

Title: Pioneering next-generation air quality monitoring by metrological validation of low-cost particulate matter sensors

Abstract

Low-cost sensors (LCS) are transforming the ambient air quality (AQ) monitoring with the prospect of delivering spatially dense data in real time through the implementation of large networks, which complement the established reference methods defined in European AQ Directives. This PRT is focused on addressing the metrology issues required to facilitate the uptake and application of this new technology, with focus on particulate matter (PM) measuring LCSs and by following the 002 CEN TC264 “Implementation low-cost sensor in air quality monitoring” need proposed after the consultation with standardisation bodies. It involves standardization activities with metrological validation of the Technical Specifications developed in CEN/TC264/WG42 by independent evaluation of LCSs, improving current European facilities for type-testing of LCSs, and ultimately facilitate uptake of developed knowledge and testing methods.

Keywords

Air quality monitoring; low-cost sensors (LCS); particulate matter (PM); standardisation; aerosol exposure chamber; field co-location testing; ambient air quality; indoor air quality; PM mass concentration; calibration aerosols.

Background to the Metrological Challenges

In 2020 in the EU, 96 % of the urban population was exposed to air pollution to levels of fine PM (PM_{2.5}; particles with diameter less than 2.5 µm) above the guideline level set by the World Health Organization (WHO). Health-based guideline levels by WHO for ambient PM_{2.5} and PM₁₀ were reduced in 2021 to annual mean of 5 µg/m³ and 15 µg/m³, respectively; thus, local and national authorities are on the frontline in taking action to reduce air pollution levels using the EU Air Quality directives (2008/50/EC). Current AQ monitoring sites include complex and expensive reference monitoring equipment, and they are used in low spatial density in fixed locations over a wide geographical area. LCS systems, however, are changing the paradigm in air quality monitoring and, in recent years, have been deployed as large networks in pilot studies to measure air pollution at a spatial and temporal resolution far beyond that of existing reference instruments. Despite this attractive perspective, widespread use of LCS systems for AQ monitoring is lagging mainly because these sensors often suffer from poor to modest performance under variable environmental conditions and pollution levels, which results in unreliable measurements. Moreover, LCS systems are poorly characterised with no standardised validation methods. External evidence from sensor and system manufacturers indicates that the lack of a standard validated protocol is a significant barrier to an orderly expansion of the market.

In Europe, CEN TC264 (Air Quality) WG42 is developing a “Technical Specification (TS)” for performance evaluation of low-cost air quality sensor systems [1]. The second part of this TS (CEN/TS 17660-2) is currently under development and concerns the measurement of PM in ambient air. The draft TS describes common procedures to evaluate the performance of PM measuring LCS systems to the requirements of EU AQ Directive for three classes corresponding to indicative measurements, objective estimation, and other application. It also proposes a choice of cost-effective routes in type-testing of these LCS systems based on a balance of field and laboratory tests. However, metrological validation of the procedures defined in this TS with extended datasets is currently missing—an essential part to convert the TS into a full standard.

The performance evaluation of LCS systems is through co-location with reference instruments (or equivalent instruments calibrated against reference instruments) under ambient conditions and sampling ambient air pollutants, but the method is time-consuming, costly, and covers a relatively limited range of environmental conditions (temperature and relative humidity, RH) and pollution level. Laboratory testing of low-cost gas or PM sensors in an “environmental chamber” or “exposure chamber” has been suggested. Nevertheless, they

often suffer from poor to modest design for accurate/traceable PM concentrations over a wide range of particle size (from fine to coarse). To address this caveat, several aerosol mixing/exposure chambers were developed at NMIs and DIs as part of the EMPIR project 16ENV07 AEROMET, where calibration aerosols with traceable number concentration are produced and used in the exposure chambers. However, not all available chambers have a means to control environmental conditions over a range relevant to Europe. These chambers are also not characterised under high RH to ensure that homogeneous or heterogeneous condensation does not occur in the chamber. Further, previous EMPIR projects such as 18HLT02 AeroTox and 16ENV07 AEROMET have developed several types of well-characterised ambient-like calibration aerosols. Despite these developments, many of the available chambers were designed for calibration and testing of optical particle counters which operate based on single particle counting. Most low-cost PM sensor systems, however, work based on the measurement of total light scattering from PM (similar to nephelometer), which is then converted to PM mass concentration (in $\mu\text{g}/\text{m}^3$). Thus, to evaluate the performance of such sensors, the mass concentration of calibration aerosols in the exposure chambers must be measured and tightly controlled.

