European Metrology Network for Pollution Monitoring

Strategic Research Agenda
Version 1.0 (09/2024)

EURAMET

POLLUTION MONITORING

Authorship and Imprint

This document was developed by the EURAMET e.V., European Metrology Network (EMN) for Pollution Monitoring.

Authors: Dirk Arnold (PTB, DE), Bertille Bonnaud (LNE, FR), Costis Bouroussis (METAS, CH), Suleyman Can (UME, TR), Romain Chasseigne (LNE, FR), Nathalie Guigues (LNE, FR), Diane Gumuchian (LNE, FR), Sarah Hill (LGC, UK), Aida Jotanovic (IMBiH, BA), Petr Kovar (CMI, CZ), Béatrice Lalère (LNE, FR), Teemu Näykki (SYKE, FI), Andreas Nowak (PTB, DE), Hayley Pennetta (LGC, UK), Panayot Petrov (NPL, UK), Christian Piechotta (BAM, DE), Dominique Rodrigues (LNE, FR), Enver Sadikoglu (UME, TR), Rudolf Schneider (BAM, DE), Will Webster (LGC, UK), Philipp Wittwer (BAM, DE) on behalf of the EMN for Pollution Monitoring with input from the EMN Members.

Part of this work has received funding from the EMPIR programme (Project 20NET03 'Support for a European Metrology Network on pollution monitoring'). The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR participating states.

Version 1.0 (09/2024)

EURAMET e.V.
Bundesallee 100
D-38116 Braunschweig
Germany

E-Mail: secretariat@euramet.org
Phone: +49 531 592 1960

Official language

The English language version of this document is the definitive version.

Copyright

ISBN 978-3-942992-97-8

Image on cover page: istockphotos.com/fermate
Images on page 13: 1. istockphoto.com/Rawpixel, 2-3, 5 & 7-8. Courtesy of NML at LGC,
4. istockphotos.com/ra2studio, 6. istockphoto.com/Ekkasit919
Images on page 26: 1. istockphoto.com/Максим Шмаков, 2. istockphoto.com/pcess609,
3. istockphoto.com/archerix, 4. Courtesy of NML at LGC, 5. istockphoto.com/EtiAmmos
6. istockphoto.com/eugenesergeev

Further information

This is the first version of the Strategic Research Agenda for EMN for Pollution Monitoring, which provides guidance towards metrology needs and the technical challenges that need to be solved as a priority through collaborative efforts between National Metrology Institutes (NMIs), Designated Institutes (DIs) and stakeholders. This document will be revised periodically in accordance with priority changes from the Pollution Monitoring community.

For further information about this document, please contact your national contact person of the EURAMET European Metrology Network on Pollution Monitoring (see https://www.euramet.org).

Table of Contents

List of Abbreviations

ACTRIS	Aerosol, Clouds and Trace Gases Research Infrastructure
AI	Artificial Intelligence
AMR	Antimicrobial Resistance
AQUILA	Air Quality Reference Laboratories Association Network
Am-241	Americium-241
As	Arsenic
BaP	Benzo-a-pyrene
BioAbfV	Bioabfallverordnung (Ordinance on Biowastes)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
Be-7	Beryllium-7
CCIR	Consultative Committee for Ionizing Radiation
CCQM	Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology
CCQM GAWG	Consultative Committee for Amount of Substance Gas Analysis Working Group
Cd	Cadmium
CEN	European Committee for Standardisation
CMC	Calibration Measurement Capabilities
CO	Carbon Monoxide
CRM	Certified Reference Material
Cs-137	Caesium-137
Cs-134	Caesium-134
C6H6	Benzene
DEFRA	Department for Environment Food & Rural Affairs
DG ENV	EU Directorate-General for Environment
DG GROW	EU Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
DIs	Designated Institutes
DNA	Deoxyribonucleic acid
EC	European Commission
eDNA	Environmental DNA
EMEP	European Monitoring and Evaluation Programme
EMN	European Metrology Network
EMN COO	European Metrology Network Climate Ocean Observation

EMN POLMO	European Metrology Network for Pollution Monitoring
EMPIR	European Metrology Programme for Innovation and Research
EMRP	European Metrology Research Programme
EOSC	European Open Science Cloud
EPM or METPART	European Partnership on Metrology
EQA	External Quality Assurance
ERLAP	European Reference Laboratory for Air Pollution
ESDAC	European Soil Data Centre
EU	European Union
EURAMET TC-F	Technical Committee for Flow
EURAMET TC-IR	Technical Committee for Ionising Radiation
EURAMET TC-IM	Technical Committee of Interdisciplinary Metrology
EURAMET TC-MC	Technical Committee for Metrology in Chemistry
EURAMET TC-IR-WG2	Technical Committee for Ionising Radiation Working Group 2
EV	Electric Vehicles
GAP	Gemeinsame Agrarpolitik (Common Agricultural Policy (CAP))
Hg	Mercury
H2	Hydrogen
I-131	Iodine-131
IAEA	International Atomic Energy Agency
IAWG	Inorganic Analysis Working Group
IMPEL	European Union Network for the Implementation and Enforcement of Environmental Law
IoT	Internet of Things
IRCM	International Committee for Radionuclide Metrology
IPPC	Integrated Pollution Prevention and Control
IRWG	Isotope Ratio Working Group
ISO REMCO	International Organization for Standardisation Committee on Reference Materials
ISO TC 264	ISO Technical Committee 264
JNP	Joint Network Project
JRC	Joint Research Centre
JRC REMON	Joint Research Centre Radioactive Environment Monitoring
K-40	Potassium-40
LOD	Limit of Detection
ML	Machine Learning

MS	Mass Spectrometry
NAWG	Nucleic Acid Analysis Working Group
NH3	Ammonia
Ni	Nickel
NMHC	Non-Methane Hydrocarbons
NMIs	National Measurement Institutes
NORMAN	Network of Reference Laboratories, Research Centres and Related Organisations for Monitoring of Emerging Environmental Substances
NO2	Nitrogen Dioxide
NOx	Nitrogen Oxides
O3	Ozone
OAWG	Organic Analysis Working Group
PAHs	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PEMS	Portable Emissions Measurement System
PFAS	Polyfluoroalkyl Substances
PFOA	Perfluorooctanoic Acid
PFOS	Perfluoroctanesulfonic Acid
PM	Particulate Matter
PMT	Persistent Mobile Toxic
PRTs	Potential Research Topics
PT	Proficiency Testing
Ra-226	Radium-226
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RMs	Reference Material
SI	International System of Units
SO2	Sulfur Dioxide
Sr-90	Strontium-90
SRA	Strategic Research Agenda
SVG	Soil Value Guidelines
UBA	Umweltbundesamt (German Environment Agency)
Tc-99	Technetium-99
UDE	University of Duisburg-Essen
UFP	Ultra Fine Particles

UKRI	UK Research and Innovation
UWWTD	Urban Wastewater Treatment Directive
VOCs	Volatile Organic Compounds
WE	Water Europe
WFD	Water Framework Directive
WWQA	World Water Quality Alliance

Executive Summary

The Strategic Research Agenda (SRA) for the European Metrology Network for Pollution Monitoring (EMN POLMO) identifies the key measurement challenges and opportunities in pollution monitoring and sets out a roadmap for future research and development. The SRA is a living document that will be updated on an annual basis to reflect the latest developments in the field.

Key Measurement Challenges

The SRA identifies several key challenges in traceable pollution monitoring, including the need for:

- Novel fit-for-purpose measurement approaches to address unmet stakeholder needs. This is essential to ensure that pollution data is reliable and can be used to make informed decisions.
- Support for more portable and affordable measurements. This is needed to make pollution monitoring more accessible and cost-effective.
- More integrated measurements. This is important for understanding the complex interactions between different pollutants.

Key Opportunities

The SRA also identifies several key opportunities in pollution monitoring, including the potential for:

- Using novel sensor technologies which may have the potential to provide more accurate, sensitive, and portable measurements.
- Developing new data analysis methods based on emerging technologies such as AI or ML. These methods can be used to extract more information from pollution data and to identify trends, patterns, and dependencies.
- Improving international cooperation via standards development and interlaboratory studies. This can help to share best practices, develop more harmonised measurement methods, and demonstrate equivalence of measurements.

