AIR QUALITY EXPERT GROUP

Air pollution horizon-scanning: Seven potential risks of relevance to the UK.

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doi: 10.15124/yao-a0db-qp05

This is a short advice note from the Air Quality Expert Group (AQEG) to the Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of Agriculture, Environment and Rural Affairs in Northern Ireland. It summarises an air quality horizon-scanning exercise undertaken at AQEG Meeting 66 on 28th September 2023. The information contained within this summary represents the authors views based on understanding and evidence available at the time of writing.

Introduction.

Horizon scanning is used to help identify potentially significant societal, economic or technological shifts which if they occurred would have major impacts on society.

AQEG generally approaches the science and technology of air pollution either through retrospective analyses – what has happened to air quality and why, - or *via* future projections. These future projections are generally short to medium term and bounded by well-established science, but it is also AQEG's role to identify evidence gaps that include uncertainties. It is valuable to periodically look beyond established evidence, towards emerging science to identify potential perturbations and assess risks that might plausibly lead to unexpected and large future air quality changes, for example those arising from climatological, technological and behavioural shifts.

Since atmospheric chemistry is often non-linear in the generation of secondary pollutants and has dependencies on weather and climate, there exists the potential also for chemical and physical tipping points that may amplify changes in air quality (either positively or negatively). Often unanticipated air quality outcomes occur not because of a single large event but instead through the accumulation or interaction of multiple smaller changes Air quality outcomes are closely linked to policy and regulation but also to hard-to-predict public choices around transport, diet and lifestyle. A possible impact from these types of future changes can be difficult to capture and often requires in-depth knowledge of the science field Also noteworthy is that the chemical nature of air pollution is not fixed; it changes over time as sources change reflecting wider regulatory, technological and social trends.

New perspectives can also arise from new scientific knowledge. The history of air pollution science is littered with events and discoveries that revealed new risks and required rapid evolution of regulation and policy. Examples include the great smog of London in 1952 and the Clean Air Act of 1956, the discovery of the pervasive harm from lead additives in fuel and the measurement campaigns of the 1970s that revealed that photochemical ozone was not just confined to warmer climates but affected air quality in western Europe too. On the health front research from the 1990's revealed that the health-harm from long-term exposure was far greater than that from short-term smog events laying the foundations for modern air quality regulation.

At AQEG meeting 66 a round-table discussion on the long-term future for air quality in the UK was undertaken. Members each highlighted up to three areas of possibly under-recognised significance in a horizon scanning context. The focus of the discussion was on events, changes and processes that required specialist knowledge of the air pollution science field to discern rather than more generalised high impact and extreme events on air quality such as war and terrorism, chemical, biological, radiological or nuclear releases (CBRN) or major chemical accidents. These latter types of events are already identified in Defra Futures Team horizon scanning activities and more broadly are well-captured in the Cabinet Office National Risk Register. A wide range of issues related to atmospheric emissions, novel materials, human behaviours, monitoring, regulation, atmospheric processes and social factors were discussed.

A number of consensus themes emerged which are summarised in this short note.

It is important to stress that the workshop did not explore the **probability** or **likelihood** of individual and/or cumulative outcomes occurring, only that the events or changes to processes were plausible based on current scientific understanding and that if actualised they could lead to large and currently unanticipated impacts on air quality.

The existence of a scenario should not be interpreted as meaning it is likely to occur, and the existence of related risk is not a criticism of current technologies, regulations or policies in the relevant sectors. The intended audience for this paper is horizon scanning professionals within Defra, Government Office for Science and related Departments that have responsibilities for sectoral atmospheric emissions. The paper is made accessible publicly since it may be of wider interest and in line with AQEG principles of open and transparent communication of its work.

Seven key horizon scan air pollution risks were (in no particular order):

- Systemic underperformance of technical and regulatory air pollution abatement.
- Multi-causal increases in atmospheric ammonia over the UK.
- Increasing concentrations and health impacts of ultrafine particles (UFP).
- Emergence of novel airborne materials and health effects
- Climate-driven drought effects and increasing PM pollution.
- Enhanced emissions of biological particles and antimicrobial resistance (AMR)
- Loss of confidence in air pollution science and increasing uncertainty in forecasting

Systemic underperformance of technical and regulatory air pollution abatement.

Very large air quality improvements have been delivered in recent decades often arising from the implementation of innovations that supported emissions abatement. However, a key learning from the past is that technical interventions to reduce pollution emissions are often less effective than anticipated at the policy design phase, and can take longer than expected to generate the desired benefits. More broadly, introducing retrospective ‘fixes’ to air pollution problems once technologies or processes are established is much less efficient and effective than pro-active avoidance of emissions as technologies are developed and approved for use. Underperformance can sometimes arise because of sub-optimal regulation, for example setting standards for total air pollution emissions from a sector or source, but not the subset of those emissions that occur in close proximity to people or sensitive ecosystems and that consequently give rise to a greater health or other adverse impacts.

