Imperial College London

Environmental Research Group

30th Anniversary Series

The Future of Air Quality Measurement

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IMPERIAL POLICY FORUM

The Future of Air Quality Measurement: 30 Years of the London Air Quality Network

Introduction

At the start of 2023, the Environmental Research Group (ERG) launched a seminar series to celebrate 30 years of research, innovation and contribution to the greater understanding of environmental issues in London, the UK and beyond. The ERG was born in 1993 with the creation of the London Air Quality Network (LAQN) - a detailed, data-rich network of air quality measurements across London.

As part of its 30^{th} Anniversary Series, and in partnership with Imperial College London's Policy Forum, the ERG hosted "The Future of Air Quality Measurements – The 30^{th} Anniversary London Air Quality Network Seminar" on September 29^{th}, 2023. The celebratory event, chaired by Professor Benjamin Barratt, Deputy Director of the ERG and Professor in Environmental Exposures and Public Health, explored an array of topics: from citywide sensor networks to developing targeted mitigation to collaborating with communities, outlining the future focus areas and opportunities for air quality (AQ) measurement.

> "The London Air Quality Network has been the bedrock of our campaigning."
>
> Simon Birkett
> Founder and Director
> Clean Air in London

What is the London Air Quality Network (LAQN)?

The LAQN started as a small group of measurement sites in London, brought together by some of the first members of the Environmental Research Group, several of whom are still here today. Dr Gary Fuller, now one of the UK's Clean Air Champions, described how the LAQN had a vision to go further than simply looking at compliance with air quality regulations and limit values, to understand the reasons behind the results and what action could be taken. By coordinating, building evidence and promoting collaboration, they added value to the core measurement data and increased engagement with stakeholders. The team was the first to disseminate air quality information to the public. This has developed from the first air quality webpage, with pollutant readings and dots on a map, to more sophisticated high resolution air pollution maps, apps and pollution alerts.

Various themes have continued throughout the history and development of the Network. The measurements are a key source of evidence for air quality policy and interventions. They were pivotal in uncovering the failures of vehicle manufacturers to meet stricter emissions standards in real world conditions. Measurements are vital in tracking policies and technical solutions and have shown that compliance with interventions such as the Low Emission- and Ultra Low Emission Zones starts even before implementation. The scale of the LAQN allows differentiation of impacts in different location types. The finding that some locations in London would take 193 years to achieve the NO_2 annual mean Limit Value inspired the current mayor, Sadiq Khan, to take action on air pollution.

Measurements are also important in identifying sources of air pollution. Techniques have progressed: from early source apportionment to complex compositional measurements at research supersites, combined with advanced analysis. New discoveries are still being made, such as burning of waste construction wood indicated by detection of arsenic in seasonal wood burning emissions. Recently, air quality sensor technologies and data processing have advanced to enable the development of hybrid monitoring networks, exemplified by ERG's Breathe London.

The LAQN underpins work by other ERG teams including modelling of air quality scenarios and investigation of health impacts.

