Clearing the air:

How to resolve UK breaches of EU air quality laws

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Executive Summary

Samantha Mullender

The passing in 2008 of **Directive 2008/50/EC on ambient air quality and cleaner air for Europe** set in law new rights for residents of EU member states regarding the quality of air that they should expect. In the ensuing seven years however, citizens in many countries could be forgiven for questioning the commitment of policy makers to meeting the new restrictions. Despite progress on many pollutants, the UK in particular is still failing to meet targets on nitrogen dioxide (NO_2) and ozone (O_3), and as a consequence Defra (Department for Food, Environment, and Rural Affairs) has received mandatory orders from the Supreme Court obliging it to produce a new air quality plan by the end of 2015 that will enable the EU targets to be met in all areas of the UK[1]. The consequences of missing these targets however extend well beyond the threat of financial retribution. As this paper will discuss, even marginally higher levels of NO_x (the NO_2 mentioned above and it's precursor NO) and O_3 can have numerous negative consequences, including a diverse array of health implications for those exposed and economic losses arising both from the side-effects associated with this poorer health and wider implications. Lost working days, greater pressure on the health service, reduced crop yields, and eutrophication are all possible outcomes from failure to meet recommended pollutant limits.

The continuing failure of the UK to meet the EU pollutant limits suggests an inadequacy in the existing policy response. This could arise from misdirected policies, focusing on areas of lesser impact; policies of insufficient ambition; or policies that for whatever reason have been ineffective. By considering the actions being implemented elsewhere globally, it is possible to draw inspiration for further policies that the UK could pursue to help it meet the set limits. This paper highlights a number of such schemes, drawing from these and from a wider analysis of the causes and effects of air pollution to set out a number of potential policies that could be pursued to help improve the UK air quality with respect to NO_x.

Transport is identified as a key area of focus. Within this, policies are recommended to reduce vehicle use through the promotion of cycling, and to reduce pollution from the vehicle use that does occur by means of electrification. Although existing policies make movements towards both of these ambitions, evidence suggests that these do not go far enough.

With regards to cycling, there appears to be a need for cycling to be established as a safe and everyday activity. It is proposed that this could be achieved through inclusion of cycling as part of the school national curriculum and as a standard component of the driving test, accompanied by infrastructure changes, including blind spot mirrors, side guards and extended mirrors on heavy goods vehicles, and by a reduction in speed limit to 20mph on roads where cycle lanes merge.

A scheme of retrofit is proposed for the electrification of the public vehicle fleet, a proposal that could be extended to private and commercial vehicles. As a lesser and perhaps intermediary stage, improved regulation, testing and enforcement of emissions limits for individual vehicles is proposed. Schemes and incentives promoting the uptake of electric vehicles, or other greener transport, by the general public are considered, although recognising the constraints imposed by infrastructure – charge points, electricity generation capacity etc. – it is identified that the electrification of the vehicle fleet must be carefully controlled and occur concurrent to infrastructure investments. Finally, electric car banks, mimicking the set-up of the 'Santander Cycles' in London, are put forward as one possible mechanism to take vehicles off the road.

Beyond policies to reduce the amount of pollutants being released into the atmosphere, it is also important to identify ways in which those that are released can be cleaned up. The final policy suggestion tackles this, with ecological solutions being put forwards as an innovative way to both clean the air of our cities and to improve the general ambience. Rather than focus on the current trend towards green roofs, although not denying the benefits of these, it is suggested that far greater air quality benefits are attainable through the construction of urban green walls. This is particularly the case when used in a localised manner to protect specific vulnerable groups.

To tackle the recalcitrant problem of air pollution, strong and directed actions are required. Changing the way in which we view and structure our cities will be critical to see a substantial reduction in concentrations of pollutants, and it will only be through a multi-pronged approach that European limits will be met. Current efforts are insufficient. We feel that this paper identifies several novel, and as yet unexploited, means of reducing air pollution. If pursued, these represent a good first step towards helping the UK meet the EU Directive on **ambient air quality and cleaner air for Europe.**

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1 Introduction

Niruthavignesh Sundararajah

From the pea-soup fogs of the 19th century to the Great Smog of 1952, air pollution has plagued United Kingdom for centuries. While air quality has generally improved in comparison to previous centuries, it remains a pertinent concern today. Unlike in the past, when air pollution stemmed from heavy usage of coal as an industrial and domestic fuel, the current air pollution issue is primarily attributed to the transport sector. The proliferation of vehicles has resulted in an increase in nitrogen oxides and particulate matter in the atmosphere – posing significant health risks to the public. While significant measures have been taken to alleviate this issue, air pollution remains a serious, unresolved problem. The United Kingdom has repeatedly exceeded the legal limits for both nitrogen dioxide and ozone in urban areas imposed by European Union (EU) regulations, with this breach of EU law potentially resulting in costly fines in the coming years. A recent Supreme Court ruling obligates the Department for Environment, Food and Rural Affairs (Defra) to produce an air quality plan by the end of the year that will ensure all areas of the UK meet EU standards on NO_2.

This report suggests policy interventions that aim to help bring air quality in the United Kingdom in line with EU standards for NO_2. We begin by dissecting the causes and larger-scale implications of the urban air pollution problem. We then provide an overview of existing strategies used to tackle the issue. Finally, we present a number of pragmatic, novel and underutilised policy suggestions.

2 Importance of the air pollution problem

David Gregory

The 2008 EU air pollution directive[1] "establishes the need to reduce pollution to levels which minimise harmful effects on human health… and the environment as a whole". The directive sets legally binding limits on the concentration (in outdoor air) of major air pollutants that impact public health.

The directive has set limit values for many pollutants. These are legally binding maximum concentration values that the member states must reach. Both short- and long-timescale limit values are used. Hourly objectives, in which the concentration of the pollutant in the air is averaged over the period of one hour, are used to protect against short episodes of high pollutant concentrations (usually associated with particular weather conditions). Annual objectives, where pollutant concentrations are averaged over the course of a year, are used to protect against chronic, long-term exposure to elevated pollutant values.

The limit values for nitrogen dioxide (NO_2) set out in the 2008 EU directive[1] are as follows:

- Annual limit value - Over a calendar year, the average hourly sample must not exceed 40µg/m^3
- Hourly limit value - over a calendar year the hourly sample must not exceed 200µg/m^3 over 18 times.

Additionally, the directive sets non-legally binding guidelines for other air pollutants for EU member states. These include oxides of nitrogen (NO_x) and ozone (O_3), and are as follows:

Nitrogen oxides (NO_x), primarily NO_2 and NO:

- A critical level of 30 µg/m^3 averaged over all samples in a calendar year. This is the level at which adverse effects may occur to vegetation but not humans based on scientific knowledge.

Ozone (O_3):

- Target values
  - For the protection of human health: A maximum 8 hour mean (a period of 8 consecutive hour samples in a day) in a day of 120µg/m^3, not to be exceeded more than 25 times in a calendar year averaged over 3 years.
  - For the protection of vegetation: A maximum sum of amount of O_3 over 80µg/m^3 in hourly daytime (08:00 - 20:00) samples between May and July of 18,000 µg/m^3, averaged over 5 years.
- Long term objectives, longer term target values to be achieved except where not proportionately feasible.

- For the protection of human health: A maximum 8 hour mean (a period of 8 consecutive hour samples in a day) in a day of 120µg/m^3 in any calendar year
- For the protection of vegetation: A maximum sum of amount of O_3 over 80µg/m^3 in hourly daytime (08:00 - 20:00) samples between May and July of 6,000 µg/m^3.

