n/a)	Regulation/legislative enforcement

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Singapore Standard [48, 51]				
Cap on the sulphur content of fuel oil in industrial estates [48]	Required to use fuel oil containing no more than 1% sulphur.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
Improvement of the Public Transport System [48, 83]	Including full day bus lanes, island wide public bus network, development and extension of Mass Rapid Transit Routes.	Transport	lower emissions (n/a)	Infrastructure investment
Land and Transport Planning to minimise the needs for Travel [83]	e.g concentrating high building density around mass rapid transit stations to encourage commuting via public transport	Transport	lower emissions (n/a)	Regulation/legislative enforcement
Energy Conservation Act [51-54, 56]	Requires energy intensive companies to appoint an energy manager, monitor and report energy use and submit efficiency improvement plants.	Power & energy production	lower emissions (n/a)	Regulation/legislative enforcement
My ENV Smartphone app [52, 54]	Providing key real time environmental information incl. air quality information (pollutant standards index readings).	Multiple sources (or unspecified)	lower emissions (n/a)	Education/engagement
Grant for Energy Efficient Technologies [50, 52, 54, 56] (GREET)	Encourages industrial facilities to invest in energy efficiency by offsetting part of the cost.	Power & energy production	lower emissions (n/a)	Financial: Incentive

Initiative	Details	Source of emission addressed	Aim/intention of initiative	Mechanism
Design for Efficiency (DfE) scheme[54, 56]	Encourages investors in new industrial facilities to integrate energy-efficiency improvements into manufacturing development plans during the early design stages of the project. "The maximum amount of funding is 50% of the qualifying costs or S$600,000, whichever is lower. The qualifying costs would include the design workshop fees comprising: Consultancy fees, comprising manpower and overheads Transportation and accommodation for consultants Venue and other logistical costs for workshop"	Power & energy production	lower emissions (n/a)	Infrastructure investment
Guaranteed Energy Savings Performance Model [51, 56]	Encouraging public sector agencies to adopt the Guaranteed Energy Savings Performance Model when undertaking building retrofits. Under this model an energy audit company is brought in to audit, implement energy efficiency measures and guarantee annual energy savings of retrofitted equipment	Power & energy production	lower emissions (n/a)	Education/engagement

Annex C Further details on current state of air quality and initiatives in Westminster

Ward Level Data for NO_2 and Particulate Matter

Maida Vale is the only ward in Westminster that meets the EU Limit Value of 40 ug/m^3 for NO_2 (Table C1). There is very little variation in the rankings across the three emissions. Bryanston and Dorset Square, Marylebone High Street, West End, St James's and Hyde Park are the worst affected by air pollution overall, falling in the bottom five ranked wards for all three emissions.

Table C1: Ward concentrations for NO_2 PM_{10} and $PM_{2.5}$ in Westminster [11]

Ward	NO_2 (ug m^3) / Rank*	PM_{10} (ug m^3), Rank*	$PM_{2.5}$ (ug m^3), Rank*
Abbey Road	42.0 / 3	26.3 / 3	16.7 / 3
Bayswater	47.4 / 8	27.5 / 8	17.5 / 12
Bryanston and Dorset Square	60.7 / 20	29.7 / 20	18.4 / 17
Church Street	48.8 / 12	27.6 / 12	17.4 / 10
Churchill	48.1 / 10	27.6 / 9	17.4 / 9
Harrow Road	42.7 / 4	26.5 / 4	16.7 / 4
Hyde Park	57.1 / 16	29.0 / 16	18.1 / 16
Knightsbridge and Belgravia	47.6 / 9	27.6 / 10	17.5 / 11
Lancaster Gate	45.4 / 6	27.1 / 6	17.2 / 6
Little Venice	48.2 / 11	27.6 / 11	17.3 / 8
Maida Vale	39.5 / 1	26.0 / 2	16.6 / 2
Marylebone High Street	57.7 / 19	29.5 / 18	18.6 / 18
Queen's Park	40.8 / 2	26.0 / 1	16.4 / 1
Regent's Park	43.1 / 5	26.7 / 5	17.0 / 5
St James's	57.1 / 17	29.4 / 17	18.6 / 19
Tachbrook	48.9 / 13	27.8 / 13	17.5 / 13
Vincent Square	50.7 / 14	28.1 / 14	17.7 / 14
Warwick	52.4 / 15	28.1 / 15	17.7 / 15
West End	57.3 / 18	29.6 / 19	18.8 / 20
Westbourne	47.3 / 7	27.4 / 7	17.3 / 7