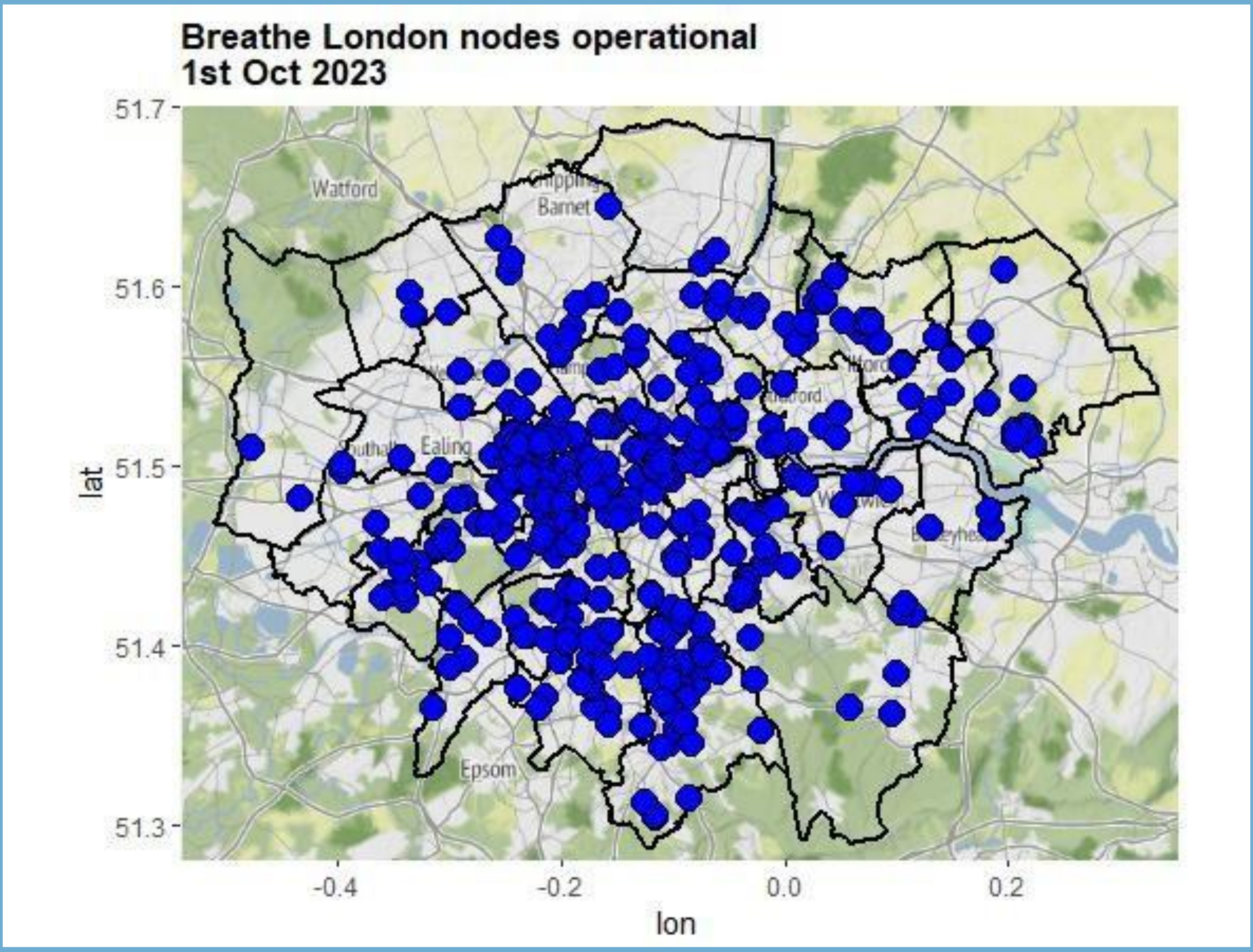

Image: map of operating Breathe London sensors as of 1st October 2023.

The Future of Air Quality Measurement

Measuring Aerosol Composition: Developing Targeted Mitigation

Measuring aerosol composition is an important step to developing targeted mitigation. However, understanding aerosol composition is a challenging process. Aerosols form a complex mixture. They can stem from both natural and man- made sources, and some are formed from gases via atmospheric reactions. Measuring what particulate matter (PM) is made of helps recognise which sources are most important in contributing to PM pollution and create effective policies to reduce concentrations.

Dr David Green, Senior Research Fellow at the ERG, detailed the four main challenges in developing targeted mitigation. The first major challenge is in quantifying the sources of aerosols, which can be overcome with the help of AQ supersites. Supersites collect a lot of information, ranging from aerosols to gases to meteorological data.

In London, the Honor Oak Park and Marylebone supersites measure air pollution in the urban background and at roadside sites. Research networks, such as ACTRIS and RI Urbans have been developed to link up international supersites. Working closely with colleagues from Europe, we can develop an understanding of where particles come from over a long-distance and how they change as they are transported in the atmosphere.