For the purposes of air quality monitoring, the UK is divided into 43 zones. The main monitoring networks in the UK are the Automatic Urban and Rural Network (AURN), which is funded mainly by the UK government, and the London Air Quality Network (LAQN), which is made up of solely local authority sites.[2] According to the Department of Food, Environment and Rural Affairs[3], as of 2013, the UK was largely compliant with EU directives when it came to short term, high pollution events (hourly limits), but exceeded longer term limits for NO_2 and O_3 in the majority of its zones. However, hourly limit values were also regularly exceeded in Greater London: hourly mean levels of NO_2 on Oxford Street had been breached on 19 occasions in the first 5 days of 2015, despite the National and EU legal obligation that hourly means should not be exceeded on more than 18 occasions in one year.[4]

Specifically, in 2013 UK:

- Met the NO_2 hourly limit value in all but one zone (Greater London)
- Met the NO_2 annual limit value in five zones, and in a further seven zones met the NO_2 annual limit value given a margin of tolerance. The remaining 31 zones had annual NO_2 annual values above the limit value plus margin of tolerance.
- Met the NO_x critical levels in all zones
- Met both O_3 target values for both protection of human health and vegetation in all zones
- Met the O_3 long term objective for human health in ten zones (33 zones exceeding)
- Met the O_3 long term objective for protection of vegetation in 35 zones (five zones exceeding)[2]

Human health effects

Acute exposure to high concentrations of NO_2 (greater than the 200 µg m^3 hourly limit) can cause inflammation of the airways, as well as increasing susceptibility to respiratory infections and allergens.[5]

While it is difficult to isolate the long term health effects of chronic exposure to lower concentrations of NO_2, as it is often emitted from the same sources of and is concurrent with other harmful pollutants, there is evidence that long term exposure to even slightly above ambient concentrations of NO_2 is associated with increased morbidity. For example, studies on animals have indicated that lung lining fluid may be damaged by NO_2 exposure, and human volunteer studies indicate that lung function and airway responsiveness may decrease, while respiratory symptoms and the response of asthmatics to allergens increase.[5]

Clean Air In London[6] have, based on estimates of years of life lost from the health impact assessment for the London Ultra Low Emission Zone[7] and a "universal application of an average loss of life per attributable death of 12 years" from Public Health England[8], calculated yearly mortality from long term exposure to slightly above ambient concentrations of NO_2 in Greater London to be:

- The equivalent of 2,684 deaths in 2020. (Assuming the population will be 9.13 million; and a population-weighted annual mean concentration of NO2 of 31.0 µg/m3)
- The equivalent of 1,893 deaths in 2025. (Assuming the population will be 9.48 million; and a population-weighted annual mean concentration of NO2 of 27.3 µg/m3)

The estimates are based on an assumed threshold for mortality impacts of NO_2 of 20µg/m^3 (half the EU annual limit) and also do not account for the estimated 33% overlap with life years lost due to exposure to fine particulate matter ($PM_{2.5}$)[7]. Accounting for this, calculated yearly mortality from long term exposure to above ambient concentrations of NO_2 and PM2.5 in Greater London would be the equivalent of 6,851 deaths in 2020 and 6,422 deaths in 2025 [6]

Clean Air In London [6] speculates that yearly mortality from combined exposure to NO_2 and fine particulate matter ($PM_{2.5}$) is currently the equivalent of 55,000 deaths in the UK, with 7,500 of these deaths occurring in London.

One issue arising from NO_x (both NO and NO_2) emissions is the formation of secondary pollutants[9]. NO_x can react with other chemicals in the atmosphere to form nitrate, nitrous and nitric acids. These secondary nitrogen-based particles are thought to contribute around 10% of the mass of respirable particulate matter (PM_{10}), although this contribution is likely to account for less than 5% of the detrimental respiratory health effects of PM_{10}.[5]

In the presence of particulate matter and other volatile organic compounds, NO_x can also contribute to the formation of O_3 at ground level. Although O_3 in the upper atmosphere is beneficial to human health, absorbing UV radiation from the sun, O_3 indirectly produced from pollution at ground level can be harmful.[3] Ozone occurs naturally in low concentrations at ground level[10], but exposure to high ambient concentrations, even for short periods, can inflame the respiratory tract and irritate the eyes, nose, and throat. High short term exposure also presents a particular danger for asthmatic individuals, as it may exacerbate their condition or trigger asthma attacks.[3] In addition to this, longer term exposure to lower (but above natural baseline) concentrations of O_3 has recently been found to be associated with increased mortality. In one study in the USA, it was estimated that for every 20µg/m^3 rise in concentration of O_3, the risk of death from respiratory problems increased by 4%.[8] This meant that the risk of dying from a respiratory-related illness was more than three times higher in the metropolitan areas with the highest ozone concentrations as compared to those with the lowest O_3 concentrations.[11]

<u>Ecological effects</u>

The combined direct effects of NO_x and O_3 can lead to loss of yield and quality of crops, as well as to negative impacts on biodiversity and ecosystem services.[3]

High levels of NO_x can be directly toxic to plant growth. Elevated concentrations of the pollutant also lead to a number of detrimental secondary effects. For example, NO_x can combine with water in the atmosphere to produce nitric acid, leading to acid rain. This directly damages crops and acidifies freshwater ecosystems, which can lead to widespread environmental damage. The nitrogen deposited by this acid rain can also cause eutrophication of terrestrial and aquatic ecosystems, a state in which the oversupply of nutrients leads to a loss of biodiversity in the ecosystem.[3]

As stated earlier, NO_x also contributes to the formation of O_3 in the troposphere (the lowest portion of the earth's atmosphere). Ozone, like NO_x, can cause direct damage to plants. Additionally, O_3 in the troposphere acts as a greenhouse gas, and thus contributes to climate change.[3]

Economic effects

The cost of the reduced life expectancy attributed to air pollution in the UK is estimated to be around £16 billion per year.[12] While there are no estimates for other costs to the UK, across Europe it is estimated that 100 million work days are lost each year due to air pollution-related illnesses such as asthma, and direct economic costs of air pollution (including damage to crops and buildings) amount to €23 billion a year.[13]

The 2007 UK air quality strategy[14], which included cost-benefit analyses for a number of UK air pollution control scenarios, did not account for the effects of nitrogen dioxide. A study based on data from Tokyo between 1973 and 1994 estimated the best ratio of health and social benefits to the costs of nitrogen dioxide control policies to be 6:1.[15]

Legal implications

As discussed, the UK is breaching legally binding values for NO_2 set by the EU in 31 of its 43 zones for annual limits and 1 zone for hourly limits.

Although member states were allowed an extra five years from the 2010 deadline to achieve NO_2 values at or below the limits if they could produce plans to achieve this reduction[13], the UK was still unable to meet this deadline, and Defra estimated that 16 zones would still not meet the limit values by 2015, and that some zones may not meet the limit values until 2030.[16]

Following a case brought by the environmental lawyers ClientEarth, judges agreed that the UK was in breach of its legal obligations regarding air pollution, and the EU commission launched legal proceedings against the UK. These proceedings passed through the UK Supreme Court in April 2015, with the verdict compelling Defra to produce a new air quality plan before 31 December 2015.[17]

Need for action

The UK, although largely compliant with EU directives relating to high concentrations of air pollutants for short periods, exceeds EU standards on longer term, low-level pollution, breaching annual limit values for NO_2 and long-term objectives for O_3 in the majority of its zones. Excessive NO_2 and O_3 are clearly harmful to both people and the environment. Additionally, as the full range of the health and environmental impacts of these pollutants remain unclear, it may be best to take a precautionary approach to ensure their atmospheric concentration is minimised. Policies implemented to achieve this would likely have additional favourable impacts by reducing the atmospheric concentrations of other harmful pollutants.