* Rankings are based on how a ward's average annual concentration value compares with other wards, where 1 is equal to the highest performing ward and with 20 referring to the ward with the highest levels of pollution. The colour scheme above refers to whether a ward is meeting its emissions value targets, green shows that it is meeting the EU limit values.

Automatic Monitoring Sites

There are five automatic monitoring sites in the City of Westminster that monitor air quality (Table C2).

Table C2: Air Quality Monitoring sites in Westminster [13]

Site Name	Site Type	Pollutants monitored*	Distance to Kerb of nearest road

Marylebone Road	Kerbside	NO_2, PM_{10}, $PM_{2.5}$, SO_2	1.5m
Horseferry Road	Urban Background	NO_2, PM_{10}	N/A
Oxford Street	Kerbside	NO_2, PM_{10}	1m
Victoria Palace Theatre	Urban Background	NO_2	7m
Strand	Roadside	NO_2	2.5m

The following are data collected by these monitoring sites. The automatic monitoring site data follow a similar trend to the rest of Westminster; the EU limit for NO_2 is often exceeded (particularly kerbside sites that are close to road transport) but levels are improving, whilst PM_{10} is generally below the EU Limit Value and looks like it will remain below the limit. In 2015 there were exceedances of the NO_2 annual mean objective and the NO2 1-hour mean objective at Marylebone Road, Oxford Street and Victoria Palace Theatre. There were no exceedances across any of the sites for PM_{10} or $PM_{2.5}$ in 2015.

Automatic Monitoring Sites: NO2 Annual Mean [14]

The results presented have been adjusted for "annualisation" and for distance to a location of relevant public exposure, in accordance with the London Local Air Quality Guidelines.

Table C3. Annual Mean NO_2 Ratified and Bias-adjusted Monitoring Results (µg m^{-3})

Site ID	Site type	Valid data capture for monitoring period % [a]	Valid data capture 2015 % [b]	Annual Mean Concentration (µgm^{-3})						
				2009 [c]	2010 [c]	2011 [c]	2012 [c]	2013 [c]	2014 [c]	2015 [c]
Marylebone Road	Automatic	99	99	107	98	97	94	85	94	88
Horseferry Road	Automatic	96	96	44	49	41	39	45	46	39
Oxford Street	Automatic	89	89	N/A	N/A	N/A	N/A	135	143 (73%) *	135
Victoria Palace Theatre	Automatic	95	95	N/A	N/A	N/A	N/A	N/A	69 (54)**	77 (52)**
Strand	Automatic	>90	60	N/A	N/A	N/A	N/A	N/A	N/A	122 (60%)

Notes: Exceedance of the NO_2 annual mean AQO of 40 µgm^{-3} are shown in **bold**.

[a] data capture for the monitoring period, in cases where monitoring was only carried out for part of the year

[b] data capture for the full calendar year (e.g. if monitoring was carried out for six months the maximum data capture for the full calendar year would be 50%)

[c] Means should be "annualised" in accordance with LLAQM Technical Guidance, if valid data capture is less than 75%

*Annual data capture 73%. Not annualised as reduced data capture due to intermittent maintenance issues.

** Monitoring site not representative of public exposure, concentration estimated using procedure specified in LLAQM.TG(16). Measured concentration shown in brackets.