Image: An operational Breathe London node measuring NO_2 and $PM_{2.5}$, powered by a small solar panel.

Thorough measurements taken at supersites are used to undertake receptor modelling, where different mathematical models are used based on how much is understood about the sources. Across Europe, approximately half of PM measured is made up of organic compounds, with different influences and sources in different countries. In London, 45% of aerosols come from organic mass, with important local contributions from cooking, wood burning, and traffic emissions (Chen et al., 2022).

The second challenge lies in informing abatement policies. A good example is cooking and by using source apportionment techniques, 7% of PM mass was found to be derived from this source. A cooking emissions inventory was produced using this data and used to develop a UK-wide map at 5 km resolution and a more detailed 1 km resolution map for London. This is an important tool to identify source locations and inform policies to tackle future emissions.

The third challenge is in assessing progress. To allow various stakeholders to track progress, a PM dashboard was created. The PM dashboard shows what $PM_{2.5}$ is made of at Honor Oak Park in London every hour of every day.

The final challenge is to establish the health impacts of PM and understand what parts of PM cause the most health impacts. This requires linking more detailed measurements of sources to population exposure and subsequent health studies. Ultimately, the understanding of sources and exposures is complex. Measurements at high time resolution are essential in linking sources to concentrations and tracking long-term trends. This will lead to a more detailed understanding of health effects and inform targeted policies.

Assessing Compliance with the New $PM_{2.5}$ Targets

Isobel Moore, part of the $PM_{2.5}$ targets team at the Department for Environment Food & Rural Affairs (Defra), discussed the new $PM_{2.5}$ targets for England and how to assess legal compliance.

In the last 13 years, $PM_{2.5}$ concentrations have reduced by around a third, with concentrations beginning to level off before lockdowns for Covid-19 were implemented. While PM concentrations have dropped during the Covid-19 lockdowns, it is too early to know whether these lower concentrations will remain or if they are temporary. The concentrations of PM vary annually and are influenced by changes in weather and manmade emissions. When looking across the country, there is a clear gradient, with PM concentrations lower in the northwest compared to the southeast. Higher levels are also seen in larger towns and cities.

The Environment Act 2021 established a new framework for setting environmental targets to drive action to improve the environment. In particular, the Environmental Targets (Fine Particulate Matter) (England) Regulations 2023 set two air quality targets for $PM_{2.5}$:

1. An annual mean concentration target of 10 µg/m3 by 2040.
2. A population exposure reduction target of 35% compared to 2018 by 2040.

To assess legal compliance, monitoring data from the Automated Urban and Rural Network (AURN) are used. To meet the legal requirements by 2040, all AURN sites in England need to be below 10 $\mu g/m^3$ in 2040. In addition to meeting the legal limits for $PM_{2.5}$ concentrations, there are also legislative sampling requirements that will require a significant expansion of the existing network. New locations for $PM_{2.5}$ monitors are chosen based on a set of guiding principles to ensure the measurements best represent population exposure, as well as locations where higher concentrations are likely to be observed, for assessment against the annual mean concentration target. The site identification process takes into account population, deprivation, and location.

In December 2021, there were 63 $PM_{2.5}$ monitoring locations. This has since increased to 86 as part of the ongoing expansion programme. By the end of 2025, the $PM_{2.5}$ network will have expanded to at least twice the size of the original network. The expansion is pertinent in underpinning assessment of progress towards the targets and provide more real-time data on UK AIR. Isobel echoed the sentiments of other speakers in the symposium that understanding of source contributions will help drive progress to meet legal targets for $PM_{2.5}$ and dictate
policy priorities.

Citywide Sensor Networks

In an increasingly urbanised world, many cities are taking the lead on AQ and are often able to push through action using local powers, explained compared to the political and bureaucratic difficulties faced by national governments. For example, the C40 group of cities is a global network of mayors aiming to address environmental issues, including climate change, air quality and sustainability.

