

Sensor Network Metrology Across Sectors

FunSNM Workshop Summary Report

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1 Introduction

This report summarizes a series of technical workshops organized within the framework of the European project FunSNM (Fundamental Principles of Sensor Network Metrology) to address metrology, data quality, and uncertainty evaluation in distributed sensor networks. The purpose of these workshops was to present novel methodological developments and software tools developed in the project, foster dialogue with end-users, and gather practical insights and feedback across three key sectors: industrial processing, environmental monitoring, and utilities.

1.1 Overview of the Workshop Series

The series comprised three targeted events with a total of more than 230 participants:

- **Industrial Processing:** 6 May 2026 (*Online*)
- **Environmental Monitoring:** 28 November 2025 (*Online*)
- **Utilities:** 28–29 October 2025 (*Hybrid: DTU, Denmark and Online*)

2 Workshop: Industrial Processing

The workshop on industrial processing was held online on 6 May 2026, organised by NPL with support from DTI and VTT in collaboration with the *23IND11 ThermoSI*-project. It brought together over 60 participants from industry, academia, and national metrology institutes.

The event featured 9 technical presentations split across two main sessions. The first session focused on embedded SI traceability for industrial applications, covering topics such as traceable thermal imaging, practical Johnson noise thermometry, phosphor thermometry for high temperatures, and AI approaches to thermometry. The second session focused on sensor network metrology, featuring presentations on generic network tools, data-driven optimization of district heating networks, drift correction techniques for thermocouple networks, and industrial digitalization trends.

The Q&A session highlighted key themes in modern industrial thermometry, particularly the ongoing evolution of Digital Calibration Certificates (DCCs), where adoption is increasing but global standardisation remains incomplete, alongside concerns around ensuring data security and integrity in digital systems. Participants showed strong interest in extending advanced drift monitoring methods—such as network-based approaches used for Pt-Rh thermocouples—to other sensors like platinum resistance thermometers, and raised important questions about maintaining SI traceability for self-validating thermometers. Discussion also touched on practical industrial challenges, including district heating system

flow management, as well as emerging measurement technologies such as thermochromic materials, phosphor thermometry, and thermal imaging techniques for calibration and gradient assessment. Overall, the session reflected a community focus on digital transformation, improved traceability frameworks, and the validation of innovative measurement and calibration methods, supported by positive feedback on the breadth and relevance of the topics covered.

3 Workshop: Environmental Monitoring

The environmental monitoring workshop was conducted online on 28 November 2025, organised by VTT, UH, and METAS. It attracted over 100 online participants representing environmental monitoring networks, research infrastructures, and metrology institutes.

The workshop included 12 technical presentations organized into three sessions. The morning session linked sensor network developments with EU air quality directives and large-scale research infrastructures (such as ACTRIS and SMEAR II), alongside updates from European Metrology Networks (EMN MathMet, EMN COO, and EMN PolMo). Together, these contributions demonstrated strong alignment between FunSNM objectives and EMN priorities, particularly regarding low-cost sensors, network-level non-conventional calibration, and regulatory support.

The remaining sessions presented technical developments in accounting for spatio-temporal error correlations using Gaussian processes, ISO-based standardized data quality dimensions, infrastructure topologies, agent-based software frameworks, and semantic descriptions. Applied case studies demonstrated global calibration models for low-cost sensors, particle pollution mapping in the Paris region, ML-based soft sensors for ozone estimation, and Laplace-domain tools for in-situ drift detection.

Overall, the workshop demonstrated that sensor network metrology is progressing toward integrated, automated, and system-level methodologies. Key technical challenges identified across presentations included correlated uncertainties, scalable calibration and traceability transfer, uncertainty propagation in AI-based methods, and machine-interpretable information in sensor network metrology. The FunSNM project has since continued to address these challenges through coordinated methodological development, software tools, and applied demonstrations, contributing to the establishment of robust metrological foundations for sensor networks.

Feedback gathered from the audience highlighted strong interest in the open-source software tools made available by the project and generated constructive discussions regarding how spatial and temporal error correlations can be practically incorporated into regulatory air quality reporting without overestimating or underestimating network measurement uncertainties.

4 Workshop: Utilities & District Energy

The utility-focused workshop was held as a two-day hybrid event on 28–29 October 2025 at DTU Lyngby Campus, Denmark, organised by DTI in collaboration with DTU Construct and IEA DHC Annex TS9. It brought together approximately 70 participants (around 50 attending in person and 20 joining online). The second day included technical site visits to a large-scale pit thermal energy storage facility at Høje Taastrup Fjernvarme and a 5th-generation district heating and cooling (Termonet) network in Jyllinge.

The event featured a comprehensive multi-block agenda with over 15 presentations. A dedicated block was focused on sensor network metrology, featuring presentations on measurement uncertainty evaluation in sensor networks, standardized data quality metrics, infrastructure and topology requirements for distributed networks, and continuous in-situ parameter identification. Specifically, case studies demonstrated the application of Unscented Kalman Filtering (UKF) to hourly heat meter data, allowing for the automated identification of temperature measurement offsets and service pipe insulation degradation without requiring physical inspections.

Participant survey responses and panel discussions provided highly positive feedback regarding the combination of research-based insights and applied industry case studies. Discussions emphasized key practical challenges facing the utility sector, including handling missing data points, data privacy, standardized data exchange across equipment manufacturers, and the need to translate advanced research algorithms into clear commercial business cases for utility operators.

5 Summary of Stakeholder Feedback and Conclusion

Participant evaluations across all three events demonstrated high overall satisfaction with both the organization and technical content of the workshop series. Across the different sectors, stakeholders consistently highlighted the need for improved data standardization, seamless interoperability between multi-vendor platforms, and clear frameworks for digital security. Furthermore, discussions underscored a shared priority to bridge the gap between advanced mathematical models and practical, cost-effective implementation within daily operational workflows. Overall, the three workshops successfully engaged a broad European audience and fostered meaningful knowledge exchange across the industrial, environmental, and utility sectors. Sincere thanks are extended to all speakers, organizers, and participants for their active involvement, constructive questions, and valuable contributions throughout the series.