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3 Causes and drivers of air pollution

Oscar McLaughlin

How does it occur?

Nitrogen is an extremely abundant element, accounting for approximately 78% of the earth's atmosphere. Combustion causes a reaction between oxygen and nitrogen particles, which produces mono-nitrogen oxide (NO_x) particles. Nitrogen dioxide (NO_2) and nitric oxide (NO) are the two primary oxides that make up NO_x. NO reacts with ozone (O_3) to produce NO_2, however the ratio of NO to NO_2 varies significantly spatially and temporally, because of factors such as local driving conditions, local sources of biogenic hydrocarbons and chemical process rate which is influenced by parameters such as wind speed, fetch and albedo.[1]

The primary emission source of NO_x in the UK is road transport, followed by the electricity supply industry and then other industrial and commercial sectors (Table 1). However, it is worth noting that there is significant uncertainty in the calculation of emissions as the actual volume is dependent on factors such as the conditions of combustion, in particular temperature, air exposure, and vehicle maintenance and power output.

Sector	% of National NO_x emissions
Transport Sources	45.5
Energy Industries	25.8
Industrial Combustion	17.3
Commercial Combustion	3.4
Residential Combustion	3.3
Other	3.0
Public Sector Combustion	1.0
Industrial Processes	0.6

Table 1. Sources of NO_x emissions in the UK. Data from NAEI, 2012.[2]

How are emissions distributed?

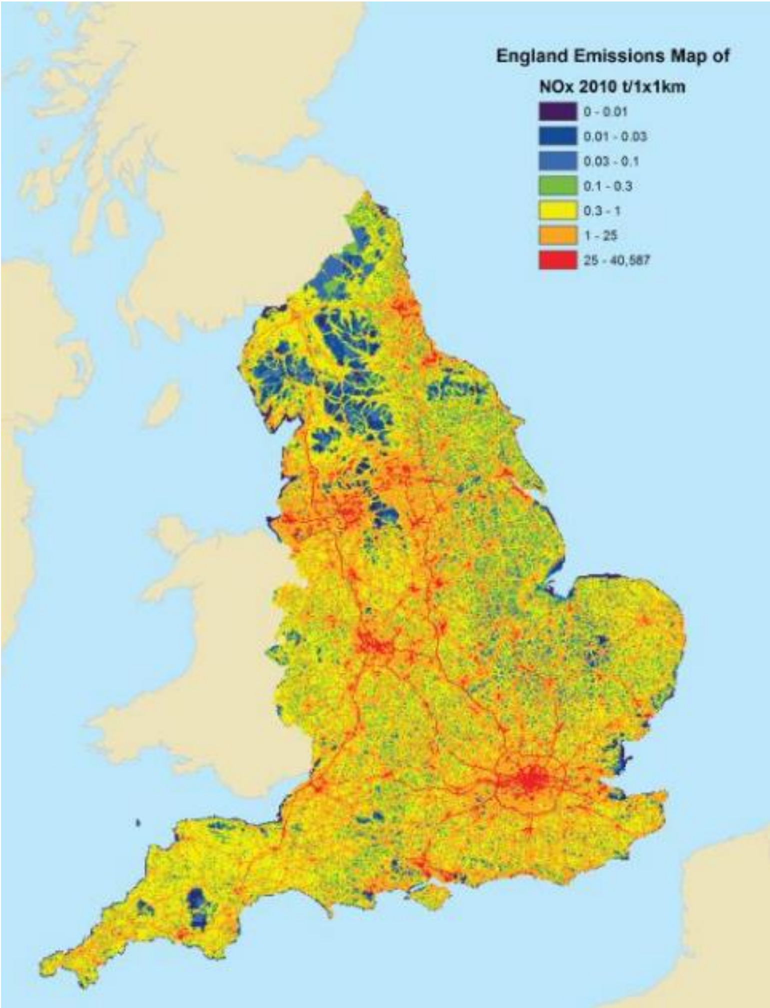

Figure 1. Geographical distribution of NOx emissions in England in 2010. Figure from Thistlethwaite (2013).[2]

Figure 1 shows the geographic distribution of NO_x emissions in the United Kingdom in 2010. Emissions are clearly concentrated in England in urban areas and along major road networks, while the lowest emissions are in rural areas near national parks. Emissions of NO_x were estimated to be 778 kilotonnes in 2011 in England, representing 75% of the UK's total.[2]

What are the emissions trends?

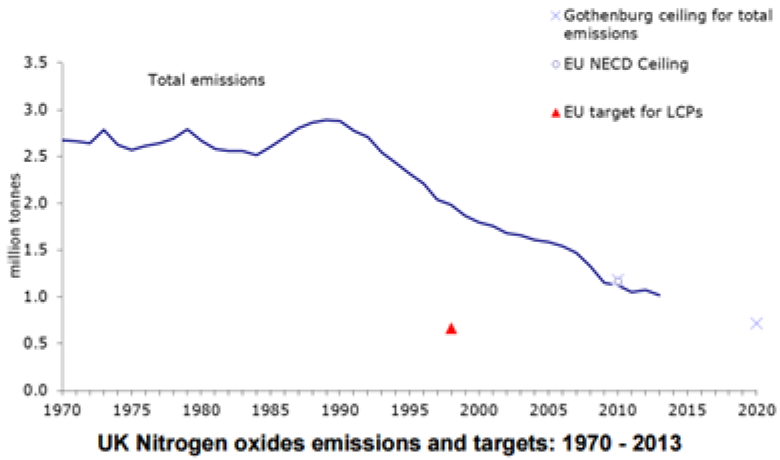

Figure 2. UK NO_x emissions 1970-2013**.** Figure from Defra (2014).[3]

Unlike many other pollutants, such as sulphur dioxide, NO_x concentrations have declined over the past 40 years. Emissions of NO_x have declined nationwide by 66% since 1990, with 36% of the decline stemming from road transport combustion sources and 23% from power generation, however research suggests that NO_2 has not decreased at the same rate NO (Figure 2).[4]

NO_x emissions from electricity generation remained relatively constant from the mid-twentieth century until 1990, as the increased use of gas displaced coal and oil.[4] From 2000 the absolute level of gas used for electricity generation remained constant and since 2006 efficiency and the phasing out of coal has led to a substantial decrease in NO_x emissions.

Road transport is the primary source of NO_x emissions and although emission control strategies for stationary emissions have been introduced, these have been somewhat offset by increasing numbers of road vehicles. That said, technological innovations, such as the first three-way catalytic convertors (TWCs) in petrol cars in 1992 and emission limits for diesel cars and light goods vehicles in 1993, have led to significant decreases in per-vehicle emissions over the past two decades.[4] When considered alongside the increased power output of diesel cars over the past 20 years and the NO/NO_2 ratio, however, there has been some disagreement as to actual emission reductions.

Why the uncertainty?