The effectiveness of regulation is a key cross-cutting future issue for air quality since the pathway to net zero will require successful use of abatement technologies to manage air pollution emissions arising from a profoundly changed energy, food, buildings and transport system. For example, net zero will require the widespread use of low carbon fuels (e.g. hydrogen and biofuels) that will often be burned. It may use new chemicals at industrial scale for carbon capture and storage, create energy efficient homes that need ventilating, and deliver carbon drawdown *via* large-scale afforestation.

Abatement options for each are notionally available – for example the use of Selective Catalytic Reduction (SCR) to manage NO_x emissions from burning low carbon fuels or the selection of low VOC emitting tree species. However, should past experiences be repeated then the cumulative effects of widespread abatement under-performance on air quality may be significant. From a narrow legal compliance perspective higher than anticipated air pollution emissions in a net zero future may lead to non-attainment of outdoor air quality targets. However more important would be increased consequential productivity losses and health service costs.

The impacts of net zero on air pollution may not be evenly spread; lower income households may retain legacy combustion systems such as cars and gas boilers longer, whilst the more affluent may transfer to low carbon alternatives. Whether this will further increase disparity in exposures to air pollution would depend ultimately on differences in emissions between new and old technologies.

More broadly, widespread air pollution technological or regulatory under-performance may engender a public perception that climate-positive policies lead to negative impacts in other areas and with detrimental health outcomes. A perceived failure of air quality and public health controls in support of delivering government net zero objectives, similar for example to the 2015 ‘VW scandal’ may substantially weaken the social license for action on climate change.

Multi-causal increases in atmospheric ammonia within the UK system.

Ammonia is a critical pollutant with wide-ranging effects. Via formation of ammonium nitrate and ammonium sulfate it is a major contributor to the mass of airborne particles including $PM_{2.5}$ and is a source of excess nitrogen into soils and watercourses. Nitrogen pollution is a major factor influencing local and central government planning and development decisions and the ability of the UK to meet biodiversity and habitat objectives. Ammonia is principally viewed however as an issue for the farming sector to manage since most ammonia currently comes from fertiliser use and animal waste.

The future for ammonia is hard to predict however and includes some non-linearities. There are a variety reasons why farming may transition to using less synthetic fertiliser and more animal waste, a change which may increase gas phase emissions. Nutrient addition (either synthetic fertiliser or organic) to land could be needed to increase productivity from the same land area to meet increasing food demand, the need for energy crops, to establish new trees and support efforts to maintain or increase yields from increasingly degraded farmland.

Composting and anaerobic digestion of waste may be used in a net zero future as a source of lower carbon methane as a fuel, but this can generate ammonia as an unwanted byproduct. There is the technical potential for ammonia to become an important stand-alone fuel for the future , for example it has been mooted as being suitable for international shipping and other industries that currently rely on larger heavy fuel oil and diesel engines. Avoiding direct atmospheric leakage and loses of fuel ammonia will be critical.

There are also pressures on ammonia emissions through its use in abatement technologies such as SCR and three-way catalysts, which reduce NO_x emissions but can result in emissions of ammonia. The likely switch to alternative low carbon fuels in off-road machinery, dispatchable power and larger road vehicles will see a continued widespread reliance on these technologies.

There exists a possibility therefore of substantial cumulative increases in non-farming emissions should new uses of ammonia not all be well-managed.

There are further uncertainties in how the atmospheric chemistry of ammonia may change in the future. A future with lower nitrogen oxides (NO_x) emissions may lead to less conversion of ammonia into particle-borne ammonium nitrate and lead to more ammonia available for gas phase deposition. An increase in co-location of ammonia emissions alongside NO_x in cities and industrial areas (e.g. if used as a fuel or emitted from NO_x abatement systems) may give non-farming ammonia a disproportionately larger effect in generating secondary $PM_{2.5}$. Finally, a warmer climate would be predicted to increase volatilisation and drive more gas phase ammonia from the condensed phase. Each of these individual effects is poorly understood. However, should emissions increase, and atmospheric processes change in parallel this may lead to substantial increases in atmospheric ammonia, beyond what is currently considered in existing ammonia policies. It is also noteworthy that technologies for monitoring ammonia in air are less developed than for other pollutants.

Increasing concentrations and health impacts of ultrafine particles (UFP) .

Ultrafine particles (UFP) are defined as those with at least one dimension less than 100 nanometres. They contribute only a small amount of overall particle mass and to the metric $PM_{2.5}$ but represent a large fraction of the number of the particles found in a given volume of air. They may possibly have significant health impacts and be affected by changes to other pollutants in air. Whilst the health evidence remains very uncertain there have been some notable claims of UFP implication in enhancing the long-term risk of high-profile diseases such as dementia and Alzheimer's. Exposure may be *via* the olfactory bulb and nasal cavity, which is different to conventional wisdom that the lungs are the main exposure route for PM. There is little regulation or monitoring of ambient UFP as a class of pollutant (although it is regulated at source for new road vehicles as part of type-approval emissions standards) and they are in essence invisible within current national networks detecting $PM_{2.5}$.