Roadmap for Future Research and Development

The SRA sets out a roadmap for future research and development in pollution monitoring. This roadmap includes a number of specific research priorities, such as:

- Developing and validating new methods for measuring emerging pollutants (contaminants of emerging concern). Emerging pollutants are pollutants which are known or suspected to be harmful to human health and the environment, but for which regulations have only recently been established, or are still in development.
- Improving the relevance, accuracy, and precision of measurements of existing pollutants. This is important to ensure that pollution data is reliable and can be used to make informed decisions.
- Developing and validating new methods for measuring the combined effects of multiple pollutants. This is important to understand the complex interactions between different pollutants and to assess the overall risk to human health and the environment.

- Developing and validating new methods for measuring pollutants in the field in real time. This is important for monitoring pollution levels and for responding to pollution incidents, particularly in areas that are difficult to access.

Conclusion

It is hoped that this SRA will become a valuable resource for anyone who is interested in pollution monitoring. It provides a comprehensive overview of the key challenges and opportunities in the field, and it sets out a roadmap for future research and development. The SRA will be updated on an annual basis to reflect the latest developments in the field, and it will be a valuable tool for ensuring that pollution monitoring continues to meet the needs of European society.

1 INTRODUCTION

1.1 Context: Grand challenges in pollution monitoring

In a Europe striving for a healthier and more sustainable future, the air we breathe, the water we drink, and the land we tread upon face unprecedented challenges. Pollution in its many forms poses a threat to ecosystems, public health, and quality of life. Metrology has an important role to play in addressing these challenges by providing the high-quality data necessary to support Europe's progress towards a zero-pollution ambition.

In October 2021 the EU Commission launched five new 'EU missions', new and innovative ways to work together and improve the lives of people in Europe and beyond.[1] EU missions aim to tackle big challenges in health, climate, and the environment, and to achieve ambitious and inspiring goals in these areas. These missions are:

1. Adaptation to Climate Change: support at least 150 European regions and communities to become climate resilient by 2030.
2. Cancer: working with Europe's Beating Cancer Plan to improve the lives of more than 3 million people by 2030 through prevention, cure, and solutions to live longer and better.
3. Restore our Ocean and Waters by 2030.
4. 100 Climate-Neutral and Smart Cities by 2030.
5. A Soil Deal for Europe: 100 living laboratories and lighthouses to lead the transition towards healthy soils by 2030.

Pollution monitoring has a role to play in all these missions.

Figure 1: The European Green Deal (Source: EU Commission COM/2019/640)

Mission 1: Adaptation to Climate Change & Mission 4: Development of Climate Neutral Cities

The European Green Deal (see Figure 1) is the central pillar of the Commission's commitment to tackling climate and environmental-related challenges, and a zero-pollution ambition for a toxic-free environment is a key element of this. The Green Deal acknowledges that "the EU needs to better monitor, report, prevent and remedy pollution from air, water, soil, and consumer products and to look more systematically at all policies and regulations".[2] This highlights the need for a robust metrology infrastructure in this space.

Metrology will also be needed to support the Zero Pollution Strategy's ambitions for the challenges facing Europe's cities including the aim of reducing the health impact of particulate air pollution by 55% by 2030[3] and promoting zero-pollution buildings through the New European Bauhaus initiative.[4]

Mission 2: Cancer

In 2019, the European Environmental Agency estimated that 254,000 deaths every year in Europe are attributable to cancers caused by environmental pollution.[5] Indeed, many of the highest priority chemicals identified by the EU's chemicals strategy for sustainability towards a toxic-free environment are known carcinogens.[6] One such example are polyfluoroalkyl substances (PFAS). In 2023 two common PFAS (perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS)) were reclassified by the World Health Organization's International Agency for Research on Cancer as Group 1 and Group 2B carcinogens respectively.[7,8] PFAS are known as "forever chemicals" which do not break down easily and have significant potential for bioaccumulation, and thus the need to be able to accurately monitor their presence in the environmental chain is clear.

Mission 3: Ocean and Waters

The Zero Pollution Strategy acknowledges the centrality of the Water Framework Directive (WFD) in ensuring the preservation of the quality of the water we drink and the seafood we eat.[3] Metrology will be required to support the provisions of this legislation including limit values and characterisation of at-risk water bodies to achieve healthy, pollution-free ocean, seas and waters.[9]

Mission 5: A Soil Deal for Europe

Whereas pollution monitoring for soil is perhaps more of an emerging environmental compartment relative to air or water, it's centrality to the Green Deal should not be ignored. The Zero Pollution Strategy aims to ensure that by 2030 75% of soils are healthy, and robust and metrologically sound data will have a key role to play in supporting this endeavour.[3]

Against the background of these grand challenges facing Europe, it is clear that the metrology community has a role to play. However, there is also a need to bridge the gap between metrology and end-user communities in order to demonstrate the added value that robust SI-traceable measurements can bring in helping them to achieve their goals. This is one of the core missions of the EMN POLMO and this SRA is a key tool in achieving this aim.

1.2 Background to the EMN POLMO

The EMN-POLMO aims to create a sustainable metrology infrastructure to support European and international regulations and directives targeting pollution monitoring, using smart specialisation to maximise outcomes from currently available research resources.

The network seeks to establish a continuous dialogue between National Metrology Institutes (NMIs), Designated Institutes (DIs), and stakeholders to inform research pathways, with a dedicated strategy for knowledge-sharing that will accelerate the dissemination of research

results. POLMO is envisaged as an EU-wide metrology hub of excellence, which will be established to support EU and national authorities in addressing current, emerging, and future metrological needs around pollution monitoring. POLMO will focus on chemical, biological and radionuclide pollution in air, water, and soil, with a scope to expand its expertise to other pollution such as light and noise.

Figure 2: EMN-POLMO member institutes

The EMPIR JNP 20NET03 POLMO (2021-2024) supported the establishment of the POLMO EMN.[10] The EURAMET Board of Directors approved the formation of the EMN on 1 June 2022, and the EMN was formalised by a Memorandum of Understanding signed by the 24 institutes listed in Figure 2: EMN-POLMO member institutes, above.

One of the objectives of the JNP 20NET03 was to develop an SRA and roadmaps for pollution monitoring.[11] This document represents the culmination of this objective.

1.3 Purpose of the SRA

This document is a “Strategic Research Agenda” for Pollution Monitoring. It will be used by the EMN to describe and disseminate a vision for a harmonised and sustainable European measurement strategy and infrastructure. This will support the European metrology community’s response to the grand challenges in pollution monitoring and will provide measures to support innovation, assist competitiveness, ensure comparability, and prioritise future research.

The aims of the SRA are as follows:

1. It is a living document that will be maintained by the EMN.
2. It is a mechanism for obtaining, integrating and sharing input from all stakeholders.
3. It guides the development of metrology in support of pollution monitoring.
4. It will help steer the direction of funded research – e.g. future EPM calls.
5. It acts as a key reference for metrology needs in any proposed research.
6. It also facilitates inputs into other initiatives, TCs, and EMNs.

This is version 1 of the SRA (2024). Going forward, it will be updated by the EMN on at least an annual basis.

1.4 Analysis Methodology

The development of the SRA was facilitated by a number of activities undertaken as part of JNP 20NET03 POLMO during the period 2021 to 2023.

Work Package 1 (WP1) of the JNP evaluated the needs of relevant stakeholder communities involved in pollution monitoring, and WP2 captured the landscape against which these needs are set, including legislative drivers, existing European NMI and DI capabilities, previous research projects, scientific literature, and available reference materials.

These data sources (Figure *3*: SRA Data Sources) are described in detail in the following sections.