The developed capabilities will be used extensively for round-robin comparisons to underpin the metrological validation of CEN/TS 17660-2 and to further improve performance requirements for LCS systems. As a result of these developments, the TS will be converted into full standard faster and European low-cost air quality sensor networks will ultimately have better measurement accuracy.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on metrology research necessary to support standardisation of next-generation air quality monitoring with low-cost particulate matter sensors.

The specific objectives are

1. To underpin the metrological validation of CEN technical specifications (TS) developed by CEN/TC264/WG42 (such as CEN/TS 17660-2 “Air quality – Performance evaluation of air quality sensor systems – Part 2: Particulate matter in ambient air”) to ensure that the TSs are fit for purpose and can be turned into full standards. To include in the validation specific performance requirements (e.g. indicative measurements, objective estimation, and other applications) for PM measuring low-cost sensor (LCS) systems.
2. To retrofit current aerosol exposure chambers at participating institutes, if necessary, to ensure a range of relative humidity (RH), temperature, and PM concentration representative and valid for Europe. To maintain high RH levels (85 %–95 %) while ensuring condensation does not alter the properties of PM.
3. To use calibration aerosols representative of ambient PM, covering both fine ($< 2.5 \mu\text{m}$) and coarse ($2.5 \mu\text{m} - 10 \mu\text{m}$) PM, to improve the traceability in PM mass concentration (target expanded uncertainty $< 5 \%$ at $k = 2$) as the primary output metric by LCS systems. To produce test aerosols with properties representative of PM from biomass sources (e.g. wildfires, wood stoves) through the development and standardisation of a laboratory-based biomass aerosol generator.
4. To develop improved calibration methods for enhanced LCS system performance by evaluating the performance of a range of commercial LCS systems in the improved chamber facilities (objective 2) and using the new test aerosols (objective 3). These LCS systems will be also exposed to real ambient conditions in the field. By considering the laboratory and field tests results and their uncertainties, improved performance requirements will be developed for LCS systems to be used in the TS.
5. To collaborate with the technical committee CEN/TC264/WG42, and the users of the standards they develop to ensure that the outputs of the project are aligned with their needs, including the provision of a report on next-generation air quality monitoring using low-cost particulate matter sensors and recommendations for incorporation of this information into future standards at the earliest opportunity.

The proposed research shall be justified by clear reference to the measurement needs within strategic documents published by the relevant Regulatory body or Standards Developing Organisation or by a letter signed by the convenor of the respective TC/WG. EURAMET encourages proposals that include representatives from industry, regulators and standardisation bodies actively participating in the projects. The

proposal must name a “Chief Stakeholder”, not a member of the consortium, but a representative of the user community that will benefit from the proposed work. The “Chief Stakeholder” should write a letter of support explaining how their organisation will make use of the outcomes from the research, be consulted regularly by the consortium during the project to ensure that the planned outcomes are still relevant, and be prepared to report to EURAMET on the benefits they have gained from the project.

Proposers should establish the current state of the art and explain how their proposed research goes beyond this. In particular, proposers should outline the achievements of the EMPIR projects 16ENV07 AEROMET and 18HLT02 AeroTox and how their proposal will build on those.]

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.0 M€ and has defined an upper limit of 1.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 30 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the ‘end user’ community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g., letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the air quality sensor sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of the Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

- [1] *002 CEN TC264 Implementation low-cost sensor in air quality monitoring.*
<http://www.metpart.eu/normative-call-2022>