Annex 3. Air Quality Expert Group - commentary

‘Task and Finish Group’ report – Achievability of WHO Guidelines for PM2.5 in the UK

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Q1. What role might the setting of a new long term target for PM2.5 play in reducing health impacts of air pollution in the UK?

$PM_{2.5}$ is considered a non-threshold pollutant and there is no evidence that there is a safe level of $PM_{2.5}$, below which human health impacts can be ruled out. The $PM_{2.5}$ Air Quality Guideline of 10 µg m^{-3} was set by the WHO under consideration of what was deemed possible “in the context of local constraints, capabilities and public health priorities” with a global perspective. As such any target that drives reductions in exposure both above and below 10 µg m^{-3} will also drive further health benefits, independent on whether current nationally or internationally agreed limit values are being met or not. While it is therefore recognised that a threshold-based target is fairly crude, it does serve as a useful basis for driving progress in the reduction of air pollution and associated health impacts. Use of the WHO air quality guideline concentration has international provenance. However, it will be of limited use for the motivation of continuous improvement for areas that achieve this target (see Question 5) and can drive unintended negative behaviours such as ‘polluting up to’ the limit value.

DISCUSSION: The use of 10 µg m^{-3} as a threshold figure is a very crude means of quantifying the estimated effect of air pollution on human health due to the inherent uncertainties in health burdens at the lower concentrations. Also, because it is treated as a threshold, it may not accurately capture any health benefits of reducing the exposures of those just below or just above the threshold. However, it is a defined quantity to work towards, with international providence, that employs a standardized metric, so serves as a good target for air quality improvements, both nationally and locally. Also, by quantifying concentrations rather than exposure, there is less of the inherent uncertainty in estimating how people are individually affected by air pollution.

It should be noted that, as the CAS recognises, much of the human exposure to air pollutants occurs indoors. This is affected by outdoor concentration, but also by indoor sources and ventilation and filtration rates of buildings, and therefore the

reduction of outdoor air pollution alone is not necessarily sufficient to safeguard the public from the effects of air pollution.

Q2. What challenges are inherent in the setting and formulation of AQ targets (generally) and a $PM_{2.5}$ target (specifically) and how might these be best reconciled to enable effective monitoring and reporting of progress?

All AQ targets carry inherent limitations and uncertainties related to linking ambient concentrations to individual exposure. There is challenge in maintaining consistency temporally and spatially in the measurement and modelling approach used to quantify progress against the target. Our ability to model concentrations is limited by uncertainties associated with both current and projected emissions. PM is complicated further by the mixed nature of its composition and sources and also the role of secondary aerosol formation, which can respond non-linearly to changes in precursor emissions. Secondary aerosol contributes to PM concentrations at locations that are removed from emission sources presenting issues for responsibility and ability to control. Appropriate monitoring and reporting will depend on the targets chosen. A metric based on the population living in areas where the concentrations are below a certain threshold becomes very sensitive to measurement and models to quantify / predict concentrations near this threshold concentration. An exposure-based metric would reduce this sensitivity and lower associated uncertainty (see also Q5).

DISCUSSION: With any target setting, there is always a challenge associated with consistently measuring and modelling the concentrations over all locations where people are exposed and going forward in time so as to reliably measure progress against the target. There are also fundamental uncertainties concerning the exposure-dose relationship for atmospheric pollutants. For $PM_{2.5}$ specifically, there are additional challenges brought on by the fact that this is an aggregate of different pollutants from different sources, and that these sources can be both primary (directly emitted) and secondary (arise through chemistry). In terms of understanding the toxicity of $PM_{2.5}$, it is intuitive to expect that some components will have more of a health impact than others; however, a consensus has yet to be reached on which (if any) components are a better health outcome predictor than $PM_{2.5}$ mass. It has also yet to become established as to whether there is a minimum dose before which a health burden is incurred.

While the methods for monitoring $PM_{2.5}$ are well-established, the complex, mixed and dynamic nature of $PM_{2.5}$ also presents major challenges for quantitative modelling and source apportionment. Many different sources and processes must be accounted for, some of which lack reliable data in the emissions inventories and may

have to invoke chemical or physical processes that are poorly understood scientifically or not properly constrained within a given model. The formation of secondary aerosols in particular is governed by complex atmospheric processes that are known to be non-linear and interdependent, so assigning discrete sources to this category of PM is very difficult. In many cases, the initial sources of the secondary PM precursors can be upwind and outside of a given jurisdiction, thus imposing a fundamental limit on the amount of control an individual local authority may have on concentrations.

Q3. What conclusions can be drawn from the presented work with regards to the potential achievability of annual mean levels of $PM_{2.5}$ in the UK that are commensurate with WHO AQ guidelines?