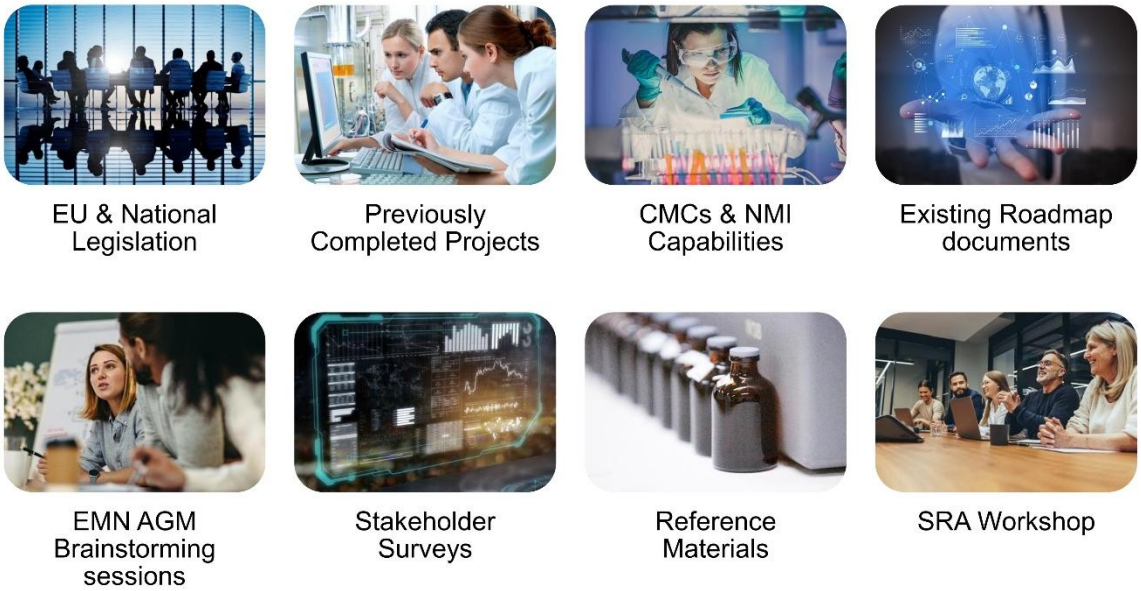

Figure 3: SRA Data Sources

1.4.1 EU & National Legislation

Regulation is a fundamental driver of environmental pollution monitoring. At an EU level, numerous directives dealing with chemicals and radionuclides pollutants have been issued during the last 30 years. These include the Air Quality Directive, Marine Strategy Framework Directive, Water Framework Directive, Groundwater Directive, Drinking Water Directive, Waste Framework Directive, Industrial Emissions Directive, IPPC Directive, Sewage Sludge Directive, Nitrate Directive, Directive Safety Standards to Ionising Radiation.

Against this background, many European countries have also enacted legislation to regulate pollution in air, soil, and water. For the purposes of this SRA several national case studies (based on EMN member expertise) have been considered to provide a snapshot of these national initiatives. These include France (all pollutants), UK (all pollutants), Germany (organic soil pollutants), Czechia (Radionuclides), and Finland (water pollutants).

Table 1: Key Legislative Instruments (EU)

	Air	Water	Soil
EU	Air Quality Directive (2008/50/EC)[12]	Water Framework Directive (2000/60/EC)[13]	Sewage Sludge Directive (86/278/EEC)[14]
	Directive relating to arsenic, Cd, Hg, Ni & PAHs in ambient air (2004/107/EC)[15]	Marine Strategy Framework Directive (2008/56/EC)[16]	
		Groundwater Directive (2006/118/EC)[17]	
		Urban Waste Water Treatment Directive (UWWTD) (Council Directive 91/271/EEC)[18]	
		Priority substances in the field of water (2013/39/EU)[19]	
		Drinking Water Directive (2020/2184)[20]	
		Nitrates Directive (91/676/EEC)[21]	
	Commission recommendation on the application of Article 36 of the Euratom Treaty (2000/473/Euratom)[22]		
	Waste Framework Directive (2008/98/EC)[23]		
	Industrial Emissions Directive (2010/75/EU)[24]		
	Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (1907/2006)[25]		
	Regulation on Mercury (2017/852)[26]		
	Basic safety standards for protection against the dangers arising from exposure to ionising radiation (2013/59/Euratom)[27]		
	Consolidated version of the Treaty establishing the European Atomic Energy Community (C2012/327/01)[28]		

Table 2: Selected National Legislative Instruments

	Air	Water	Soil
FR 	Arrêté du 16 avril 2021 relatif au dispositif national de surveillance de la qualité de l'air ambiant.[29]	Arrêté du 28/02/22 modifiant l'arrêté du 2 février 1998 relatif aux prélèvements et à la consommation d'eau ainsi qu'aux émissions de toute nature des installations classées pour la protection de l'environnement soumises à autorisation (relating to water withdrawals and consumption as well as emissions of all kinds from installations classified for environmental protection subject to authorisation)[30]	
		Arrêté du 9 octobre 2023 modifiant l'arrêté du 25 janvier 2010 relatif aux méthodes et critères d'évaluation de l'état écologique, de l'état chimique et du potentiel écologique des eaux de surface pris en application des article R. 212-10, R. 212-11 et R. 212-18 du code de l'environnement (relating to the methods and criteria for evaluating the ecological state, the chemical state and the ecological potential of surface waters taken in application of articles R. 212-10, R. 212-11 and R. 212-18 of environmental code)[31]	
		Arrêté du 26 juin 2023 portant modalités d'agrément des laboratoires effectuant des analyses dans le domaine de l'eau et des milieux aquatiques au titre du code de l'environnement (laying down conditions for approval of laboratories carrying out analyzes in the field of water and aquatic environments under the environmental code)[32]	

	Air	Water	Soil
UK 	The Air Quality Standards Regulations 2010[33]	The Environmental Permitting (England and Wales) Regulations 2010[34]	Environmental Protection Act 1990[35] & Associated Soil Value Guidelines (SVGs)[36]
	Environmental Protection Act 2021[37]		
DE 	Gesetz zum Schutz vor schädlichen Umwelteinwirkungen durch Luftverunreinigungen, Geräusche, Erschütterungen und ähnliche Vorgänge (Bundes-Immissionsschutzgesetz - BImSchG)[38]	Gesetz zur Ordnung des Wasserhaushalts 1) 2) (Wasserhaushaltsgesetz - WHG)[39]	Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Bundes-Bodenschutzgesetz - BBodSchG)[40]
	Neunundreißigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes[41]	National Water Strategy (published by Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), March 2023)[42]	National Water Strategy (published by Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), March 2023)[43]
			Bundesnaturschutzgesetz (BNatSchG)[44]
			Fünfter Bodenschutzbericht der Bundesregierung
			Bodenschutz in der Gemeinsamen Agrarpolitik (GAP) der EU nach 2020[47]
		Zweite Verordnung zur Novellierung der Trinkwasserverordnung[46]	Zweite Verordnung zur Novellierung der Trinkwasserverordnung[48]
			Umweltgutachten 2008 - Umweltschutz im Zeichen des Klimawandels[49]
	Neufassung der Ersten Allgemeinen Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz (Technische Anleitung zur Reinhaltung der Luft – TA Luft)[48]	Trinkwasserleitwerte (UBA): Liste der Stoffe mit Trinkwasserleitwert[50]	Trinkwasserleitwerte (UBA): Liste der Stoffe mit Trinkwasserleitwert[51]
			Methodensammlung Feststoffuntersuchung[52]
			Sicherstellung des Verbraucherschutzes bei der Bewirtschaftung PFC-verunreinigter Flächen[53]
			PFC-Leitfaden für Liegenschaften des Bundes[54]

	Air	Water	Soil
	Allgemeine Verwaltungsvorschrift zum integrierten Mess- und Informationssystem zur Überwachung der Radioaktivität in der Umwelt (IMIS) nach dem Strahlenschutzvorsorgegesetz (AVV-IMIS)[55]		
	Messanleitung für Radionukilde[56]		
	Gesetz über Naturschutz und Landschaftspflege (Bundesnaturschutzgesetz - BNatSchG)[57]		
	Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz - KrWG)[58]		
	Bundes-Klimaschutzgesetz (KSG)[59]		
CZ 	Czech Atomic Act 263/2016[60]		
	Czech Decree 360/2016 on radiation situation monitoring[61]		
	Czech Decree 377/2016 on radioactive waste[62]		
	Czech Decree 422/2016 on radiation protection[63]		
	Czech Act 350/2011 Chemical Law[64]		
	Czech Decree 231/2004 safety data sheet of dangerous substances[65]		
FI 		Government Decree on Substances Dangerous and Harmful to the Aquatic Environment (1022/2006)[66]	

The review demonstrates the centrality of EU legislation, supplemented by national initiatives. Even in the UK, most key EU legislation has been absorbed into British law. However, this remains a politically sensitive issue.

