Imperial College London

London Forum for Science and Policy
Briefing paper

April 2016

New solutions to air pollution challenges in the UK

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Produced by the London Forum for Science and Policy; published by the Grantham Institute.

Introduction

Recent studies have estimated that 9,500 people die each year in London due to long-term exposure to air pollution – primarily particulates (PM2.5) and the carcinogenic gas nitrogen dioxide (NO_2)[1]. Policy responses from central government have so far been inadequate in addressing this[2] and immediate action is required. This paper discusses the problem of NO_x (here used to refer to NO and NO_2) pollution and suggests potential policy solutions.

Why does air pollution matter?

NO_x emissions are associated with a number of negative consequences. Perhaps most notably, air pollution can have a diverse range of health implications for those exposed. Exposure to concentrations of NO_2 greater than the 200 µg m^{-3} hourly recommended limit – and levels exceeding 940 µg m^{-3} have been reported[3] – can cause constriction of airways and reduced lung function in asthmatics[4], as well as increasing susceptibility to respiratory infections and allergens[3].

NO_x emissions cause direct effects, as well as indirect effects through the secondary pollutants formed when NO_x reacts with other chemicals in the atmosphere[4,5]. These secondary nitrogen-based particles – nitrate, and nitrous and nitric acids – contribute to particulate matter (PM), for example. Around 10% of the mass of PM10 is thought to originate as secondary N-based particles, although this contribution is likely to account for less than 5% of PM10's detrimental respiratory health effects[6].

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Grantham Briefing Papers analyse climate change and environmental research linked to work at Imperial, setting it in the context of national and international policy and the future research agenda. This paper was written by students at Imperial with these same goals, and therefore published as a Grantham publication. This paper and other Grantham publications are available from **www.imperial.ac.uk/grantham/publications**

In addition to PM, NO_x also contributes to the formation of ground level ozone (O_3) when in the presence of PM and other volatile organic compounds. Although O_3 in the upper atmosphere is beneficial to human health, absorbing UV radiation from the sun, O_3 at ground level can be harmful. O_3 occurs naturally at low concentrations at ground level[7] but exposure to high ambient concentrations, even for short periods, can inflame the respiratory tract and irritate the eyes, nose, and throat[8]. High short-term exposure presents a particular danger for asthmatic individuals, as it can exacerbate their condition and trigger asthma attacks. Longer-term exposures to lower (but above natural baseline) concentrations of O_3 have meanwhile been associated with increased mortality. In one study in the USA, it was estimated that for every 20µg m^{-3} rise in O_3 concentration, the risk of death from respiratory problems increased by 4%. Therefore, the risk of dying from a respiratory-related illness was more than three times higher in the metropolitan areas with the highest O_3 concentrations as compared to those with the lowest O_3 concentrations[9].

Accompanying these health consequences are economic losses – up to £23 billion a year[10] –arising both from the side-effects associated with this poor health and from other, wider consequences. Lost working days, greater pressure on the health service, reduced crop yields and eutrophication (pollution of water with excess nutrients) are all possible outcomes from the failure to meet recommended pollutant limits[8].

What are the pollutants?

NO_x is formed during the combustion of fossil fuels such as coal, natural gas and petrol. Existing data suggests that 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). For both NO_x and PM2.5, industrial sources and power stations combine to contribute 35% of emissions, compared to road transport's single-handed contribution of 24% of national primary anthropogenic emissions[11]. These statistics are useful, but it is worth noting that emission measurements are subject to a number of uncertainties, with emissions a function of the specific combustion conditions: air exposure and machine/vehicle maintenance and power output for example.

Table 1: Sources of NO_x emissions in the UK[33].

Sector	% of national NO_x emissions
Transport sources	45.5
Energy industries	25.8
Industry combustion	17.3
Commercial combustion	3.4
Residential combustion	3.3
Other	3.0
Public sector combustion	1.0
Industrial processes	0.6

How has air pollution in the UK changed with time?

Like many other pollutants, NO_x and PM2.5 concentrations have declined over the past four decades (Figure 1). Emissions of NO_x have declined nationwide by 66% since 1990, with 36% of this decline stemming from road transport combustion sources and 23% from power generation. However, research suggests that NO_2 has not decreased to the same extent as NO[12].

