

We thank the reviewers for taking time to read the article thoroughly and their valuable comments. We have answered all comments and we think the quality of the article has significantly improved in the review.

Reviewer #2

This article is a short opinion paper in which the authors propose three specific topics (use of sensors for regulatory monitoring, siting criteria and new air pollutants to monitor) that should be considered for the current revision of the European Air Quality directive. This article provides in my view a valuable input to this review process. It is well written and is also of interest to readers who are not directly involved in the review of the Air Quality Directive and even to readers who are not familiar with this legal framework document. This paper should therefore be published in ACP.

I have few comments that should be taken into account:

1. Page 2, last section: I don't really understand what the authors mean with the sentence. "Currently, the devices used for measurement-based online observation are almost exclusively limited to fixed measurement types." What are measurement-based online observations, and are the authors advocating for mobile measurements? Please check if this is clear or rephrase.

'Measurement-based online observations' refers to observations that are made using actual measurement instruments (no modelling or objective estimation) and which produce data in real-time (concerns mainly PM monitoring; no manual filter replacement and weighing). The term 'fixed measurement' in this context refers to the most stringent and accurate measurement mode (see Table 1 in the preprint) and not the type (mobile or stationary) of the measurement. We are not advocating for mobile measurements to be included in the AAQD. The wording used in the AAQD for fixed (sometimes also referred to as 'continuous') and indicative measurement modes is slightly confusing, and perhaps not very well thought-out.

To be clearer, the last section of page 2 has been rephrased as:

"Currently, the devices used for measurement-based (fixed or indicative measurements; no modelling or objective estimation) online observations are almost exclusively limited to the most accurate fixed measurement types."

Then the authors state that type approval is mandatory for regulatory measurements. I think this is not correct (but maybe I'm wrong): Regulatory measurements must be done according to the reference method as defined in EN standards, and the easiest way to do this is by using an instrument that is type approved according to the corresponding EN standard. However, any other method can be used which give results that are equivalent to the reference method. Of course, equivalence needs to be demonstrated (see the Air Quality Directive). I therefore also don't think that the conclusion is correct that there is no "incentive for a company ... (page 3, first line)".

This is an unclear point in the AAQD, and we are not entirely sure what is the correct interpretation. As noted by the reviewer, it is said in the AAQD that a reference method OR a method equivalent to the reference method can be used if the equivalence is demonstrated to be sufficient (not necessarily type-approved). We have discussed this issue with the Finnish National Reference Laboratory (NRL) for Air Quality, and our understanding is that while type-approval may not be an absolute necessity it is, however, a standard practice to obtain one from the TUV. We speculate there are a few reasons for

this. 1) Once obtained, the type-approval is valid in all Member States. This means that the instrument can be used in other EU countries with the same type-approved certification status. The instrument must still undergo a demonstration of equivalence, which means that the suitability of the instrument for the specific measurement environment, where it is about to be used, is ensured. To our understanding, this demonstration is different and less laborious than the one alternative to the type-approval process. 2) According to the Guide to demonstration of equivalence of ambient air monitoring methods (<https://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf>), the demonstration of equivalence should be carried out by a laboratory nominated by the Member State's National Competent Authority (NCA), which typically means that the NRL conducts the testing. When coupled with the notion that the process of demonstrating equivalence appears to be similar to that of the corresponding EN reference standards, it is likely that the obtaining of a type-approval and the equivalence demonstration without type-approval are equally heavy processes. Therefore, it may be more appealing for the companies to proceed with the formal type-approval route.

This issue pointed by the reviewer is valid, and the following change was made:

"This is at least partly due to the long and costly process of acquiring a device type- approval, which is ~~mandatory~~ common practice if regulatory measurements are to be made."

2. The authors suggest that low-cost sensors can/should play a role in the hierarchical network of regulatory observations, and they somehow imply that sensors are capable for providing indicative measurements (Figure 1). I think, however, that this is what we currently expect or maybe hope, but to my knowledge the current literature does not show that sensors are in real-world applications and over longer time periods capable of providing data of higher quality than modelling or objective estimation. Anyhow, it is clear that a good data quality with sensors will not come for free, appropriate strategies for quality assurance and control must be implemented that will lead to significant operational costs. Maybe the authors want to mention this.

It is fair to say that low-cost sensors have their problems, and instead of gaining better understanding of the measured air quality, the use of low-cost sensors may in some cases lead to even more confusion and uncertainty due to the lack information regarding what the sensors are truly measuring. We slightly disagree on the statement that the literature shows no examples of successful sensor deployments where objective estimation, and to some degree modelling, would be a more appropriate way of assessing air quality. There are certainly weaknesses associated with these observation modes as well. It is true that improved quality will likely lead to increased overall costs as well. However, the key point and an open-ended question is whether the cost-benefit ratio of sensors would still indicate them to be a justifiable addition to the list commonly used measurement devices. It is worth noting that one of the main factors driving low-cost sensors forward has been the high unit and operational costs of the conventionally used instruments.

Following comment was added to the manuscript page 3:

"It is likely that the cost of owning and operating sensors would increase as a result of formal performance testing and improved overall quality. However, we believe that standardization is the most appropriate way to proceed at this stage, and it remains to be seen how the cost structure of sensors eventually compares to the conventional high-cost instruments."

3. In the summary and conclusions section it is stated that "technological development of air quality sensors is advancing rapidly". True, there is significant technological development in PM sensors, or the miniaturization of optical particle counting technologies. However, for gas sensing the applied technologies in air quality sensors (e.g. electrochemical cells and metal-oxide sensors) are not new and improvements are rather slow. Maybe we are misled by the fast technological developments in sensor integration, data communication, storage, and visualization etc. Given the improving air quality in Europe (e.g. NO₂), technological developments of sensors are needed so that they can play a role in regulatory air quality monitoring. If the authors agree, they could add a sentence.

We agree. The sentence has been rephrased as:

"Technological development of air quality sensors is advancing rapidly but more is needed for the sensors to have a major role in regulatory air quality monitoring."

4. Page 3, 2nd paragraph. I don't the first sentence "Although the testing protocol ...", is linguistically correct, please check.

The sentence was rephrased as follows:

"Although the testing protocol should be less exhaustive in order for companies to apply for device type-approval at a lower threshold, it is equally important that no major compromises are being made with respect to the quality criteria of the testing protocol; ..."

5. Page 4, line106, typo, should be "zones".

Corrected.