EU legislation is therefore the key regulatory driver for stakeholder communities involved in pollution monitoring. However, of the 19 major legislative instruments reviewed, which cover over 500 potential pollutants, less than 15% of regulated analytes specified refer to a standard or reference method. This highlights a significant gap which the European metrology community should address.

It is envisaged that the legislation database assembled by the EMN will be made available via the EMN website to provide a single point of reference for researchers in pollution monitoring.

1.4.2 Previous Projects

As part of the data gathering exercise, previous projects undertaken under EURAMET and wider EU funding streams were evaluated for their potential relevance to stakeholder communities involved in pollution monitoring. Projects were classified according to their potential relevance to pollution monitoring (according to the criteria in Table 3: Project Classification Criteria, below) in order to evaluate historical levels of spending on projects in this space.

Table 3: Project Classification Criteria

EURAMET Projects (EMRP, EMPIR, METPART)		**Wider EU Funding programmes (H2020 and FP7)**	
POLMO relevance	• All Environment & Green Deal projects • Projects from other calls with specific applications in pollution monitoring	Projects matching keywords from POLMO JNP	• Air quality • Water quality • Soil pollution • Emerging pollutant • Sensors • Analytical on-site techniques • European Metrology Network • Pollution • Pollutant • Pollution monitoring
Possible POLMO relevance	• Projects not necessarily concerned with pollution monitoring but including methods / analytes which may be of relevance		

The results demonstrated that within EURAMET projects around 25% projects under the EMRP, EMPIR, METPART programmes have a potential relevance to the pollution monitoring stakeholder community.

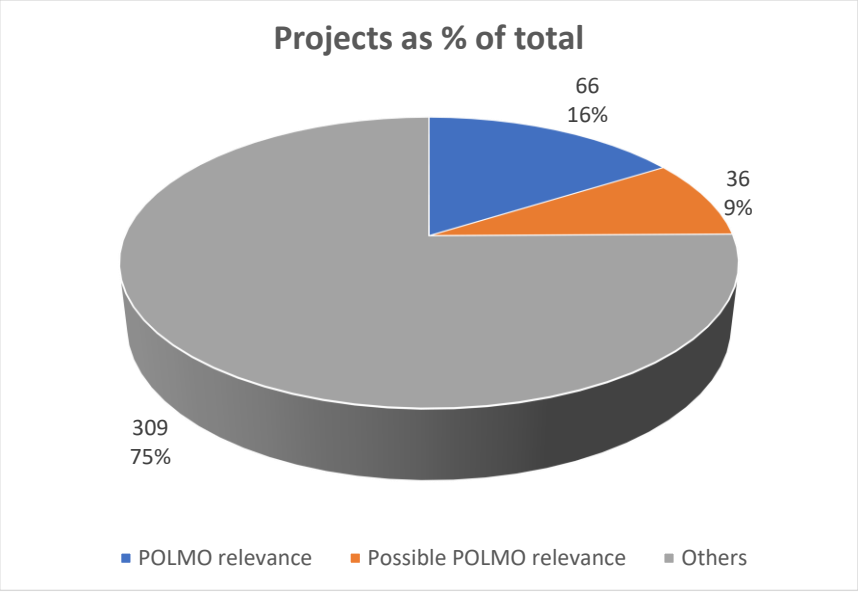

Figure 4: EURAMET Projects 2009-2022

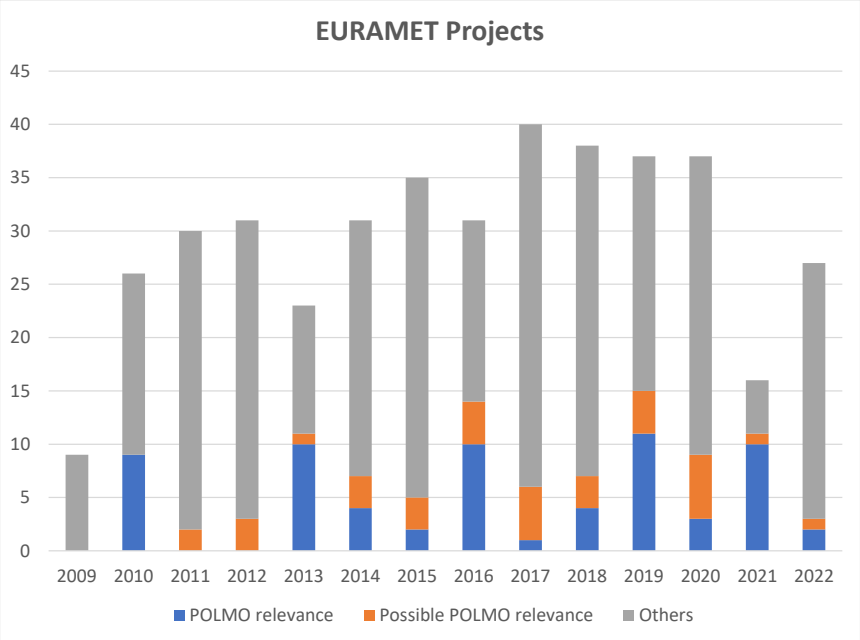

Figure 5: EURAMET Projects 2009-2022, by project year

Within wider EU projects, the percentage of projects with potential relevance was somewhat lower at around 5% of total spending. This demonstrates that within the wider context of EU funded research, the metrology community is well-positioned to respond to the challenges posed by pollution monitoring based on a longstanding financial commitment to relevant projects.

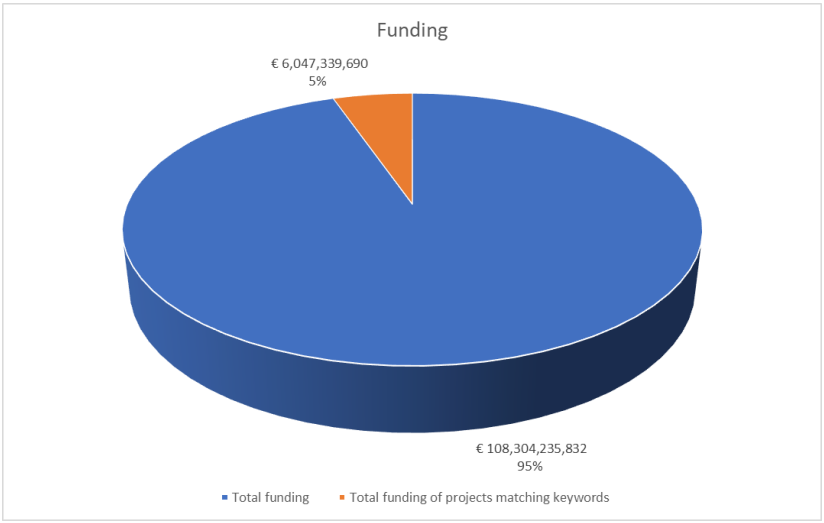

Figure 6: H2020 & FP7 projects

Going forward, Horizon Europe contains increased commitments to relevant research streams. For example, based on preliminary estimations, 4.1% of Horizon Europe spending has been allocated to address clean air for the 2021-2024 period.[67] The EU Missions are another novel feature of Horizon Europe, and these also provide a mechanism for placing POLMO-relevant research streams at the heart of the European research agenda (see Context: Grand challenges in pollution monitoring). Missions now account for 4.6% of Horizon Europe spending (based on 2023 figures).[67] The overall direction of travel is towards increasing significance of topics relevant to the pollution monitoring stakeholder community

and European metrology institutes are well-placed to respond to this given their strong track record.