Both reports conclude that concentrations below 10 µg m^{-3} are achievable for most of the UK by 2030 even under business-as-usual, with other scenarios offering bigger improvements. However, some specific urban areas (most notably in London) would still be in breach. Both reports indicate that the biggest source of improvement comes from a reduction in secondary inorganic aerosol (ammonium, nitrate and sulphate), although they differ on the importance of the other sources. A substantial part of the reduction is due to a reduction of imported pollution from mainland Europe. Here, both models assume full compliance with NECD targets from all countries, and this is a key uncertainty in the predictions which is both difficult to quantify and outside the control of UK policy. Both studies also raise the caveat that exceedances could be larger in meteorologically extreme years. The results would suggest that *halving* of the population exposed to $PM_{2.5}$ concentrations above 10 µg m^{-3}, as expressed in the CAS ambition, should be well achievable through an ambitious emission reduction programme. However, a fraction of the population will remain subject to exceedances and the accurate prediction of the size of this population is difficult.

DISCUSSION: The broad conclusion of the reports is that the annual average $PM_{2.5}$ concentration will reduce below 10 µg m^{-3} by 2030 in large areas where it is currently above 10 µg m^{-3}. Both studies agree that the CAS ambition of halving the population exposed to concentrations above the WHO guideline value should be achieved under the BAU2030 scenario, but importantly point out that inter-year variability of meteorology will lead to variation in the extent of exceedances between years. The 2030 Ct+ scenario has additional benefits over BAU2030. The two models presented give quite different results in detail but both show that by 2030 annual average concentrations will have reduced by around 20-25% to be below 10 µg m^{-3} except in large cities and in London in particular. However, the two reports differ slightly in the sources of these gains; while both studies agree that a large contributor will be the reduction of emissions from other countries, the KCL study finds this to be a larger factor than the ICL study. Generally, both studies conclude that most of the reduction will come from abatement of secondary inorganic precursors (e.g. ammonia), but the

SIA response is stronger in the KCL study, whilst the ICL study seems to indicate that a larger additional benefit will come from a reduction in primary emissions. Another detail of note is that the ICL projects potential health (and economic) benefits beyond that perceived from the simple metric of the reduction in individuals exposed to <10 μg m^{-3}, so this raises the question of what priorities to set beyond this threshold value.

Quantitative comparison of the two reports is hampered by the output statistics not being directly equivalent, but rough comparisons can be made by comparing concentrations of the different components and their changes (base case to 2030) of population weighted means (ICL) and median values (KCL). The KCL median value (in μg m^{-3}) of SIA declines from 4.13 (2012) to 2.95, - 29% (2030BC) and to 2.44, -41% (2030Ct+) whereas the ICL model population weighted mean value of SIA including water declines form 3.33 (2016) to 2.15, -35% (2030BC) and to 2.05, -38%, (2030Ct+). The KCL median SOA declines from 1.21 (2012) to 1.04, -14% (2030BC) to 0.87, -28% (2030Ct+), whereas the ICL SOA population mean value of 0.87 does not change. The primary and other components of KCL seem much smaller than those of ICL: KCL median 'primary plus other' declines from 1.05 (2012) to 0.85, -19% (2030BC) to 0.59, -44% (2030Ct+), whereas ICL population weighted mean of 'primary plus other' declines from 3.5 (2016) to 3.25, -7% (2030BC) to 2.75, -21% (2030Ct+). The overall conclusion is that KCL shows faster declines because it has a higher proportion of SIA, the component which shows the largest reductions in both models. It also reduces SOA, which does not change in ICL, and has relatively small primary components and 'other' components which are assumed to be broadly constant. ICL has much larger primary and 'other' contributions. Whilst the UK has direct control over reductions in primary components, some of the benefit the UK will gain from reductions in the SIA component is derived from precursor emissions reductions outside the UK.

Q4. What are the key uncertainties within the presented work and what additional insight might be beneficial to further inform or strengthen the findings?

Aerosol modelling suffers from a general lack of scientific understanding regarding key processes, the formation of secondary organic aerosols in particular (it is notable that this is not considered at all by the ICL model). Both the current emissions inventory and the projected scenarios are also subject to considerable uncertainty, particularly for primary particle emissions. As such, while reductions in PM in response to the abatement of the major sources (e.g. traffic, ammonia) can be expected, the absolute accuracy of the future projections cannot be assured and, specifically, both studies assume that agreed emission reduction targets for 2030 will be met across Europe. The work would benefit from a more systematic comparison of the two model outputs to diagnose their differences and potentially offer insight into

uncertainty, including validating both base case runs, and also their multi-year trend predictions, against network measurements of particle composition. To offer deeper insight into the role of specific sources, the simulations could be rerun according to a larger suite of scenarios, varying according to individual source categories and/or impacts of policy interventions.