Image: Installation of Breathe London nodes is straightforward: they can be attached to a pole, post or wall using brackets and fixings and must be south-facing.

To achieve progress on air pollution, ERG's Dr Mohammed Iq Mead stresses that further information is needed to quantify exposure of the population across daily activities as cities grow and change. Knowledge gaps in regulatory reference measurement networks exist due to small numbers of sites per city or complete absence of monitoring in some areas, particularly in Low- and Middle-Income Countries (LMICs). Many pollution sources are not captured by this type of arrangement. The type and number of locations of reference measurement sites is constrained by cost and logistical considerations. Hyperlocal measurement networks have been shown to highlight hotspots and enable targeted, cost-effective and impactful strategies but these have often been limited in scale.

High density hybrid reference-sensor networks are an ideal solution to reach previously unmonitored areas. The suitability of sensor-based instruments for AQ measurement has been hindered by a lack of standardised operational framework, testing procedures, certification/accreditation and traceability to existing standards. The ERG's community-led Breathe London network uses a unique approach to transfer value between London's reference network and a rapidly growing sensor network with specified uncertainty requirements. This has proven to be a functional and scalable operational model with sites in schools, hospitals, cultural centres and communities. The network has far exceeded the proposed 5% per year expansion target, reaching 422 sites as of September 2023, compared to the 136 nodes set up with the initial funding in 2021.

Looking to the future, operation of this type of network needs to be regulated and standardised by way of best practice protocols, including a need for ongoing calibration. Increasing the range of pollutants, integrating indoor air quality measurements sources and combining with other measurements sources, such as from satellites, are other areas for potential improvement.

> "Community ownership is a really important element when planning AQ actions."
>
> Georgina Hammerton
> Senior Project Manager
> The Social Innovation Partnership

Exposure in Transport Micro-Environments

When in transit, an individual is likely to be exposed to high levels of air pollution. Dr Audrey de Nazelle, Senior Lecturer at the Centre of Environmental Policy at Imperial presented work from multiple studies evaluating the exposure to air pollution from these highly polluted transport microenvironments, and the subsequent implications for active travel and improving public health.

Despite a relatively small amount of time spent travelling, there is a disproportionally high exposure when in transport microenvironments (including in and around vehicles such as cars, buses and vans). For example, in one study travel accounted for approximately 6% of people's time but 24% of their daily dose of NO2. However, exposures to air pollution differ with transport modes. In 2017, Dr de Nazelle published a systematic review of the literature comparing air pollution exposure in active and passive travel modes with a focus on European cities (de Nazelle et al., 2017). This review showed that the concentration of air pollutants was generally lowest for active travel (cyclists and pedestrians), with car riders experiencing concentrations 40% higher than pedestrians.

Recently, this work has been revisited to include more global studies, more transport modes and more pollutants. Active transport modes still tend to have lower exposures compared with passive transport modes. However, these outcomes are far less clear, especially for PM2.5 and ultrafine particles. The study by Woodward et al. (2023) exemplifies the huge variability in measuring transport microenvironment exposure.

This study used advance fluid dynamics modelling to simulate nitrogen oxide (NO_X) exposure along a short (400 m) section of road. Individual simulations of exposure were characterized by low concentrations for the majority of the journey with intense peaks in concentration for short periods contributing to large variances in NOX concentration.

The lower concentrations experienced in active travel modes could be offset by two factors: a longer journey time and a higher inhalation rate. Examining ultrafine particles in Barcelona, de Nazelle found concentrations three time greater in cars than walking, on bus or in car. However, when accounting for the inhalation rate over a normalized 24-hour period, the inhaled ultrafine particles were 40-50% greater in active transport modes. From this an interesting question arises: does active travel worsen the risks from air pollution? Generally, the literature demonstrates that the benefits of active travel do outweigh the risk of greater exposure but, for some sub-groups of the population the benefits can be counteracted by high air pollution (see the 2007 Oxford Street study).