It is envisaged that the previous projects database assembled by the EMN will be made available via the EMN website to provide a single point of reference for researchers in pollution monitoring, providing a consolidated and curated resource for discovering relevant research.

1.4.3 CMCs and NMI Capabilities

In order to determine how the European metrology community has deployed its measurement capabilities and assess its ability to respond to regulatory drivers, several capability surveys were carried out. These encompassed a deep dive into European NMI and DI CMCs, and EMN members were invited to describe both their relevant technical and measurement capabilities and their resources for disseminating best practice (e.g. training guides).

For the CMC deep dive, the chemical CMCs of all European Measurement Institutes were evaluated according to matrix relevance.[68] This demonstrated that of the 1,795 chemical CMCs held by European Measurement Institutes, just over 20% are in matrices relevant to POLMO (air, water, soil).

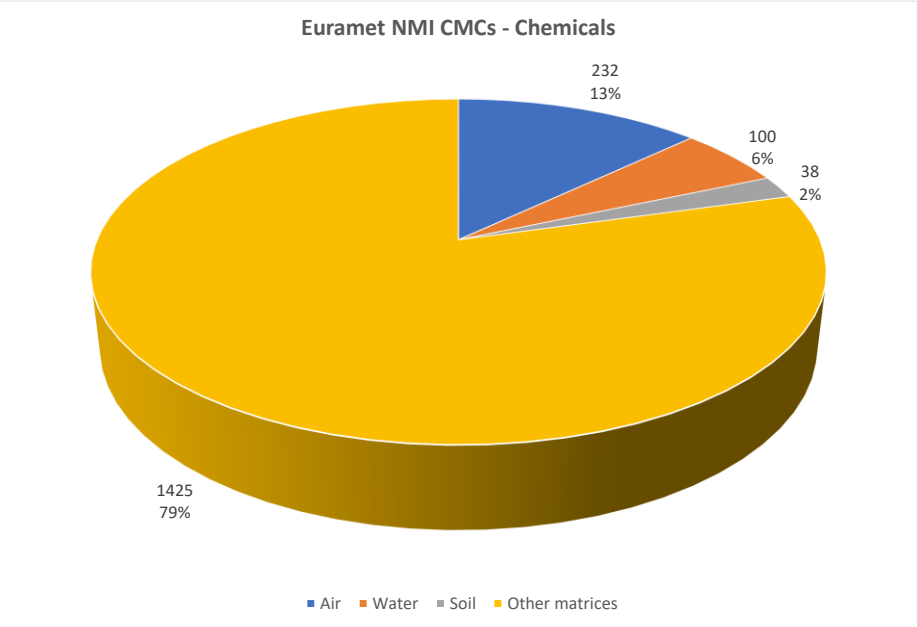

Figure 7: European Measurement Institutes - Chemical CMCs by Matrix

This analysis does not consider emerging pollutants for which CMCs are not yet well established such as particulates or environmental DNA.

The survey of EMN members was conducted during the summer of 2023 in which the 24 EMN member institutes were invited to provide details of their measurement capabilities. The results of this mirrored trends from the CMC survey and confirmed that metrological capabilities are much more mature for some classes of pollutants (e.g. chemicals) than others (e.g. biological / microbiological).

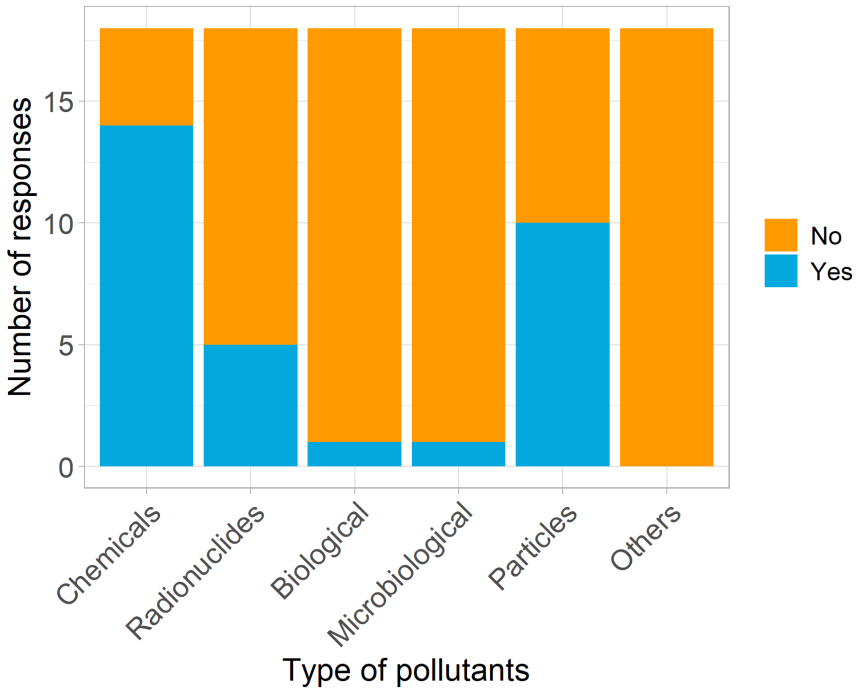

Figure 8: EMN Member capabilities, by pollutant type

The data gathered during the CMC and EMN member capabilities surveys was mapped against identified stakeholder needs (see 1.4.6 Stakeholder Surveys), and the results are presented in the sectional chapters of this SRA.

1.4.4 Existing Roadmap Documents

A literature review of existing roadmaps for pollution monitoring was conducted in order to avoid repeating work which has already been undertaken and to learn how metrology can support existing initiatives in this space.

Recent scientific literature has highlighted the promise of portable or low-cost sensors[69], in-situ measurements[70], or citizen science-based approaches using IoT technology for pollution monitoring.[71] However it is acknowledged that these novel approaches also display metrology gaps, particularly in relation to sensitivity, stability, and calibration intervals.[72]

At an EU level, in 2021 the Commission published an action plan (Pathway to a Healthy Planet for All - 'Towards Zero Pollution for Air, Water and Soil') which highlighted key targets and flagship initiatives which will be necessary to deliver the zero pollution vision.[73] The plan highlights the establishment of a “Zero Pollution Monitoring and Outlook Framework” as a key target which will support the enforcement of regulations (see 1.4.1 EU & National Legislation). Metrology will be a fundamental pillar of this framework.

Similar efforts have been undertaken at a national level. For example, in the UK the UKRI/Met Office Clean Air Strategic Priority programme identified the promise of low-cost sensors for air pollution monitoring[74], and the Defra Air Quality Open Data Roadmap identified big data approaches as a way to increase the value of future air quality research.[75] Initiatives such as these will be reliant on good quality measurements for successful implementation.

1.4.5 EMN Brainstorming Sessions

During the inaugural meeting of the EMN in April 2023, brainstorming sessions in the air, water, and soil sections were held to inform the strategic direction of the network. The questions considered were:

1. What are the future challenges in pollution monitoring in relation to recent EU directives or EU directives under revision or construction?
2. Smart specialisation: how can we best organise ourselves (as an NMI / DI community), in close relation with key stakeholders, to answer these challenges?
3. What are the initiatives (EU or national) that can sustainably support the metrological developments or other activities in relation with the EMN POLMO?

The results of these sessions were used to inform the wider SRA workshop held during November 2023 (see 1.4.6 Stakeholder Surveys), and are also presented in the sectional chapters of this SRA.

1.4.6 Stakeholder Surveys

Engagement with stakeholders and translation of their views and needs into research priorities is a key mission on the EMN POLMO. Therefore, under WP1 of JNP 20NET03 a comprehensive stakeholder survey was undertaken to inform this SRA. This questionnaire was conducted in spring 2023 and received a total of 42 responses. The Questionnaire covered a wide range of pollutants, including chemicals, radionuclides, particles, and biological and microbiological substances in all relevant matrices (water, air, soil). In addition to questions related to development needs for pollutant measurements, the survey sought to identify the gaps in current EU legislation on metrology-related content as well as to obtain respondents' views on future capability, tool development needs, and the role of the POLMO metrology network as a source of information on metrology issues related to pollution monitoring.