Automatic Monitoring Sites: NO2 one hour mean [14]

Table C4. NO_2 Automatic Monitor Results: Comparison with 1-hour Mean Objective

Site ID	Valid data capture for monitoring period % [a]	Valid data capture 2015 % [b]	Number of Hourly Means > 200 μgm^{-3}						
			2009[c]	2010 [c]	2011[c]	2012 [c]	2013[c]	2014 [c]	2015 [c]
Marylebone Road	99	99	469	524	217	122	59	60	56
Horseferry Road	96	96	0	3	0	0	0	0	0
Oxford Street	89	89	N/A	N/A	N/A	N/A	1502	1532 (73%)*	1391
Victoria Palace Theatre	95	95	N/A	N/A	N/A	N/A	N/A	3**	0**
Strand	>90	60	N/A	N/A	N/A	N/A	N/A	N/A	284 (60%)

Notes: Exceedance of the NO_2 short term AQO of 200 μgm^{-3} over the permitted 18 days per year are shown in **bold**.

[a] data capture for the monitoring period, in cases where monitoring was only carried out for part of the year

[b] data capture for the full calendar year (e.g. if monitoring was carried out for six months the maximum data capture for the full calendar year would be 50%)

[c] Means should be "annualised" in accordance with LLAQM Technical Guidance, if valid data capture is less than 75%

*Annual data capture 73%. Not annualised as reduced data capture due to intermittent maintenance issues.

** Monitoring site not representative of public exposure.

Automatic Monitoring Sites: PM_{10} Annual Mean [14]

Table C5 Annual Mean PM_{10} Automatic Monitoring Results ($\mu g\ m^{-3}$)

Site ID	Valid data capture for monitoring period % [a]	Valid data capture 2015 % [b]	Annual Mean Concentration (μgm^{-3})						
			2009[c]	2010 [c]	2011[c]	2012 [c]	2013[c]	2014 [c]	2015 [c]
Marylebone Road	96	96	36	35	41	38	33	31	30
Marylebone Road FDMS	97	97	37	32	38	31	29	26	24
Horseferry Road	92	92	N/A	21 (56%)*	19	18	N/A	19	17

Notes: Exceedance of the PM_{10} annual mean AQO of 40 μgm^{-3} are shown in **bold**.
[a] data capture for the monitoring period, in cases where monitoring was only carried out for part of the year
[b] data capture for the full calendar year (e.g. if monitoring was carried out for six months the maximum data capture for the full calendar year would be 50%)

[c] Means should be "annualised" in accordance with LLAQM Technical Guidance, if valid data capture is less than 75%

*Annual data capture 56%. Not annualised as reduce data capture due to intermittent maintenance issues.

Automatic Monitoring Sites: PM_{10} 24 Hour Mean [14]

Table C6: PM_{10} Automatic Monitor Results: Comparison with 24-Hour Mean Objective

Site ID	Valid data capture for monitoring period % [a]	Valid data capture 2015 % [b]	Number of Daily Means > 50 μgm^{-3}						
			2009[c]	2010 [c]	2011[c]	2012 [c]	2013[c]	2014 [c]	2015 [c]
Marylebone Road	96	96	36	43	73	48	29	22	13
Marylebone Road FDMS	97	97	43	23	57	23	21	14	10
Horseferry Road	92	92	0	1 (56%)*	8	10	N/A	8	3

Notes: Exceedance of the PM_{10} short term AQO of 50 $\mu g\ m^{-3}$ over the permitted 35 days per year or where the 90.4th percentile exceeds 50 $\mu g\ m^{-3}$ are shown in **bold**. Where the period of valid data is less than 90% of a full year, the 90.4th percentile is shown in brackets after the number of exceedances.
[a] data capture for the monitoring period, in cases where monitoring was only carried out for part of the year

[b] data capture for the full calendar year (e.g. if monitoring was carried out for six months the maximum data capture for the full calendar year would be 50%)

[c] Means should be "annualised" in accordance with LLAQM Technical Guidance, if valid data capture is less than 75%

*Annual data capture 56%. Not annualised as reduced data capture due to intermittent maintenance issues.