Finally, Dr de Nazelle highlighted the numerous benefits of active travel through a health impact assessment that converted 50% of car travel to walking, cycling and public transport in London. The economic benefits from positive health outcomes alone were greater than £1.7bn. The value of increasing active travel rises further when considering the many co-benefits such as reducing air pollution and reducing noise pollution—as well as the health benefits from physical activity—which can be compounded by increases in green spaces.

$PM_{2.5}$ from Domestic Wood & Solid Fuel Burning

Domestic wood and solid fuel burning (WSFB) is currently the second biggest source of $PM_{2.5}$ emissions in London and one of the main components of ambient $PM_{2.5}$ that can be influenced on a local level. This study investigated indoor, house adjacent, outdoor and city scale WSFB.

Burning was linked to $PM_{2.5}$ increases of around 175 µg/m^3 indoors, associated with fire lighting and refuelling. However, the contribution of stoves and fireplaces to indoor $PM_{2.5}$ was found to be lower than from cooking and cigarette smoking. WSFB caused short-term peaks of up to 50 µg/m^3 outside homes, typically up to a distance of approximately 10 m from the chimney, again linked to fire lighting and refuelling.

Newer appliances, highly rated for efficiency and low emissions, may have advantages in terms of air quality compared with older appliances. Although, emissions were detected from these also. Burning authorised and exempt fuels did not show benefits for indoor or outdoor air quality compared to burning seasoned wood in this study.

WSFB particulate concentrations were calculated from portable micro-aethalometer measurements. Hotspots detected along two transects in north and south London agreed well with modelled emissions. Agreement between measurements and reported WSFB odour demonstrated that smell can be a reliable indicator of WSFB pollution.

WSFB particulates contributed 8-9% of the total annual mean $PM_{2.5}$ at two urban background locations in London in 2022, both considered to be representative of the wider urban area. Over half was attributed to urban sources of WSFB within London with a slightly smaller contribution from WSFB in the regional background.

This study improves understanding of WSFB emissions and their role in the urban air quality landscape. Further observations and management are needed to enable progress towards meeting the WHO air quality guidelines 2021, especially for $PM_{2.5}$.

Summary

While $PM_{2.5}$ is still one of the key focal areas of AQ measurement, much has changed in the field over the last 30 years. The work of the LAQN and its partners exemplify the potential for impact within communities, researchers and regulating bodies. From improved technology to the expansion of measurement networks to the inclusion of citizens throughout the data collection process, AQ measurement has become increasingly innovative, collaborative and effective in its activities and outputs—and it is these values that will continue to grow and strengthen the future of AQ measurement, for the betterment of environmental and human health for generations to come.

About the ERG & the 30th Anniversary Seminar Series

Founded in 1993, the **Environmental Research Group** initially consisted of measurement, modelling and toxicology teams. 2023 is the ERG's 30th anniversary. The group is now located at Imperial College London and is nine teams strong with over 100 staff members studying air pollution, water pollution, and microplastics in order to better understand the impact of these stressors on our environment and health.

This seminar was the fourth of six as part of the ERG's 30th anniversary seminar series. More information on the ERG and the 30th Anniversary celebrations can be found here: Celebrating 30 years 1993 - 2023 | Faculty of Medicine | Imperial College London.

The ERG 30th Anniversary Seminar Series is hosted in partnership with Imperial Policy Forum, the College's policy engagement unit. More information about the Environmental Research Group's work on AQ measurements can be found on the ERG's Measurement Team Page and the Aerosol Team Page.

Photo description: Panel discussion during the *The Future of Air Quality Measurement: 30 Years of the London Air Quality Network* seminar. From left, Professor Frank Kelly, Director of the ERG; Simon Birkett, Founder and Director of Clean Air in London; Lucy Parkin, Director of ESG, KLEANBUS; and Georgina Hammerton, Senior Project Manager at The Social Innovation Partnership.