DISCUSSION: A key uncertainty in predicting future concentrations of $PM_{2.5}$ is associated with the future emission scenarios, both for domestic sources and wider European sources. In particular, with about 50% of the UK $PM_{2.5}$ arising from emissions outside the UK, the conclusions critically depend on agreed 2030 emission targets being met across Europe.

Uncertainties also arise from the use of two modelling systems with different approaches to approximating reality. In order to gain confidence in the future projections produced by these models (or others like them), it is necessary to compare the predictions of current concentrations with measurement data and this could have been done more thoroughly with the base cases. It would ideally include the comparison of multi-year modelled vs measured trends to establish confidence in the skill of the models to respond adequately to emission changes. For instance, the figure in Appendix A of the ICL report could have been separated according to site type (e.g. urban, rural) to explore bias. It would be good to compare both models' outputs in terms of aerosol composition systematically and in tandem with AGANet, LAQN and the EMEP supersites (Auchencorth Moss and Chilbolton/Harwell). It may also be informative to directly compare the two model outputs, although it is noted that they used different base cases. More generally, it would have helped if the two models could have presented their outputs in a comparable form.

One of the dominant sources of uncertainty with modelling of this nature is in the emissions inventories, which for some primary particles and gaseous precursors of secondary particles are recognized as being highly uncertain. This affects both contemporary and projected emissions scenarios. Both models refer to adjusting some source emissions compared with the published NAEI emissions to take account of recent research that indicates omissions of some important sources and/or inappropriate spatial distributions of these sources. However, the models differ in exactly what additional sources and/or adjustments were made so it is to be expected that the model outputs and conclusions can differ. For example, the KCL study, but not the ICL study, includes an estimate of primary cooking particles and generation of anthropogenic SOA from additional diesel-related IVOC emissions, both of which are likely important in high-traffic, densely-urbanized environments where $PM_{2.5}$ is a problem. The KCL study spatially redistributes a component of its SNAP2 residential combustion emissions (which are also increased by a factor of 3 c.f. the UK NAEI) according to population density, but it is not clear if the ICL study spatially redistributes these emissions similarly. Non-exhaust emissions (NEE) from road traffic are treated differently by the models. The magnitudes and spatial and temporal distributions of all of these sources – cooking, residential solid-fuel

combustion, and NEE – remain highly uncertain. The partitioning of the emissions from these primary sources into $PM_{2.5}$ (vs coarser fractions) is also highly uncertain, and this feeds directly into uncertainty in evaluating compliance with a $PM_{2.5}$-based target. Neither model currently accounts for the new ULEZ. Given that London is the location which is predicted to suffer greatest from the exceedances, it is logical to target efforts to improve the inventory here.

There are also differences in how the models treat losses; for instance, the ICL model uses a constant drizzle model for wet deposition. None of these losses are validated in the reports, e.g. through comparison with wet deposition measurements.

Another major source of uncertainty in all air quality models is the mechanistic treatment of secondary aerosol formation, in particular SOA. The ICL study assumes SOA formation from anthropogenic precursors to be negligible and treats any SOA formed from biogenic precursors as an irreducible background. Neither of these are likely to be strictly true; recent research has shown that anthropogenic SOA may be more important than had been traditionally thought (e.g. due to IVOCs) and that the formation of SOA from biogenic emissions may be enhanced through interactions with pollutants such as sulphur, ozone and NO_x. While the model employed by KCL is more advanced in this regard, because of uncertainties in the fundamental science, there remains a considerable amount of mechanistic uncertainty concerning SOA formation, so even these findings should be treated with caution. In addition, with secondary aerosols in general, there are also uncertainties associated with whether the secondary material will likely for $PM_{2.5}$ or PM_{coarse}, the latter of which does not contribute to the target.

Neither study appears to incorporate changes in population numbers and population distributions between current day and 2030. There is therefore a need to realise that gains in population exposure in absolute terms in 2030 scenarios may be less than these simulations suggest because there are likely to be more people living in higher population density areas in 2030 than used in these simulations.