Recent remote sensing data collected from the roadside has provided a clear indication of discrepancies between currently-used emission testing methodology and actual emissions from vehicles, especially the NO_x emission factors for diesel cars and LGVs for euro 3 vehicles (which entered the fleet in 2000). Remote sensing data also suggests much higher NO_x emission factors for Euro 1 and 2 petrol cars than is currently used by the UK National Atmospheric Emission Inventory (NAEI).[6]

As a result, transport emissions data may not accurately reflect absolute emissions, which in turn may mean that control measures are neither appropriate nor effective. This is primarily due to the standardised method of analysing NO_x emissions from vehicles. The European Commission is currently finalising a proposal to introduce new vehicle emissions testing that reflects real driving; this is further discussed in Section 7.

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4 Existing Policies

Samantha Mullender

Numerous policy strategies have been pursued by governments globally in response to the air pollution problems suffered within their jurisdictions. In the EU, these have largely been driven by the requirements laid down in the Directive 2008/50/EC on ambient air quality and cleaner air for Europe.[1] However, with the exact measures implemented left to the discretion of the respective Member States (MS), a degree of divergence has been seen in the policies implemented and the success of individual MS at reducing air pollution levels. With the UK being one of the worst performing MS[2], it stands to reason that the selection of policy measures currently implemented in the UK have room for improvement. By considering the strategies implemented elsewhere in the world and the successes they have had in these locations, it is possible to gain insight into policy solutions that could be applied in the UK.

Air pollution control policies can be broadly divided into three main areas: cleaner vehicles, energy and industry, and promoting sustainable mobility.[3] The sources of NO_x in a locality will determine which area of policy should be the key focus. Generally speaking, European countries have tended to focus on traffic related measures – 80% of German air pollution policies fall under this category[4], and 60% of those in Prague[5] – but with some studies putting the traffic contribution to NO_2 levels at just 21% in London[6] and a stagnation of NO_x reductions being seen in many MS in recent years, such focus should be viewed with some caution.

<u>Cleaner vehicles</u>

The use of cleaner vehicles can either be promoted or enforced. Enforcement is achieved through legislative means, setting minimum requirements on the vehicles permitted to be sold or driven in certain areas. This is currently implemented in the UK through the London Low Emission Zone. Copenhagen, Berlin and Amsterdam however extend this further, permanently restricting non-EURO standard vehicles or diesel cars without filters from entering into the city.[3] Similarly, enforcement can start at a smaller scale by ensuring that all publicly procured vehicles meet high cleanliness standards. Copenhagen, one of the few European cities to have shown a continuing downward trend in air pollution levels, aims to create a carbon neutral public transport system by 2025 and similarly aims for 85% of municipal passenger cars to be electric or hydrogen powered by the end of 2015.[7]

Caution, however, must be taken surrounding the interactions between various pollutants – PM, NO_x etc. In Delhi in 2006 for example, there was a movement towards Compressed Natural Gas, rather than diesel, as a fuel for buses and rickshaws.[8] Yet studies suggest that although decreasing PM_{10} emissions from buses by over 1000 tonnes per year, such a strategy would in fact increase NO_x emissions by around 5000 tonnes per year.

Roadside tests are another way of ensuring cleaner vehicles, by allowing malfunctions or the temporal degradation of catalytic converters to be corrected and thus maintaining higher vehicle efficiency. Although such tests exist across the EU, the exact specifications and requirements vary. Similar inspection and management tests also exist in North America, where they are arguably more stringent. Unlike the EU, which does not currently test motorcycles (although 'heavy motorcycles' have now been included in the Directive 2014/47/EU to be implemented in 2018[9]) and tests cars statically under load, Phoenix and British Columbia for example test cars on a dynamometer.[10] This tests emissions under conditions much more similar to normal driving conditions, and also enables the testing and therefore regulation of NO_x emissions. On the contrary, the testing currently seen across most of the EU covers only carbon monoxide (CO) emissions, and the difference between test and actual performance can be immense. In tests done by the UK firm Emissions Analytics, just 8 out of 500 cars tested met the official performance standards stated by the manufacturers. In some cases, these official values were exceeded by up to 5 times.[11]

Some questions exist regarding the effectiveness of such a roadside test policy. In Phoenix for example it is estimated that only a 7% reduction in NO_x emissions is achieved through the inspection and management of passenger cars with three-way catalytic converters (TWCs)[10] and therefore money spent on the testing could arguably be better spent elsewhere.

In terms of promoting cleaner vehicle use, a number of incentive schemes can be used. Incentives for businesses and the public to invest in a cleaner vehicle can take the form of retrofit incentives, tax breaks or scrappage schemes. In Germany, a tax exemption based on the EURO standard of the vehicle means that consumers are better off investing in a cleaner vehicle.[10] Germany also provided an incentive for retrofitting high-emissions vehicles by permitting the use of only retrofitted cars in cities during periods of smog.[12]

Scrappage schemes typically take one of two forms: cash for scrapping an old vehicle, or credits towards the purchase of a new, cleaner vehicle. Although the latter has been shown to be more effective in reducing emissions[10], avoiding people scrapping their car only to replace it with an old, second hand car, or with a new, highly polluting model, there are disadvantages. Ultimately, the aim in many cities should be to reduce car use altogether – in Copenhagen for example 52% of residents claim that a bicycle as opposed to a car is their main means of transport.[7] There would be no incentive for people to make this shift under a credits system. To address this issue, an alternative solution was pursued in Hungary: people who scrapped but did not replace their vehicle were offered instead a free 1-year public transport pass for themselves and their family across Budapest.[10]

Energy and industry

Globally, legislation governing emissions from energy and industry is fairly uniform in approach, comprising regulations and standards enforcing emissions capture/cleaning at source, regulations regarding chimney stack height, and permitted combustion inputs (a move from coal to gas for example).[13] Even stricter regulation includes the banning of certain industries from within specific 'control areas'. In China, for example, new or enlarged construction projects are prohibited in key control areas, while high pollution coal generation (iron, steel, non-ferrous metal and building materials industries; coking; and petrochemical and chemical projects) are prohibited nationally unless accompanied by cogeneration. [13] Internationally, there is a move to cleaner energy sources, particularly renewable energy sources, which have the additional benefit of being accompanied by low-CO_2 credentials.

Promoting sustainable mobility

Shifting from a culture of personal, potentially polluting cars to public transport, where environmental credentials are more controllable, offers an obvious way to reduce emissions of harmful pollutants. This has particularly high potential in urban settings, where a high interconnectivity and density of people yields more routes common to many passengers and thus makes dense public transportation networks far more practical and economic than in rural settings.

Car use is influenced by alternative opportunities available (e.g. public transport), a person's resources (money, time, knowledge), and motivational factors (physical/psychological needs).[14] Making driving more expensive relative to public transport by means of taxes, or through subsidies to alternative transport means, is therefore one option, but it is important to note that, while relevant, cost is not the main driver of car use.[14] An alternative solution that has been pursued is hard restrictions on personal vehicles – pedestrianizing key routes and areas (or limiting to buses and bicycles) like along the Seine in France, or simply restricting the number of vehicles. For example, Paris, Mexico City, and Beijing have implemented policies in which during times of high pollution, cars with an even last number on their license plates are able to drive on roads one day while cars with odd last numbers are allowed on the roads the next. An important observation with regards to such restrictions, however, is the degree to which they are circumvented. In Mexico City both car use and emissions increased following the implementation of restrictions as wealthier households purchased cheap, 2nd cars in order to circumvent the ban.[15] A similar response has been seen in Beijing.[16]

An alternative approach, popular in many countries, is the use of 'soft measures' to promote sustainable mobility.[14] Brussels for example has pursued a programme that included limiting parking space and implementing car share schemes and regional bike plans aimed at improving cycling facilities. Parking prices in particular have been shown to have a real impact: by increasing roadside parking fees in non-residential areas, Beijing saw a 26.9% reduction its congestion index during peak hours, and 3.3% increase in bus journeys.[16] Transport Feedback Programmes, as engaged in experimentally in Japan, have also been shown to have significant positive effects, especially when accompanied by formation of a 'behaviour plan' setting out how an individual can best increase their public transport use.[17] Such schemes have shown up to 25% reductions in car use and 100% increase in public transport use.