Automatic Monitoring Sites: $PM_{2.5}$ Annual Mean [14]

Table C7 Annual Mean $PM_{2.5}$ Automatic Monitoring Results ($\mu g\ m^{-3}$)

Site ID	**Valid data capture for monitoring period %** [a]	**Valid data capture 2015 %** [b]	Annual Mean Concentration (μgm^{-3})						
			2009[c]	2010 [c]	2011[c]	2012 [c]	2013[c]	2014 [c]	2015 [c]
Marylebone Road FDMS	98	98	22	23	25	22	20	18	16

Notes: Exceedance of the $PM_{2.5}$ annual mean AQO of 25 μgm^{-3} are shown in **bold**.
[a] data capture for the monitoring period, in cases where monitoring was only carried out for part of the year
[b] data capture for the full calendar year (e.g. if monitoring was carried out for six months the maximum data capture for the full calendar year would be 50%)

[c] Means should be "annualised" in accordance with LLAQM Technical Guidance, if valid data capture is less than 75%

Policy documents to tackle air quality in London and Westminster

As public awareness and a scientific understanding of the health impacts of poor air quality has grown, so has the number of policies directed towards reducing pollution. Table 3 shows a brief summary of Westminster City Council's recent policy documents, excluding Westminster's Local Plan documents.

Table 10 Policy documents for London and mentions of initiatives that relate to improving air quality

Policy Document	Year	Comments
City Plan*	2016	Policy S31: Air Quality – Reduction in air pollution with the aim of meeting objectives set in the National Strategy. Policy S28: Design – Development must incorporate exemplary standards of sustainable and inclusive design to reduce energy use. Policy S41: Pedestrian Movement and Sustainable Transport – all developments will prioritise pedestrians and support sustainable transport. Policy S42: Servicing and Deliveries – developments must ensure freight, servicing and deliveries are managed in a way that minimises their effects. Policy S43: Major Transport Infrastructure – the council will support and promote improvements to transport infrastructure.
City for All **	2016	Heritage: Greener City Action Plan – an action plan has been introduced to tackle environmental concerns, including air quality. Heritage: Marylebone Low Emission Neighbourhood – plans were put in place to bid for funding from the Mayor of London. This has since been successful. Heritage: Footway and road improvements – spend 7.1m on 85 footway and road improvement schemes. Heritage: Promote environmental awareness in children – attracting over 2,500 participants to educate children about important environmental issues. Heritage: New Code of Construction Practice – introduced to minimise the impact of construction work on residents and the environment. Choice: Childhood Obesity – invest heavily in reducing childhood obesity, promoting physical exercise. Choice: Helping volunteers – help a further 2,000 volunteers by providing activities for residents including planting trees in parks.
Health and Wellbeing Strategy***	2016	Priority 1: Improving outcomes for children and young people Priority 2: Reducing the risk factors for, and improving the management of, long term conditions such as dementia.
Local Implementation Plan****	2011	MTS Goal 5: Reducing transport's contribution to climate change LIP Objective 3: Minimising impact of transport on the environment MTS Goal 1: Supporting economic development and population growth MTS Goal 2: Enhancing the quality of life MTS Goal 4: Improving transport opportunities LIP Objective 1: Supporting economic development and growth (including supporting the uptake of cleaner vehicles) LIP Objective 4: Prioritising pedestrians and effectively managing allocation of highway space LIP Objective 5: Promoting healthier lifestyles and ensuring inclusivity LIP Objective 6: Improving efficiency and attractiveness of sustainable transport LIP Objective 7: Pay for your impact (e.g. securing contributions from section 106 agreements)

* Westminster City Plan, 2016; ** City for All, 2016; *** Health and Wellbeing Strategy, 2016; **** Local Implementation Plan, 2011