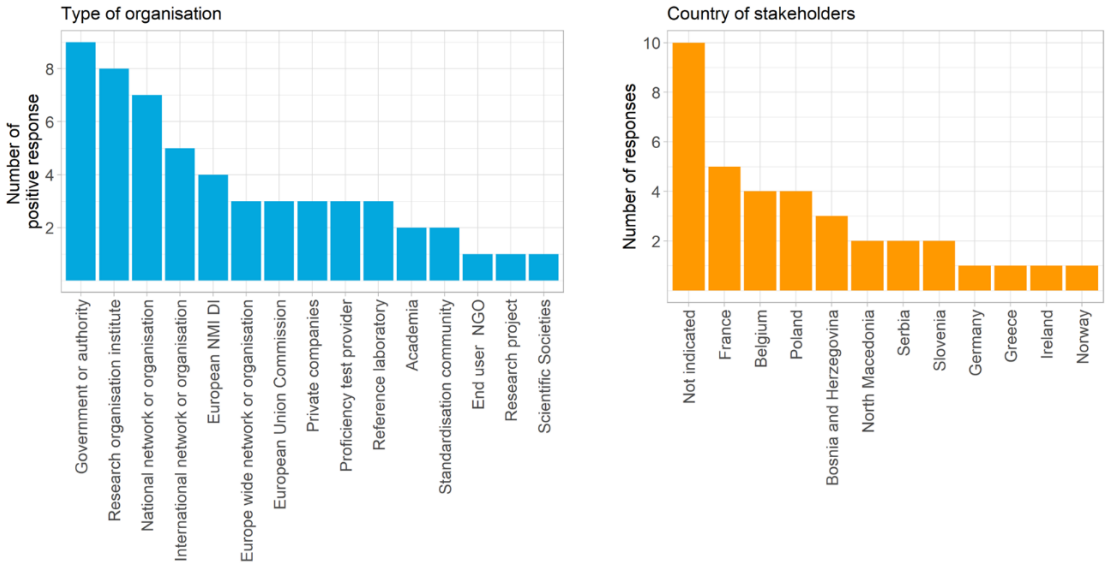

Figure 9: Stakeholder survey respondents grouped by type of organisation and country of origin.

The results gathered during this survey were used, in conjunction with the capability maps arising from 1.4.3 CMCs and NMI Capabilities and results arising from EMN workshops (see 1.4.5 EMN Brainstorming Sessions & 1.4.7 SRA Workshop), as a key data source for the recommendations presented in the sectional chapters of this SRA.

1.4.7 SRA Workshop

In November 2023 a two-day workshop was held for EMN to further develop ideas for the SRA following on from the preparatory work undertaken during the course of the JNP. EMN members were given the opportunity to see the results of the data gathering exercises conducted during the JNP, and having reflected on these, were invited to participate in collaborative sessions to develop roadmaps for each section of the EMN (air, water, soil, and a cross-sectional roadmap for pollutants which cross multiple environmental compartments).

Participants were invited to consider the following questions:

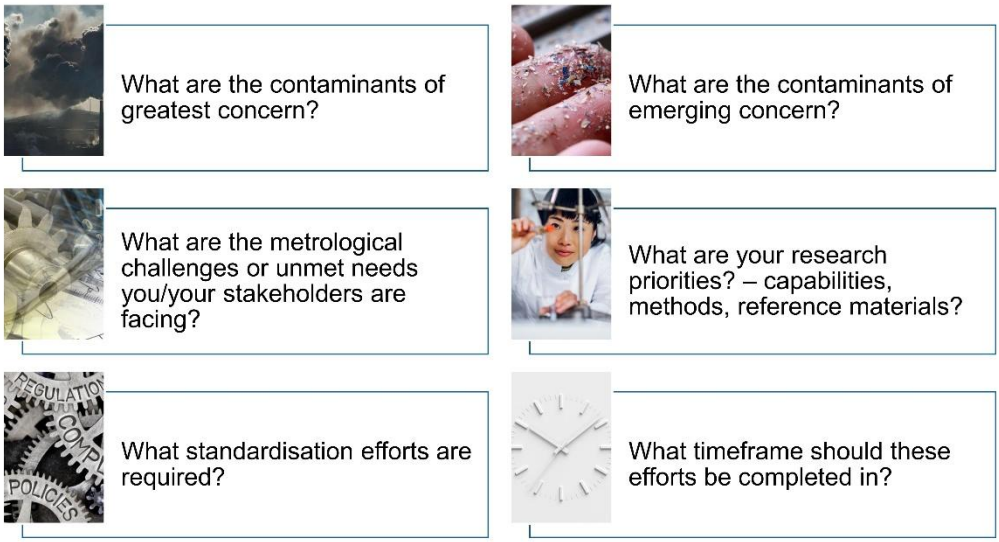

Figure 10: SRA workshop discussion points

The responses to these prompts were then classified according to priority (high/medium/low) and placed within a timeline of the next 10 years. The draft roadmaps developed during the sessions were used, in conjunction with the results of the stakeholder surveys (1.4.6 Stakeholder Surveys) and legislative drivers (1.4.1 EU & National Legislation), as a key data source for the final roadmaps presented in the sectional chapters of this SRA.

1.4.8 Reference Materials

A key aspect of realising and disseminating capabilities for pollution monitoring to ensure compliance with regulatory drivers is the availability of appropriate reference materials. To ensure that the views of reference material users in the field of pollution monitoring were captured in this SRA, engagement was sought with a leading commercial reference materials supplier (name withheld for reasons of commercial confidentiality) to understand the motivations and needs, and their customers in terms of both current needs and areas of emerging needs.

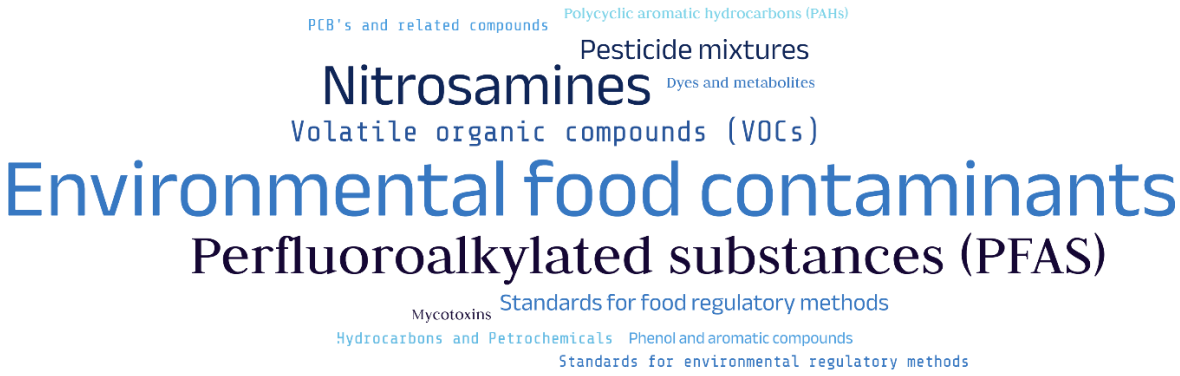

Figure 11: RM users current needs represented as a word cloud. Word size corresponds to current level of needs for RMs in various environmental categories.