Where such de-personalisation of transport is unpalatable to residents, an alternative is to encourage the use of cleaner, electric vehicles. In Paris, this is achieved through the Autolib', electric car banks much like the Santander Cycles in London[18] that lessen many of the concerns commonly associated with electric vehicles such as battery life and availability of charge points. Similarly, widespread provision of fast charge points has been undertaken to inspire public confidence in electric vehicles: the completion of the Tesla supercharger network in Norway for example closely correlated with Tesla's Model S becoming the top selling car.[19]

Other Policies

There are some policies that, instead of tackling pollution at source, try to reduce it post emission. This represents an important mechanism for dealing with air pollution levels as many atmospheric pollutants have the ability to travel long distances, and thus the air quality within one area can be heavily influenced by pollution-control policies undertaken in other jurisdictions, or even countries.

Urban landscape planning is one such policy. Vegetation cleans air by providing a deposition surface for pollutants, a process promoted by the slowing effect they have on air flows.[20] Vegetation can also reduce local temperatures, particularly in the summer, helping reduce energy requirements for air conditioning. In the US, a 2006 study suggested that urban trees are responsible for the removal of 305 100t of ozone and 97 800t NO_2, in addition to significant reductions in CO, SO_2 and particulate matter.[20] Furthermore, the tree canopy traps the cleaned air at street level, especially when combined with urban planning to control air flows.[21] Green walls, as adopted by Chinese cities including Chengdu, Shanghai, Nanjing and Beijing City are an alternative to street level trees.[22] By adorning the walls of buildings with vegetation, these have the potential to create 'filtered corridors' of fumigated air, similarly trapped in the canyon created by buildings.[21] It is important to note, however, the importance of species used. Trees emit Volatile Organic Compounds (VOCs), which combine with NO_x to form ozone. Thus, especially with the current high UK NO_x concentrations, planting trees with high VOC emission could result in a net increase in ozone concentrations.[23] Reference to the 'urban tree air quality score',[24] a measure which accounts for both the filtration capacity (related to canopy density) and potential for contributing to ozone formation, can help ensure a net benefit in policy-making.

Drawing from these policies implemented elsewhere in the world, we recommend the UK pursue policies falling into four areas. Firstly, cycling as an everyday means of transport should be encouraged, and we propose a series of policy steps that could achieve this. Secondly, we consider potential mechanisms to green the public transport system, followed thirdly by a series of policies aimed at tackling the emissions associated with the private vehicle fleet. Finally, we consider a series of ecology-related policies, a means to clean the air of the residual emissions that the first three policy areas fail to prevent.

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5 Policy Solution: Incentivise Cycling

David Gregory

Cycling is an emission-free mode of transportation, so one possible strategy to reduce UK NO_x and O_3 levels would be to encourage private road users to switch from motorised vehicles to bicycles. According to the Mayor of London, if 14% of journeys in central London were made by bicycle, NO_2 emissions could be reduced by almost one third.[1]

Many strategies have been adopted already in the UK to encourage and promote cycling, and are continuing to be altered and expanded. These include:

- **Cycle lanes**: The National Cycle Network extends over 14,000 km and passes within a mile of half all homes in the UK.[2] Plans are currently in place to build many more cycle lanes across the UK, including an investment in a "cycle super highway" covering nearly 25km in London. However, building new cycle routes can be expensive and difficult logistically, particularly in urban areas (which tend to suffer from the worst pollution).[1]
- **Public cycle hire schemes**: The Santander bike hire scheme (formerly Barclays bikes) currently operates in London[3], with cities including York[4] and Belfast[5] planning on introducing smaller-scale versions soon. While the schemes do encourage a lot of cycling, the additional cycling is thought to mostly replace walking and use of public transport, meaning that the impact on emissions is reduced[3]. Schemes are also often expensive and can require sponsorship to fund[4].
- **Financial incentives**: Either for cycling (such as cycle to work schemes)[6] or against private motorised transport (such as the London congestion charge).[7]

While these measures are often effective in increasing the number of cyclists, they are often costly, and are already in place with planned expansion in many UK areas.

One barrier to cycling is public perception of cycling and cycle safety, which is at least as critical as measured safety in determining the number of people using bikes.[8] In the UK, 48% of cyclists and 65% of non-cyclists believe cycling on the roads is too dangerous.[9] Additionally, many people perceive cycling to be, rather than a normal mode of transportation, an activity exclusive to sport, leisure or children.[10]

In many European countries, cycling is incorporated in to educational and training schemes. For example, in the Netherlands, Denmark, and Germany, training in traffic laws and cycle safety is part of the national school curriculum. This includes practical and theoretical lessons, the outcomes of which are assessed. Additionally, training for motorists in awareness of and safety around cyclists is extensive.[11]

While it is difficult to separate the educational differences from the other factors (such as better cycle networks) that result in higher cycling rates in other European countries, Table 1 indicates that the aforementioned countries which include cycle training in schooling have both a much higher proportion of journeys made by bicycle, and much lower injuries and fatalities per total distance cycled.

Cycle safety included in education?	Country	Proportion of journeys made by bicycle	Cyclists killed per 100 million km cycled	Cyclists injured per 100 million km cycled
Yes	Netherlands	27%	1.1	14
	Denmark	18%	1.5	17
	Germany	10%	1.7	47
No	UK	1%	3.6	60

Table 1. Proportion of journeys made by bicycle and fatal and non-fatal cycling accidents per 100 million km cycled in select European countries. Data from Pucher & Buehler (2008).[11]

We therefore propose the following measures:

1. Education in cycling should become part of the national school curriculum, including practical riding lessons in primary school along with basic traffic law and cycle safety lessons, followed by advanced traffic law and cycle safety lessons in secondary school. This echoes an all-party parliamentary cycling group recommendation made in 2013.[12]
2. Include cyclists as a separate category of road user (rather than within the category "vulnerable road users") in the UK driving test. Specifically, ensure at least one encounter with a cyclist occurs in the hazard perception test, at least 2 questions specifically about cyclists are included on the theory test and where possible, design practical driving test routes to include roads with cycle lanes and those likely to be shared with cyclists. While it is impossible to ensure the road is shared with a cyclist on all practical driving tests, where one is encountered it should automatically form part of the assessment, and awareness of and safety around cyclists should be taught

as standard in driving lessons. This furthers a petition put to the government by British Cycling in 2013.[13]

In order to improve the perception of cycling safety beyond formal education, one key target is heavy goods vehicles (HGVs), in particular in urban areas. 70% of the 28 fatal cycle accidents involving HGVs each year occur in urban areas.[14] While HGVs make up only a small proportion of the traffic in these areas (and thus a small proportion of the accidents), they account for a disproportionately high number of fatalities. For example in London between 2008-2012, HGVs accounted for 4% of traffic, but for 53% of the cyclist fatalities.[15] Combined with the large amount of media coverage these fatal accidents receive, these accidents greatly influence the perception of cycle safety.[14] In a recent trial by Transport for London (TFL), installation of blind spot or "trixie" mirrors at junctions improved the perception of safety of cycling and awareness of other road users from both HGV drivers' and cyclists' perspectives. Another study as part of the "Safer Lorry Scheme" from TFL found that legislation on HGV safety equipment, specifically extended mirrors for blind spots and safety guards on the sides to lessen danger of collisions, which does not apply to older HGVs, presents a serious danger for cyclists (Table 2).[15]

Sample	Total fatalities	Total serious injuries	Fatalities involving HGVs exempt from legislation (% of total)	Serious injuries involving HGVs exempt from legislation (% of total)
Side guard	35	111	21 (60%)	30 (27%)
Mirror	31	74	15 (48%)	40 (54%)

Table 2. Cyclists killed and seriously injured in London between 2008-12 in accidents involving HGVs. Data from Transport for London (2014).[15]

We therefore recommend:

3. Installation of blind spot mirrors at any urban junction at which there has been a recorded collision between a cyclist and a HGV.
4. Compulsory installation of side guards and extended mirrors on all HGVs, furthering the findings of the aforementioned TFL report.