Planned future abatement strategies for larger particles and some other gases may create atmospheric conditions where UFP concentrations can increase as a side effect, as UFP diffusion and uptake onto larger particles is a removal mechanism for UFP. High ambient PM concentrations can act to suppress the new particle formation (NPF) processes that create UFP. Their future concentrations are therefore extremely hard to predict. UFP are well-known to be emitted from combustion processes but there are also less well recognised sources from cooking and tyre wear. Trees are also implicated in UFP emission *via* natural organic emissions but this is an extremely complex process.

There is currently no clarity on whether the health impacts of UFP differ by their sources. It is possible that the health (toxicity, or epidemiological) evidence of effects arising from life-long exposure to UFP will become more robust, or be perceived as such by the public/media. A combination of plausibly increasing concentrations (despite lowering overall atmospheric $PM_{2.5}$ and related emissions) and an increased link (real or perceived) to high consequence disease may create a demand for a change to the current regulatory focus on $PM_{2.5}$. There may be a perception that the 'wrong' pollutant was chosen as a focus for policy and regulatory priority, undermining the wider pollution and health evidence system and credibility of PM-related targets in the Environment Act.

Emergence of novel airborne materials and health effects.

The key pollutants of relevance to climate change are well-characterised and unvarying, however air pollutants that cause harm to health and the wider environment change over time. There is continual development and sale of novel chemicals (perhaps as many as 20,000 new products per year) some of which will have the potential to become airborne as either gases or particles.

Whilst most new materials are assessed for their direct animal and human toxicity before going on sale there is very limited assessment of the fate of new materials once they are in the air. Unlike discharges to freshwater there is no obligation on those producing new chemicals to evaluate their atmosphere fate and potential subsequent toxicity. Materials may undergo atmospheric oxygenation or nitration, or indeed be formed via mechanical wear and abrasion in the case of tyre particles and microplastics. There is no routine atmospheric surveillance for airborne chemicals outside of a small number of species that are specified in air quality regulations. The emergence of new risks to health from novel materials would likely only be apparent once environmental prevalence of the material was well-established; only after developments in analytical science has an airborne and inhaled component arising from plastic degradation been detected and the health effects of this are yet to be ascertained.

As has been seen historically in the cases of asbestos, certain persistent organic pollutants (POPs) and lead in gasoline, many years can pass between a material entering the air and the major health effects being detected. There exists therefore an ongoing risk that a novel chemical product is developed and then subsequently used in large quantities that has acceptable *prima facie* toxicological properties in its native form, but that generates unanticipated harmful secondary products once in air. If those health effects are life-course and accumulating, for example carcinogenicity or mutagenicity, then many years may pass before effects can be attributed. This is a key issue being considered by the UN Science Policy Panel on Chemicals, Waste and Pollution Prevention.

Climate-driven drought effects and increasing PM pollution.

Climate change has many different impacts on air quality, some that lead to improvements and some that may degrade it. Climate change driven changes in rainfall and atmospheric circulation patterns have been published on extensively. A specific under-recognised risk may be associated with accumulative effects on air quality arising from multiple processes that are sensitive to drought conditions. Whilst individually many of these risks are already known, the potential effect of their concurrency is less appreciated.

In dry conditions there is the potential for an increase in the generation of PM *via* agitation of surface dust, for example released from vehicles on roads or windblown soils from agricultural land. Drought conditions elevate the risks of PM emissions from wildfires from forests or moorland that may be linked to both accidental and arson events. Net zero policies may well also lead to greater areas of the UK being forested. There is also an enhanced risk of urban fires in drought.

Drought in summer is frequently associated with periods of prolonged higher temperatures, meteorological conditions which lead to increased biogenic emissions of VOCs which in turn generate secondary PM and ozone. A reduced rate of dry deposition during drought can further increase peak ozone concentrations. During high temperature periods vulnerable individuals have increased susceptibly to air pollution effects due to heat stress.

Concurrent and additive effects of additional PM from surface dust, fires, and biogenic PM are all potentially amplified by climate change. These may be coincident with an increased population vulnerability to air pollution because of immediate heat stress conditions and a more general aging population demographic in the UK. PM pollution effects during droughts may therefore give rise to significantly larger short-term increases in health service demand.