Both reports include a breakdown of the different $PM_{2.5}$ components, however when considering secondary aerosols it would be misleading to interpret a direct relationship between these and the initial precursor sources due to interdependencies and nonlinearities in the system. To further illuminate on the roles of various sources and thus potential impacts of policy mitigations, it would be informative to rerun the models for a much larger suite of emissions scenarios (e.g. varying emissions one at a time according to SNAP category or simulating the effects of individual policy interventions), although it is accepted that this would require much more computational work. For instance, all of the 2030 scenarios have considerably more modest reductions in NH_3 compared with reductions in other SIA precursors and in primary $PM_{2.5}$. In particular, the beyond BAU scenarios have no additional NH_3 reductions beyond the BAU NH_3 emissions reductions. In the ICL study, all five 2030 scenarios have NH_3 emissions reductions around ~22%, which is

only about half or less than half the reductions in emissions of the other components. What would be the consequence on modelled $PM_{2.5}$ if there were greater NH_3 reductions, given that NH_3 will be the limiting factor on SIA formation? This question is best addressed with a full ACTM, given the relative lack of sensitivity of UK $PM_{2.5}$ to SIA shown in the ICL study.

Likewise, it would also be informative to investigate the effects of NO_x, SO_2 (e.g. from shipping) and VOC emissions in the future emissions scenarios; It is likely that the anticipated further reduction in NO_x in particular will lead to more areas in the UK becoming NO_x limited, thus increasing the sensitivity of SIA to NO_x and lowering the sensitivity to NH_3. Such work would inform the selection of the most effective emission measures beyond BAU. Also, is it worth undertaking simulations of the effect on the UK of other countries also going beyond their NECD compliance?

Whilst the ICL study considers several contributors of $PM_{2.5}$ to be irreducible, the KCL study suggests that seasalt concentrations, although already small, will decline significantly between 2012 and 2030 (Fig. 7b). The mechanism behind this somewhat surprising response is not elucidated in the report.

An assessment of overall uncertainty is absent in both studies and notoriously difficult to achieve. The fact that the models arrive at similar conclusions but based on different attributions of the $PM_{2.5}$ reductions to responses in SAI and primary aerosol indicates that there are considerable uncertainties in the modelling systems.

Q5. What alternative formulations (beyond a concentration threshold) might be worthy of consideration in order for the target to most effectively drive benefits for public health?

In order to motivate continuous improvement in air pollution and thus health outcomes for areas below the annual threshold, one of the variations of a population-weighted mean concentration metric should be considered. This would like more closely to exposure and therefore the potential for health impacts and is less sensitive to the ability of models and measurements to quantify concentrations around 10 $\mu g\ m^{-3}$**.**

DISCUSSION: Although the WHO frames ambitions to protect human health in terms of guideline values and standards, the fact remains that PM is a non-threshold pollutant and evidence suggests that further reduction in exposure can further reduce health impacts, even below the threshold of 10 $\mu g\ m^{-3}$. Thus, there is no scientific rationale for distinguishing between progress made in reducing concentrations above and below this threshold. Similarly, the CAS sets the ambition to reduce exposure in terms of the number of people living in areas with concentrations above 10 $\mu g\ m^{-3}$. Whilst this is a tangible ambition that is easy to communicate to the public, additional metrics such as population-weighted mean will be needed to monitor the progress. It may also be of value to monitor an upper percentile (e.g. 90%) of population-weighted $PM_{2.5}$ concentration.

Quantifying population health gains through an exposure reduction approach is somewhat less affected by the systematic uncertainties in modelling all $PM_{2.5}$ component concentrations, since the quantification is assessed through relative changes in concentration rather than absolute concentrations against a fixed concentration value. It also informs the public of the full benefit of the health gains, as compared with a target based on numbers of people with exposure exceeding a threshold for which some of the health gains from exposure reduction are 'hidden.' There is precedent of an exposure reduction target in the current Average Exposure Indicator for $PM_{2.5}$. In its simplest expression, the target of an exposure reduction approach could be a requirement to reduce concentration everywhere.

While still threshold-based, it may also be prudent to utilise a metric based on reduction in population-weighted $PM_{2.5}$ exceedance of 10 $\mu g/m^3$, expressed either as a 'population number x accumulated exceedance concentration' metric (analogous to the ozone AOT40 metric) or as the 'average population-weighted exceedance concentration' as defined in the ICL study. The two are simply linearly related by the population number, but the latter variant is conceptually easier to understand. These capture not just the amount of population living with excess $PM_{2.5}$, but the amount to which they are doing so. However, this approach would not reflect the health benefit arising from further reduction of concentrations already below 10 $\mu g/m^3$. However, such an accumulated-exceedance metric could be based on a lower threshold value, including 0 $\mu g/m^3$.

As with all targets setting solely an attainment date encourages assessment only at that point in time. This approach is vulnerable to meteorological variations between years and does not encourage continuous assessment of progress towards the objective. Supporting the development of modelled trajectories towards the objective and annual assessment of progress against that through considering trends over recent years could enable early diagnosis of potential non-attainment and remedial action.