Although the main focus of this paper in terms of cycling policy is the perception and awareness of cycling hazards, one other area of particular concern was found to be where cycle lanes merge with roads and cyclists mix with motorised vehicles. These areas present a particularly high danger to cyclists.[10] In the Netherlands, Denmark and Germany, on most roads where cyclists mix with motorised vehicles, the speed limit is reduced to 30km/h.[11] One UK study estimated that in 32km/h (20m/h) zones in the UK there were 17% less cycling casualties and 38% less fatal or seriously injured cycling casualties[16], which through this reduction would presumably improve the perception of cycle safety as well. Additionally, lower speed limits may also reduce NO_X emissions from motorised vehicles using those roads according to a review of the scientific literature carried out in 2008.[17]

Therefore, in addition to the educational measures proposed, we also suggest that:

5. On busy urban roads, on to which cycle lanes merge, speed limits are reduced to 32km/h (20m/h).

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6 Policy Solution: Electrification of public vehicles

Niruthavignesh Sundararajah

As transportation has been identified as the primary contributor to air pollution in United Kingdom, strategies addressing transportation must be devised to curb this issue. A concerted push for the modernisation of public and private transport is an effective policy to alleviate this problem.

A majority of the public transportation in the United Kingdom is fuelled by diesel. In London for instance, 90% of annual public commuting (2.2 billion journeys) is done via diesel-fuelled buses.[1] Actions are, however, being taken to alter the status quo as 1200 diesel-electric hybrid buses have been introduced. The number is expected to reach 1700 by 2016.[2] Eight hydrogen fuel buses have also been as part of a pilot project to introduce the clean fuel source in the city. These efforts, while useful, are insufficient to achieve the air quality improvements necessary.

To address this inadequacy, we propose that public buses be gradually retrofitted to be either electrically or diesel-electric hybrid operated. Retrofitting of conventional diesel buses to be hybrid or purely electrically operated has not been widely practiced in the UK despite the availability of such technologies. Current bus retrofitting programs across the country such as those in London and Edinburgh focus solely on installing NO_x and particulate matter removing equipment, which does not tackle the direct source of these pollutants – the diesel fuel. Hitherto, only a single City Sight-Seeing bus in York has been retrofitted to be fully electrically operated and only a single bus on Ensign's Route 22 which shuttles passengers between Aveley and Grays in Essex operates on a retrofitted diesel-electric hybrid.[3]

A diesel-electric hybrid bus has greater mileage and lower emissions compared to their fully-diesel counterparts. Vantage Power, developer of the retrofit engines, estimate that the hybrid engines can save £20 000 per year in terms of fuel consumption and reduce emissions by 40%[4] while fully electric buses will eliminate the emissions of harmful gases and particulate matter completely. While some diesel-electric hybrid buses are already running in cities such as London, retrofitting will be an excellent complementary measure to reduce air pollution. New diesel-electric bus, such as the latest Routemaster buses in London are expected to cost around £355 000 per bus in the near future.[5] The current buses cost approximately £1.4 million per bus, taking into account design and pilot project costs.[6] The cost of retrofitting is, however, significantly lower than the cost of procuring new buses. The York City Council spent £75 000 to retrofit the City Sight-seeing Bus[7]; this figure will likely diminish if retrofitting becomes practiced widely. Retrofitting offers not only a cheaper solution for bus companies, but more importantly, it allows bus companies to utilize their existing assets optimally without having to overhaul their fleets completely.

Besides retrofitting buses to be diesel-electric hybrid operated or fully electric operated, there are other forms of retrofit that could be considered to address the issue of air pollution.

Widespread Selective Catalytic Reduction (SCR) retrofit program should be considered as a complement to the aforementioned retrofit suggestions. SCR retrofits are known to reduce NO_x emission by up to 90% and cost approximately £ 10 000 per bus[8]. Over 1000 buses have been retrofitted in London as part of a large-scale retrofit program operated by TfL[8]. Based on a study conducted by King's College London, an improvement in air quality have already been observed in Putney High Street as a result of the SCR retrofits[9]. As such, it is conceivable that a more extensive implementation of this program through contractual or legislative means will be crucial in alleviating air pollution stemming from diesel buses. That said, it is imperative to understand the shortcomings of this policy option. While this policy significantly reduces air pollution, it does not tackle the issue of greenhouse gas emissions as CO_2 emissions are not curbed by the SCR. Hence, in the long run, electrification of public transportation presents the most ideal policy solution to curb air pollution and greenhouse gas emissions.

Additionally, hydraulic hybrid retrofits could be considered as an alternative to the diesel-electric hybrid operated retrofits. Hydraulic-hybrid systems store braking energy in a vehicle before utilizing it to accelerate the vehicle. This system, which costs about US$ 20 000[10] increases fuel efficiency by 40 percent and reduces NO_x emissions by 50 percent[11] This form of retrofit may be more favourable in contrast with the diesel-electric hybrid retrofit as it is cheaper and simpler in terms of its operating mechanism.

A number of strategies could be pursued to encourage retrofitting. The existing Green Bus Fund grant from the Department for Transport could be used to promote wider practice of retrofitting while tax credits for bus companies could serve as an incentive for companies to take the initiative in 'greening' their buses.12 Regulations could also play a crucial role in attaining this goal. Stricter control on polluting buses would naturally place more emphasis on the practice of retrofitting. As there are 4.7 billion bus journeys taken in England alone annually, it is plain to see that retrofitting is an essential to curb the problem of air pollution caused by transport.[3]

The same could be applied to the existing taxi fleet. The new taxi regulation in London, for instance, requires all taxis licensed from 2018 onwards to be zero-emitting. This regulation is crucial in addressing the problem of pollution in the capital as it targets the source of 35% of PM10 and 15% of NO_x emission in the capital - the iconic London Black Cab.13 The effectiveness of this proposed strategy would be, however, limited if it were to be executed on its own as it applies solely to newly registered vehicles. It is therefore imperative to incentivise existing cab owners to 'green' their vehicles through retrofitting. This could be done by either providing subsidies for cab owners to convert their taxis into hybrid or electric vehicles or provide capital allowance for cab drivers who have converted their vehicles. Stricter regulations on taxi emissions and increased information for taxi drivers could create an emphasis on the retrofitting of the existing taxi fleets around UK.