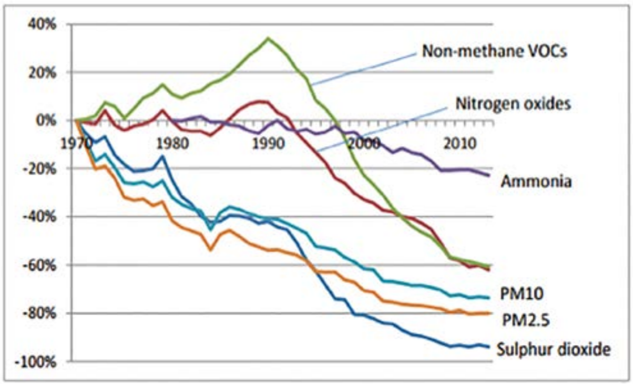

Figure 1: Most UK pollutants have fallen in recent decades. Source: Defra National Statistics Release: Emissions of air pollutants in the UK, 1970 to 2013[12].

Road transport remains the primary source of NO_x emissions despite the introduction of emission control strategies for stationary emissions. 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[12]. These, however, have been partially offset by increasing numbers of road vehicles[13], increasing power output of diesel cars[14] and compensatory shifts in the NO/NO_2 output ratio. There is also concern that the UK's policy to promote diesel vehicles over petrol vehicles has been a major contributing factor to the persistently high road transport emissions, with diesel vehicles boasting lower level CO_2 emissions but higher NO_x and PM emissions as compared to their petrol counterparts[14]. The need to balance air pollution with greenhouse gas emission reductions presents the government with a delicate dilemma.

Does our air quality satisfy legal requirements?

The passing in 2008 of Directive 2008/50/EC on ambient air quality and cleaner air for Europe[15] established new legally-binding rights for residents of EU member states regarding the quality of air that they should expect. However, after seven years, the UK is still failing to meet targets on NO_2 and O_3[10]. In consequence, in April 2015, the Department for Food, Environment, and Rural Affairs (Defra) received mandatory orders from the UK 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[2]. Although updated plans were published by the December deadline, the law firm ClientEarth argues that the proposed strategy still falls "woefully short" of the court orders. As of March 2016, ClientEarth has therefore threatened further legal challenge should these plans not be improved[16].

It is critical to recognise that the consequences of continued failure to meet the Directive's targets extend well beyond the threat of financial retribution. Even marginally higher levels of NO_x (including the NO_2 covered by the Directive) and O_3 can have numerous negative consequences, including the diverse array of health implications and wider economic losses mentioned earlier.

What can be done and how?

With road transport the primary contributor to national NO_x emissions, policies to reduce emissions in this sector are crucial to alleviate the issue of air pollution in the UK. Here we identify three key areas through which road transport emissions can be targeted, followed by one, more generic, approach to the emission problem.

Cultivating a safer and more attractive environment for cycling

Cycling is an emission-free mode of transport at point-of-use, so one possible strategy to reduce current 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[17], while reduced congestion associated with fewer cars would further reduce the emissions of the remaining vehicles[16].

Public perception of cycling and cycle safety is a major barrier to cycling at present. This perception is at least as critical as the actual safety of cyclists in determining the number of people using bicycles[19]. In the UK, 48% of cyclists and 65% of non-cyclists believe cycling on the roads is too dangerous[20]. Additionally, many people perceive cycling to be an activity exclusive to sport, leisure or children, rather than a conventional mode of transportation[21]. These perceptions must be changed in order for the number of cyclists on UK roads to increase.

Table 2: Proportion of journeys made by bicycle and fatal and non-fatal cycling accidents per 100 million km cycled in select European countries[22].

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

One means to achieve this change would be to follow the example of many European countries, where cycling is incorporated into 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[22]. Additionally, training for motorists in awareness of and safety around cyclists is extensive. While it is difficult to separate the educational differences from the other factors (such as better cycle networks), Table 2 indicates that the aforementioned countries have both a much higher proportion of journeys made by bicycle, and much lower injuries and fatalities per total distance cycled.

Electrification of public vehicles

Public transport is another key target for reducing road-transport related emissions. The majority of public transport in the United Kingdom is fuelled by diesel, a significant contributor to NO_x and PM2.5 emissions. In London for instance, where 25% of journeys made daily are by public transport, 2.3 billion journeys are made by bus every year, with the vast majority of buses fuelled by diesel[23]. Actions are already being taken to alter the status quo: 1,200 diesel-electric hybrid buses have already been introduced, with the number expected to reach 1,700 in 2016[24]. These buses are expected to reduce fuel consumption while also reducing emissions by 40%[25].