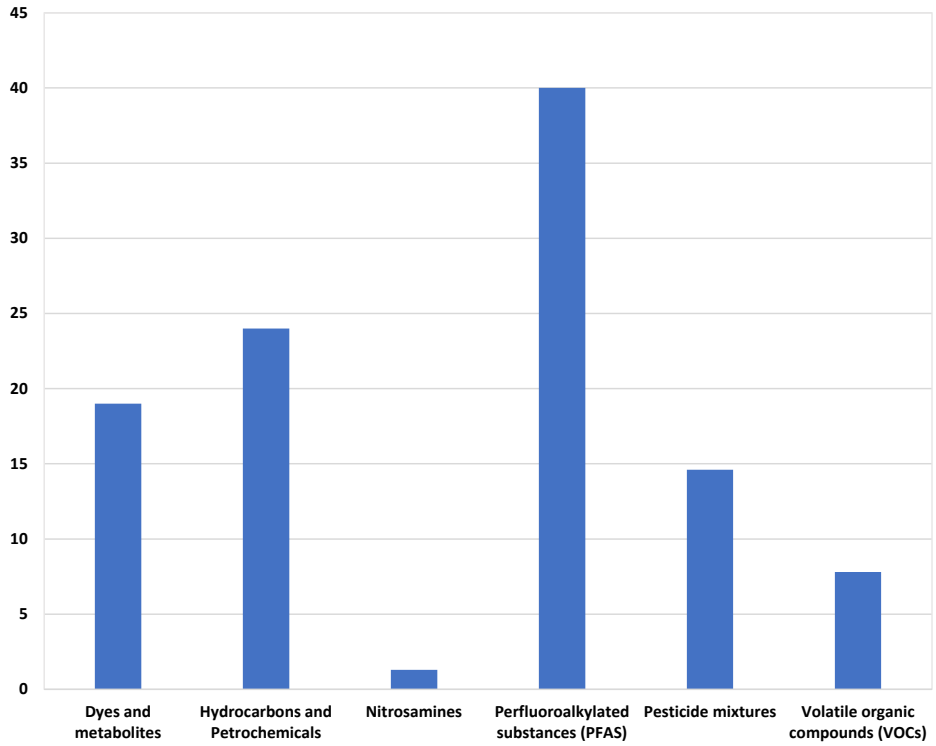

Figure 12: Emerging trends - growth in RM users requiring materials in selected environmental categories.

1.4.9 Roadmap Development

The sources described above present a wealth of important information regarding the needs, drivers, and capabilities of stakeholders involved in pollution monitoring, and the associated capabilities and priorities of the European metrology community. In the following chapters, these have been distilled into strategic roadmaps for each section (air, water, soil, and cross-sectional). The figure below outlines this process.

Figure 13: Roadmap development process.

2 AIR SECTION

2.1 Introduction

This Strategic Research Agenda outlines a critical roadmap for advancing air pollution metrology. It prioritises research efforts to:

- Develop cutting-edge monitoring technologies: Advancements in sensor technology, remote sensing, and artificial intelligence offer promising avenues for real-time, high-resolution monitoring of diverse pollutants and environmental conditions across wide areas. These must be coupled with robust metrological validation for a pathway of traceability.
- Establish standardised protocols: Harmonized sampling, measurement, calibration, and data analysis procedures are essential for ensuring data accuracy, comparability, and interoperability across the measurement landscape.
- Focus on emerging pollutants: Research must stay ahead of the curve, addressing the rising challenge of novel and poorly understood pollutants such as PFAS, ultrafine particles, and volatile organic compounds.
- Tackle the challenges of measuring lower target values while still meeting the necessary uncertainty requirements, particularly in a changing emissions landscape with the move to clean energy and greener manufacturing.
- Integrate metrology with broader environmental monitoring: Understanding air pollution requires a holistic perspective, considering the whole pollutant lifecycle, and interactions with other environmental factors like climate change and land-use patterns.

These broad principles are based on the measurement challenges faced by stakeholders in air pollution monitoring (see 2.2 Current Needs, strategies to address these; 2.3 Smart Specialisation proposals; and roadmaps and strategies for their implementation, i.e. 2.4 Implementation Roadmaps & Prioritisation).

2.2 Current Needs

What are the challenges currently facing stakeholders in air pollution monitoring?

	Measurement Challenge	Identified by: EMN Members	Identified by: Stakeholders	Existing Capability within European NMIs?	Addressed by previous/current EURAMET Projects?
1	Compliance with the **Ambient Air Quality Directive**.[12] This legislation sets EU air quality standards for 12 air pollutants: sulphur dioxide, nitrogen dioxide / nitrogen oxides, particulate matter (PM10, PM2.5), ozone, benzene, lead, carbon monoxide, arsenic, cadmium, nickel, and benzo(a)pyrene. Stakeholders and EMN members identified a particular lack of capability of NO_X and particulates, and highlighted a need for **interlaboratory comparisons** (NO_x, O_3, SO_2, CO), **reference materials** (NH_3, NO_x, VOCs, automotive emissions, and stack gas), and **reference methods** (NH_3, NO_x, phosphate, dissolved oxygen, and stack gas) at lower levels and greater stability than those currently available.	Yes. Lack of methods to ensure compliance with legislation identified as high priority.	Yes. NO_X and Pb identified as the highest priority inorganic pollutants.	Partial Limited capabilities (<2 NMIs) for C_6H_6, Pb, As, Cd, Ni. No capabilities for BaP.	Yes ENV01, ENV06, ENV55, ENV59, 16ENV05, 16ENV07 16ENV08, 19ENV06
2	Methods to support compliance with **EU Mercury regulations**[26] and directives[15], and the Minimata Convention. Stakeholders and EMN members identified a need for further development of **gas generators** and associated **calibration strategies** and **training**.	Yes	Yes	Yes	Yes ENV51, 16ENV01, 19NRM03

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/current EURAMET Projects?
		EMN Members	Stakeholders		
3	Metrology for key gaseous and particulate pollutants to support forthcoming **EURO 7** legislation on emission limits for road vehicles.[77] This covers both exhaust emissions and brake and tyre wear emissions from all light and heavy-duty vehicles, i.e., cars, vans, buses, and lorries, regardless of powertrain (petrol, diesel, EV, H_2). The new regulations will cover particles with a diameter starting from 10 nm (PN10), instead of 23 nm as in Euro 6. EMN members highlighted a need for **calibration aerosols** for counting efficiency and linearity, and for work to address challenges related to penetration efficiency and sizing accuracy for monodisperse aerosols. **Validation of PEMS devices** is also key to ensure the monitoring of key exhaust pollutants. UFP (PM2.5), in particular Black Carbon, were also highlighted as an area which requires further development. Strategies for mass concentration and ultrafine particle number concentration will be needed.	Yes Highlighted as an area of focus for low-cost and in-situ measurement systems (e.g. PEMS).	Further engagement with stakeholders in this space required.	Existing capabilities align with Euro 6 (particles from 23 nm) rather than Euro 7 (particles from 10 nm). Capabilities for newly legislated pollutants (e.g. ammonia) are missing. Capabilities development required due to conformity factors removal.	Limited Research to date has been of a more fundamental than applied nature. See ENV02, 19ENV08, 16ENV07, 19ENV09 (PEMS), 22NRM02 (BC).

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/current EURAMET Projects?
		EMN Members	Stakeholders		
4	Metrologically **validated methods** and **reference materials** to underpin **PFAS** environmental compartmentalisation and lifecycle modelling. Monitoring strategies for these 'forever chemicals' will be needed to define categories of PFAS and to establish persistency and toxicity. In the longer term, a greater understanding on the universe of PFAS is needed including sources of environmental contamination, exposure pathways, and human health and ecological effects.	Yes Noted lack of international standardisation efforts to date.	Yes Identified absence of RMs for gaseous PFAS on global level.	None reported	Not specifically
5	**Pollen** number concentration is increasing every year because of climate change. Metrological **validation of number concentration measurement methods** is needed for effective monitoring. There is also an opportunity to employ **machine learning** for identification of pollen taxa.[78,79,80]	Yes	Further engagement with stakeholders in this space required.	None reported	Not specifically EPM BioAirMet project starting June 2024.
6	Development of **Reference Materials** to support **radionuclide** measurements in both laboratory (trace analysis) and non-laboratory (environmental monitoring) applications. Extension of scope of existing sensor networks for pollution monitoring to include radionuclides, tyre- and break-wear emissions.	Yes	Yes Priorities include Be-7, Ra-226 & K-40.	Partial Current capabilities are overwhelmingly lab-based rather than in-situ.	Limited ENV57, 15SIB10, 19ENV02