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Policy Solution: 7 Changes to the private vehicle fleet

Samantha Mullender

With transport being a major contributor to street level emissions, tackling the choice of personal vehicles is an obvious policy to pursue. There is some concern that the relatively high levels of pollution seen in the UK stem, in part, from the UK's policy to promote diesel vehicles as opposed to petrol vehicles. While diesel vehicles are indeed associated with a higher level of NO_X production, it is important to recognise that this is accompanied by lower CO_2 emissions.[1] A reflexive response encouraging a switch back to petrol vehicles would therefore be highly detrimental to the UK's longer term greenhouse gas (GHG) targets. Besides encouraging the scrapping of vehicles before the end of their economic lifespan, it represents a lost opportunity. With road transport responsible for 21.6% of UK GHG emissions[2], reducing emissions from transport represents a key component of meeting the 50% GHG reduction by 2050 target.[3] Technologies for clean electricity production already exist, and therefore electrification of vehicles will both displace NO_X and PM emissions to power stations outside residential areas in the immediate term, and in the longer term provide a ready means to reduce GHG emissions. Promoting a shift from diesel to electric – rather than diesel to petrol and then a future shift to electrification – is a far more cost-effective strategy.

It is however fair to recognise that there is only limited capacity within the existing energy infrastructure to absorb the additional demands that would be created by an expanding electric vehicle fleet. It would therefore be unwise to promote a large scale, immediate shift of public vehicles from fossil-based fuels to electricity powered, as might be expected from a specific subsidy or incentive scheme. Instead, we would recommend considering a more staggered strategy, whereby the public are encouraged to choose electric vehicles when purchasing replacements for old cars (or even better to not replace their personal vehicle at all). In the meantime, efforts should be made to improve the cleanliness of the existing diesel fleet through engine regulations and improved testing and enforcement procedures.

There are therefore three recommendations we make to improve the personal vehicle fleet:

- Improving the efficiency of the existing diesel fleet through engine regulations and improved testing and enforcement procedures
- Encouraging the choice of electric vehicles when selecting replacements for old cars through public awareness campaigns and financial incentives

- Discouraging the replacement of diesel vehicles owned by city residents as they reach the end of their life, and discouraging the more general use of emitting vehicles within city limits.

It is likely that the greatest impact could be achieved through simultaneous pursuit of a number of these suggestions.

Efficiency of the existing fleet

Studies show that modern diesel cars have shown a gradual increase in engine power over time, with output increasing from 70kW for Euro 2 cars to 85, 98 and 113 kW for Euro 3–5, respectively (compared to a static 80kW for petrol vehicles). This has resulted in an increase in both CO_2 and NO_X emissions under higher loads.[1] Furthermore, it is rare for vehicle performance under general usage to reflect the performance stated by vehicle manufacturers[1] – the result being that many cars in fact fail to meet their stated performance standard when being used for day to day driving. With limits only covering the NO_2 component of NO_x, it is arguably the case that even where limits are met, this does not reflect the full impact of the engine emissions.

With national speed limits being no more than 70mph, there is arguably no need for vehicles to be more powerful than is required to safely accelerate up to, and hold, this speed. Imposing upper limits on the power of vehicles sold could therefore reverse this trend of increasing engine power seen in diesel but not petrol vehicles. It is also critical to ensure vehicles meet the standards stated during general use, and that these standards tackle the whole problem rather than just one component. While the 2014/47/EU regulations introduced in 2014 should make some progress towards these aims, there are still no plans to limit NO_x as a whole, nor is there any good way of reliably measuring vehicle emissions under a typical driving cycle. This represents a key knowledge gap. Providing financial support to applied research groups currently tackling this problem could therefore offer huge returns, with any resulting technology able to provide accurate performance measurements for vehicles during general use being immediately marketable to governments around the world.

Promoting electric vehicles

In recent years the technology underpinning electric vehicles has progressed rapidly. Vehicles such as the Tesla Model S and Vauxhall Ampera boast ranges of over 300mi per charge[4,5], whilst the improving quality of charge points means that a charge of 170mi can be achieved in as little as 20 minutes.[6] Yet this awareness has not spread to consumers. Despite the average UK commuter using their car for less than 25mi/day[5], 85% of consumers said they would prefer a hybrid over an electric vehicle because of “Insufficient battery range of full electric vehicles technology to cover [their] daily driving needs”.[7] 70% are also put off by “Charging time of full electric vehicles [being] too long”.[7]

A public awareness campaign therefore seems to be a very easy and relatively inexpensive means of encouraging electric vehicle uptake. Informing consumers of the characteristics of modern electric and hybrid vehicles, the likely charge times, and the availability of charge points could dramatically increase their uptake.

With range and charging being such key concerns, the availability of charge points should also be addressed. While initiatives are already in place to increase charge points within cities (Source London for example[8]) and at service stations[9], it is critical that these new networks are publicised widely. A consumer without an electrical car will have no need to know where charge points are being built. Thus without a specific publicity effort, preconceptions regarding the availability of charge points will simply persist.

Taking vehicles off the road

A highly successful policy in many UK cities has been the introduction of a park and ride service. There are however situations where a personal vehicle is still preferred.

Data for Greater Paris shows that at any one time, 60% of cars in the area are parked up, not being used.[10] This not only congests streets but represents an unnecessary lock-up of resources and energy spent on production. Car clubs already successfully exist in many UK cities, but the move to an electric vehicle 'car share' scheme presents a whole new range of opportunities. France's Autolib' represents a business plan with enormous potential for UK cities. Banks of electric cars run on a system similar to London's Santander Cycles, available for rental on a 15 minute basis plus a subscription fee. Cars can be reserved in advance, and customers can further reserve a parking space to leave the car in upon reaching their destination.

In the form of 'Source London', BlueSolutions – the company behind Autolib' – already plans to introduce operations in London in autumn 2015.[10] Monthly subscription charges will be £10, with a charge of £5 per 30 minutes hire. The potential benefits of the scheme are enormous. From an emissions perspective, switching journeys from petrol/diesel vehicles to electric cars offers emissions-free travel. While it is possible some people may switch from public transport to the new vehicles, thus failing to represent saved car emissions, in Paris, more than 25% of users owning a car said that the Autolib' had now become their 'main car'.[11] This demonstrates a secure source of savings. There are also wider benefits to be gained. It is estimated that in the two years from December 2011-2013, Autolib' resulted in 11 500 'normal' cars sold and not replaced/not bought.[11] This contrasts with the 3000 new 'Bluecars' added as part of the Autolib' service. This net reduction of 7500 cars will in many cases represent cars no longer parked on city roads, reducing congestion. This can further decrease emissions, as the greatest NO_X emissions are associated with acceleration and stop-start driving like that occurring during congestion. Another benefit may be familiarisation of the public with electric vehicles. Using electric vehicles in a system where the consumer does not have to worry about maintenance and charge points may help provide the confidence necessary to make electric cars a true consideration in future car purchase decisions.

With such benefits, there is real reason for the government to consider incentivising, or at least assisting, Source London's establishment in London, and encouraging its spread into other UK cities. Such assistance could be as small as providing advertising and links on the London congestion charge website, but extending it to further cities where the congestion charge would not provide such an incentive for uptake could require support to reduce hire rates or subsidise use of the service for owners of more polluting vehicles. With the vehicle fleet further requiring servicing, managing and maintenance (50 cars typically require servicing each day in Paris), expansion across the UK also represents additional job opportunities across the country.

In addition to shared vehicles, efforts should be taken to reduce vehicle use altogether. One way to do this might be through an incentive scheme (Simon Birkett pers. comm.). Much in the same way as taxes act as financial disincentives, it is possible that providing a financial incentive might encourage more people to walk or cycle. Not only would this help reduce traffic and vehicle-associated emissions, it would also carry the health benefits that physical activity can provide. A study by Anderson et al. 2015[12] for example showed that, despite the additional exposure to air pollution that this would entail, the net health effects of city-based exercise were still significantly positive.