A widespread Selective Catalytic Reduction (SCR) retrofit program could, however, also be considered. SCR retrofits are known to reduce NO_x emission by up to 90% and cost approximately £10,000 per bus. Over 1,000 buses have already been retrofitted in London as part of a large-scale retrofit program operated by Transport for London (TfL) and a marked improvement in air quality has been recorded in the region where these buses operate. Expansion of this programme nationwide could result in real benefits with regards to air pollution levels.

Transforming the private vehicle fleet

The third focal area to directly alleviate air pollution from road transport is the private vehicle fleet. In this sector it is important to avoid a reflexive response encouraging a return from diesel to petrol vehicles. Whilst such a shift would tackle air pollution, this change would also increase CO_2 emissions[14]. Road transport is currently responsible for 21.6% of UK greenhouse gas emissions[26], and the UK has pledged a 50% cut in greenhouse gas emissions pledged by 2050[27]. It is therefore important that greenhouse gas emissions in this sector are kept down.

Electrification of private vehicles could be a solution. Technologies for clean electricity production already exist and electrification of vehicles will therefore 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 greenhouse gas emissions. Based on the technologies currently available, a shift from diesel to electric is a far more cost-effective strategy than a shift from diesel to petrol, followed by a future shift to electrification. Promoting a shift to electric vehicles is now largely a matter of public awareness. Battery range and charge time are the main stated reservations of consumers to electric vehicles[28], yet with vehicles such as the Tesla Model S boasting ranges of over 400 km (250 miles) per charge[29] and a charge of 200km (170 miles) achievable in as little as 20 minutes with some technologies[28], these reservations should pose little barrier to uptake.

While the transition to electric vehicles is underway, actions must also be taken to optimise the efficiency of conventional vehicles. European legislation sets out pollution standards for passenger vehicles, which started with Euro 1 standards and now go up to Euro 6 standards. Studies report that modern diesel cars have shown a gradual increase in engine power over time, with output increasing from 70 to 85 kW for Euro 2 standard cars, and 98 to 113 kW for Euro 3–5 standard, respectively. This has resulted in an increase in both CO_2 and NO_x emissions under higher loads[14]. With national speed limits never exceeding 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 in diesel vehicles.

Ecological interventions

While tackling road transport pollution at its source is by far the most efficient pollution management strategy, interventions that actively remove pollutants from the air also have high value in improving air quality for the most vulnerable individuals.

The areas of most concern for NO_x pollution are inner city urban areas, due to the number of people 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[30].

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. 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[31]. These reductions are achieved predominantly through the vegetation providing a deposition surface for pollutants, a process promoted by the slowing effect vegetation also has on air flows[32]. In the US, a 2006 study suggested that this removal of pollutants through deposition on urban trees amounted to 305,100t of ozone and 97,800t NO_2, in addition to significant reductions in CO, SO_2 and PM[32]. 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.

Vegetation will also offer benefits in the reduction of pollution even if the traffic source is removed from city centres, by continuing to offer protection against trans-boundary pollution (i.e. pollution that originates in one region but can also cause environmental damage in another region). Thus, sensible use of vegetation (considering factors like prevailing wind speed/ direction and canyon geometry) can create an efficient urban pollutant filter, yielding rapid and sustained improvements in street-level air quality in dense urban areas.

Recommended policies

We suggest that policy makers consider implementing the following policies. These policies relate to the focal areas of this paper and cover currently underexploited, resilient and promising methods to reduce NO_x pollution in the UK:

To incentivise cycling:

- 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 20mph on busy urban roads where cycle lanes merge

To reduce emissions from transport:

- Retrofit public buses to electrical or diesel-electric hybrids
- Provide retrofitting subsidies for cab owners to retrofit their vehicles
- Set up 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. Encourage a shift to a ‘sharing economy’, where the ownership of a personal vehicle is no longer the norm, superseded by shared cars, or care hire schemes etc.

To reduce urban air pollution through urban greening:

- 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

Conclusions

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 drive substantial reductions in concentrations of pollutants. It will only be through a multi-pronged approach that European limits will be met. Current efforts are insufficient.

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 Directive 2008/50/EC on ambient air quality and cleaner air for Europe. These policies should be undertaken as part of a comprehensive strategy to tackle air pollution in the UK and deliver on these targets.

Acknowledgements

The authors would like to extend their heartfelt gratitude to Jennifer Mills for guiding them throughout the process of producing this report. They would also like to thank Simon Birkett of Clean Air for London for assisting them with the details. This report would also not have been possible without the relentless effort from Jordan Abdi. Lastly, we would like to thank Alyssa Gilbert for her invaluable feedback and effort.

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