Increasing emissions of biological particles and antimicrobial resistance (AMR)

Bioaerosols are ubiquitous in the air however their composition and abundance are heterogeneous reflecting both local (such as indoor microbiomes) and global (such as the emergence of contagious SARS CoV) ecological processes and environmental change. Associative links between antimicrobial resistance (AMR) and $PM_{2.5}$ have been documented, however the causality that underlies this association is not well known. Better understood are the drivers of emerging multidrug resistant fungal pathogens, whereby selection by agricultural fungicides in the environment appears to be leading to a near-ubiquitous UK exposure to pathogenic AMR fungal spores (for instance *Aspergillus fumigatus*) in the $PM_{2.5}$ range and that are resistant to clinical antifungal therapies.

It Is possible that green-waste recycling processes (introduced in part with the aim to reduce application of synthetic fertilisers in farming) may be leading to an exacerbation of AMR spores owing to increases in circular processes and regenerative farming practices. New mode-of-action fungicides will be introduced into the British farming system and there is no adequate risk assessment mechanism for assessing the potential off-target consequences of dual-use agricultural/clinical drugs on pathogens that may be widely aerosolised.

Housing quality, flood risk and rising humidity are likely leading to increases in cold or damp homes that are prone to mould overgrowth with known, and unknown, health consequences for vulnerable groups. Changes in housing type (more energy efficient homes) and increasing energy costs leading to fuel poverty may change and exacerbate exposures to indoor bioaerosols. There is no UK-based guidance on a safe level of mould growth in homes, however opportunities exist to develop predictive environmental DNA (eDNA) and other non-culture based methods to rapidly assay exposures in homes. eDNA methods for characterising the abundance and type of bioaerosol are also appropriate for use outdoors to establish baselines and to detect unusual or previously undescribed bioaerosols with unwanted health consequences. There may also be unwanted ecosystem impacts, for example crop diseases and forest fungal diseases.

Loss of public confidence in air pollution science and increasing uncertainty in forecasting.

For many years there has been broad consensus on the desirability of good air quality albeit with some media and public debate on issues related to government and corporate responsibilities, costs, and benefits of action. Recently aspects of air pollution science evidence have been challenged by the wider public, including foundational links to health and the effectiveness and benefits of interventions. This “non-expert” challenge and emergence of doubt contrasts with advances in the evidence base and the public information disseminated by organisations such as the World Health Organisation and through UK expert bodies, including the Chief Medical Officer's report on Air Pollution (2022).

Many aspects of contemporary and future air quality strategy rely on action that will be more overt in the lives of large numbers of people, in contrast to the less visible actions previously taken by small numbers of industrial emitters and product manufacturers. Air pollution interventions (e.g. low emissions and clean air zones such as ULEZ, low-traffic neighbourhoods, woodstoves etc.) have become a factor within wider culture-wars and have sometimes been framed in terms of taxation and loss of personal liberty, rather than in terms of individual and public health benefit. Air quality and related interventions are widely portrayed as only delivering short-term benefits for a small-subset of vulnerable individuals; the critical intergenerational transfer of long-term accumulating and population-wide health benefits being much less visible.

The air pollution science community is largely inexperienced in handling these types of communication issues.

There are increasing uncertainties in future air quality projections. This matters because it becomes harder to give clear technical advice about future direction to decision-makers. There is an associated risk that with the benefit of hindsight there is a discrediting of the science field because of past incorrect projections. The past 30 years have been characterised by ever-narrowing uncertainties in the basic chemistry and physics of pollution; emissions from major well-understood sources have now been controlled or eliminated. These have been replaced by smaller sources which are more diffuse and harder to quantify or by new technologies for which there is sometimes little precedent. In combination this is leading to growing uncertainties in the future projection of underlying emissions.

Improvements in air pollution in the later decades of the 20th century came about from technical interventions in a small number of well-characterised industrial processes and sites. Since this time improvements in air quality have required innovations and changes to an ever larger and more diverse set of emission sources. For example, the tens of millions of vehicles on UK roads today operate with exhaust control systems that were not present on vehicles two decades before and with brake and tyre materials of diverse proprietary composition.

Decarbonisation will lead to some radical changes in energy, food and transport emissions, but the air quality effects can be difficult to predict. Often there is no past experience of a new process or realistic emissions data to work with. There is also a high reliance on forecasting institutional and personal behaviour changes. The shift in dominant air pollution sources towards highly diffuse and often person- or home-based sources is coinciding with growth in public misinformation on air pollution evidence and attempts to discredit the scientific process. This to a degree mirrors the experiences of climate science and more recently that around COVID and will make it harder to communicate air pollution science to the public and to translate evidence to senior decision makers.

A further factor that may influence public confidence in air quality science may be the emergence of commercial forecasts and warnings for air quality from large technology companies. These may differ in their messaging and attribution from those generated by government or academic sources.

In combination, all these unconnected factors may impact negatively on the perceived strength of air quality scientific evidence, potentially weakening the social license for action and disincentivizing public, business and political engagement.