Careful thought would have to be given to the logistics of such a scheme – how to monitor and fund it for example. One funding option would to be to hypothecate taxes on polluting vehicles for incentivising alternative modes of transport, an option that may make vehicle taxes more acceptable to the public by providing a transparent return of these funds directly back to them. With regards to monitoring participants' activity, the main challenges will be regarding data privacy concerns. While accelerometers in smart phones are likely already of a sufficiently accurate standard – or certainly will be in the next few years – to detect whether a person is walking or cycling, and GPS capabilities will enable distances to me monitored, such data is highly sensitive and live transmission of this information would cause concerns for many. One possible solution to this could be to compile the monitoring capabilities into an app that processes this information to generate, at the end of a fixed period (24 hours for example), the net distance travelled by foot and by bike. This data – which we suggest is much less sensitive than location specific or 'live' data – could then be sent to the system responsible for processing the rewards earnt.

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8 Policy Solution: Ecological interventions

Oscar McLaughlin

While tackling pollution at its source is by far the most efficient pollution management strategy, interventions that actively remove pollutants from the air can be highly effective at improving air quality in the areas with the highest concentrations of NO_x for the most vulnerable groups.

The areas of most concern for NO_x pollution are inner city urban areas because of the number of people being exposed, the high levels of traffic and the tall urban buildings which create 'street canyons'. These canyons trap traffic pollutants and ultimately limit their dispersal into the atmosphere.[1]

Urban greening is presented as a partial solution to elevated air pollution levels with added aesthetic benefits, as leaves absorb gaseous pollutants through their pores and allow particulate matter to collect on their surfaces.[2]

The primary forms of urban greening include parks, rooftop vegetation, vertical vegetation and trees. Vertically grown vegetation is estimated to remove nearly 10 times as much NO_2 and 12 times as much PM_{10} from urban canyons as rooftop, though it should be noted that trees play a somewhat enigmatic role in NO_x mitigation as they can disturb and reduce urban wind patterns thereby reducing dispersal.[3]

<u>How does this help?</u>

Models have shown that vertical vegetation in street canyons can reduce street level concentrations in those canyons by as much as 40% for NO_x and 60% for PM. These results are consistent with field measurements of deposition on vegetation.[3] Vertical greening can also be a barrier between a high source of pollution and a vulnerable group, for example between a school playground and a busy road.

Substantial street-level air quality improvements can be gained through action at the scale of a single street canyon or across city-sized areas of canyons. Moreover, vegetation will continue to offer benefits in the reduction of pollution even if the traffic source is removed from city centres, as trans-boundary pollution is significant in the UK. Thus, sensible use of vegetation can create an efficient urban pollutant filter, yielding rapid and sustained improvements in street-level air quality in dense urban areas. However, concentration reduction is based highly on residence time (wind speed/direction and canyon geometry).[3]

Greening an urban canyon will have significant effect on that canyon and a small effect elsewhere i.e. that green walling should be focused on 'urban canyons' and between vulnerable areas such as schools and areas that have the high NO_x concentrations. Vertical green systems also act as a buffer against high-pollution episodes (which are usually associated with low wind speeds and extreme climatic events).[3]

Green walls also provide a number of auxiliary co-benefits including improved psychological well-being, climate stabilisation and reduction of the Urban Heat Island Effect, improved biodiversity, protection of buildings from environmental damage, and increased property value.[4]

What are vertical greening systems?

There are two main types of vertical greening systems[5]:

- Green façades (climbing vines attached to the building surface, or supported by cables/ trellis). Requires nutrients and a nutrient system.
- Living wall systems (multiple flora and includes a growing medium such as soil). Constructed through the use of modular panels, e.g. foam, felt, perlite and mineral wool. Requires more maintenance.

Living walls are inherently expensive to construct and maintain and should only be constructed by government as a last resort pollution management strategy as a short term policy to protect a vulnerable group from high pollutant concentrations.

However the government can play a key facilitating role encouraging and promoting the adoption of green walls and roofs. Cities such as Basel, Beijing, Vancouver, Berlin, Cologne and Toronto have used a variety of building regulations and financial incentives to successfully encourage urban greening

A recent cost-benefit analysis of green walls found that direct green facades (that grow directly on the building) and steel indirect green facades (that grow on steel structures attached to the building) show economic viability and sustainability. Both installation and maintenance costs play a decisive role for sustainability.[5]

Does it work?

While green walls are accepted as being far more efficient at NO_x absorption than roofs, there has been no large-scale promotion of green walls to date. Chicago, however, provides an example of a city wide roof greening policy.[6]

The city of Chicago has estimated that investment in “greening” only a small percentage of the city’s rooftops has significantly reduced air pollution. Converting 10% of Chicago’s rooftops removed 17,400 Mg of nitrogen dioxide each year. In turn, Chicago estimates that this investment could result in avoided public health costs of $29.2m to $111m annually (around £17m to £65m).[6]

Recommendations

While emissions reduction is clearly a far more effective policy tool, targeting key urban areas that are of particular concern with green walls could have significant health benefits and represents an opportunity for the UK to become a world leader in urban green walling.

Therefore we suggest:

- Constructing green walls as barrier between vulnerable areas such as schools and areas with the highest levels of NO_x concentrations.
- Green walls and/or roofs should be required as a building regulation for new non domestic developments in urban areas.
- Perini and Rosasco's 2013 study estimated that a 50-55% tax relief on ALL green facades construction materials would make the societal benefits received versus the cost of the lost tax revenue worthwhile.[5]

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9 Conclusions

Oscar McLaughlin

The issue of illegally elevated ambient NO_x concentrations in the UK is a serious problem that requires immediate action, as it threatens the health of British citizens and costs the economy billions every year. The UK government is also facing legal action over its inability to meet EU targets.

NO_x emissions have been decreasing steadily since the 1980s, but the current period of austerity requires a higher level of innovation from policy makers to tackle this issue. A multi-dimensional approach that compliments top-down regulations and financial strategies with strong and decisive local governance is paramount.

This paper recommends the following policies as currently underexploited, resilient and effective methods to reduce NO_x pollution in the UK:

<u>To incentivise cycling:</u>

- Integrate cycling into the national school curriculum with a focus on traffic laws and cycling safety
- Include an encounter with a cyclist in the hazard perception section of the driving theory test and two further questions about safety around cyclists
- Install blind spot mirrors at any urban junction at which there has been a recorded collision between a cyclist and a heavy goods vehicle
- Require the installation of side guards and extended mirrors on all heavy goods vehicles
- Reduce speed limits to 20m/h on busy urban roads where cycle lanes merge

<u>To reduce emissions from transport:</u>

- Retrofit public buses to electrical or diesel-electric hybrids
- Provide retrofitting subsidies for cab owners to retrofit their vehicles
- Setup tax reductions for retrofitting private vehicles to hybrid or electric
- Integrate electric vehicle recharging standards into development planning
- Improve the testing and enforcement of existing diesel fleet engine regulations
- Encourage the adoption of electric vehicles through public awareness campaigns and financial incentives
- Discourage the use and purchasing of high-emitting vehicles by urban residents and within urban areas

<u>To reduce urban air pollution through urban greening:</u>

- Encourage the construction of green walls through subsidies and tax breaks
- Adopt green walls as a mitigation method for developments in areas with high concentrations of NO_x