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/current EURAMET Projects?
		EMN Members	Stakeholders		
7	Metrological **validation of sensor networks** for environmental monitoring and **smart buildings** to move beyond indicative values and support the development of smart cities.[4] This is also identified as an opportunity to use **AI & Machine Learning** to underpin the development of '**calibration-less sensors**' or '**remote calibration approaches**'.	Yes Noted necessity of international standardisation of new sensor technologies.	Yes	None reported	Limited 17IND02, 22DIT02, EMN MATHMET
8	**Development and validation of statistical approaches** to carry out reconciliation of multicomponent measurements (often with low LODs), including **uncertainty calculation** for emission reporting in accordance with the Industrial Emissions Directive.[24] Requirements for monitoring and reporting of diffuse and fugitive emissions from industrial sources, including requirements to reconcile measurements, are made at different scales and require harmonisation. Collaboration with those working in flow measurements will be necessary to fully characterise emissions.[81,82] **Training and skills development** will also be needed to implement new approaches.	Yes Deficiencies in current processes have been highlighted by WG46 in ISO TC 264.	Yes Statistics & uncertainty identified as highest skills/training priority.	Further engagement with relevant experts required.	Yes NEW04, ENV60, 16ENV08, 17NRM05, 18NRM04, EMN MATHMET

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/current EURAMET Projects?
		EMN Members	Stakeholders		
9	**Enhanced laboratory techniques** (e.g. development of better gas storage cylinders for storing matrix-matched reference materials), and **greener laboratory practices** (e.g. reduced reliance on VOC solvents). Current reliance on dry nitrogen and/or dry synthetic air as a matrix gas (as opposed to air of matrix-matched humidity) has been identified as a significant limiting factor in the production of fit-for-purposed reference calibration standards.	Yes	Yes	Not specifically	Not specifically
10	Compliance with the revised Industrial Emissions Directive There are several key changes presenting challenges: (1) A requirement for national regulators to set emission limits across the 34 industrial processes covered by BATC legislation to the lowest end of the Associated Emission Level for all pollutants (resulting in an order of magnitude change in many cases); (2) An Implementing Act for comparing measurements to emission limits accounting for uncertainty; (3) A strengthening of the holistic target of the directive for national regulators to consider all pollutants emitted from an industrial installation including those of emerging concern; (4) Greater inclusion of agriculture emission sources increasing the fraction of emissions regulated from 18% to 60% for NH3 and from 3% to 43% for CH4.	Yes	Yes	Partial	Limited 18NRM04, 21GRD10

2.3 Smart Specialisation proposals

How can the European metrology community most effectively address the measurement challenges faced by stakeholders in air pollution monitoring?

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
1	Develop the metrology required to support current enforcement and future development of the Air Quality Directive and other key EU directives. • 2024 Green Deal Call PRTs: ○ Metrology to establish an improved network for ammonia measurement and monitoring, including standard reference method and reference materials at atmospherically relevant amount fractions. • Engagement with CCQM GAWG to encourage interlaboratory comparison studies. • Strategic engagement and partnerships with instrument manufacturers to influence development of new instruments, generators, and storage solutions. • Address the need for analytical and statistical training to ensure the next generation of measurement scientists are equipped to address these challenges. This will also necessitate engagement with the flow measurement community in order to fully characterise emissions as product of both concentration and flow rate.	• EU Commission Ambient Air Quality Expert Group • National regulatory bodies • EURAMET TC-F • Instrument manufacturers • CCQM GAWG • IMPEL[1] • EQA providers • Industry bodies • AQUILA • ACTRIS[2] • ERLAP[3]	1, 2, 8, 9

[1] European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) - https://www.impel.eu/en
[2] Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) - https://www.actris.eu/
[3] European Reference Laboratory for Air Pollution (ERLAP) - https://joint-research-centre.ec.europa.eu/laboratories-and-facilities/european-reference-laboratory-air-pollution_en

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
2	Holistic approach to characterising the nature of pollution from PFAS (and other 'forever chemicals'). Research is needed to understand environmental contamination, exposure pathways, and human health and ecological effects. Whereas this is certainly an important challenge for the air section, PFAS is a topic which must also be addressed cross-sectionally. See Cross Sectional Smart Specialisation proposals.	• National regulatory bodies • EURAMET TC-MC • NORMAN[1]	4, 8
3	Start to develop the metrology required to better validate sensor networks for air pollution monitoring and underpin 'calibration-less' sensors or sensors using 'digital' calibration certificates. ○ Metrology to harmonise low-cost sensor measurement techniques to improve air quality (cloud-based calibration techniques for low-cost sensor networks) ○ Pioneering next-generation air quality monitoring by metrological validation of low-cost particulate matter sensors • Engagement with existing air quality monitoring networks to help them adapt to emerging pollutants, or established pollutants not previously considered. • Acknowledgement of the centrality of data-driven approaches (ML, AI) in this area and the need to engage with this at all stages of the research lifecycle.	• Existing air quality monitoring networks[2] • EURAMET TC-IM • EMN COO • EMN MATHMET • Sensor manufacturers • EOSC[3]	4, 5, 6, 7, 8

[1] Network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances (NORMAN) - https://www.norman-network.net/
[2] e.g. European Monitoring and Evaluation Programme (EMEP) - https://www.emep.int/ ; "Ring of Five" Task Group - https://www.iur-uir.org/en/pro/task-groups/id-22-ring-of-five-task-group
[3] European Open Science Cloud (OESC) - https://eosc-portal.eu/

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
4	Begin work to develop the next generation of radionuclide reference materials. • Materials that have lower levels, enhanced stability, and better matrix matching are required. • Achieve more robust traceability by replacing legacy radiochemical methods with mass spectrometry. • Engage with technology providers to find innovative solutions to gas storage so that the next generation of materials can be stored and deployed reliably.	• Industry • IAEA • EMN Radiation Protection • IRCM[1] • EURAMET TC-IR WG2 • National regulatory bodies	6, 9

5	Develop the metrology required to support Euro 7.
	• 2024 Green Deal Call PRTs:
	  ○ Supporting the implementation of new Euro 7 emission limits by improved metrology for vehicles emission estimations (NH_3, NMHC, NO^2).
	  ○ Supporting new Euro 7 emission limits by improved metrological traceability for key gaseous and particulate pollutants and exhaust flow.
	• Engagement with the automotive industry to ensure the metrological community is well-placed to support the development of new PEMs devices, as well as validation of devices currently in use.
		• Industry
		• AQUILA
		• Existing air quality monitoring networks.
			1, 3, 7

[1] International Committee for Radionuclide Metrology (ICRM) - https://physics.nist.gov/ICRM/index.html

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
6	Develop the metrology required to support the revised Industrial Emissions Directive. • 2024 Green Deal Call PRTs and Normative PRTs in future years. • Formal validation of existing CEN documentary standard reference methods (HF, formaldehyde, SO^2, HCl, dust, mercury, heavy metals, dioxins & furans, polycyclic aromatic hydrocarbons, etc.) for enforcement of more stringent emission limits in accordance with the validation requirements of CEN/TC 264. • Guidance documents harmonising reporting of emission measurements to national regulators, uncertainty estimation and accounting for measurement uncertainty when determining legal compliance. • Development of new measurement methods where currently none exist for eventual standardisation at CEN for pollutants of emerging concern (e.g. PFAS, brominated dioxins). • Development of new capabilities for measuring livestock emissions in pasture and barn environments. Standardisation at CEN over the longer term. • Validation of livestock emission factors and models for reporting commercial farm emissions.	• DG GROW[1] • DG ENV[2] • IMPEL • CEN/TC 264 • ISO/TC 146 • National regulators • Industrial installation operators • National Accreditation Bodies • Accredited measurement service providers	10, 8, 4

[1] EU Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) - https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/internal-market-industry-entrepreneurship-and-smes_en

[2] EU Directorate-General for Environment (DG ENV) - https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/environment_en

2.4 Implementation Roadmaps & Prioritisation

The following section presents Implementation Roadmaps for each of the Smart Specialisation proposals presented in 2.3 Smart Specialisation proposals. Key themes within each proposal are grouped and presented in a timeline to 2030. Long term goals / topics of interest for 2030+ are presented towards the far right of each roadmap.

These roadmaps provide a reference point against which future progress can be measured.

2.4.1 Smart Specialisation Proposal 1: Support for the Air Quality Directive

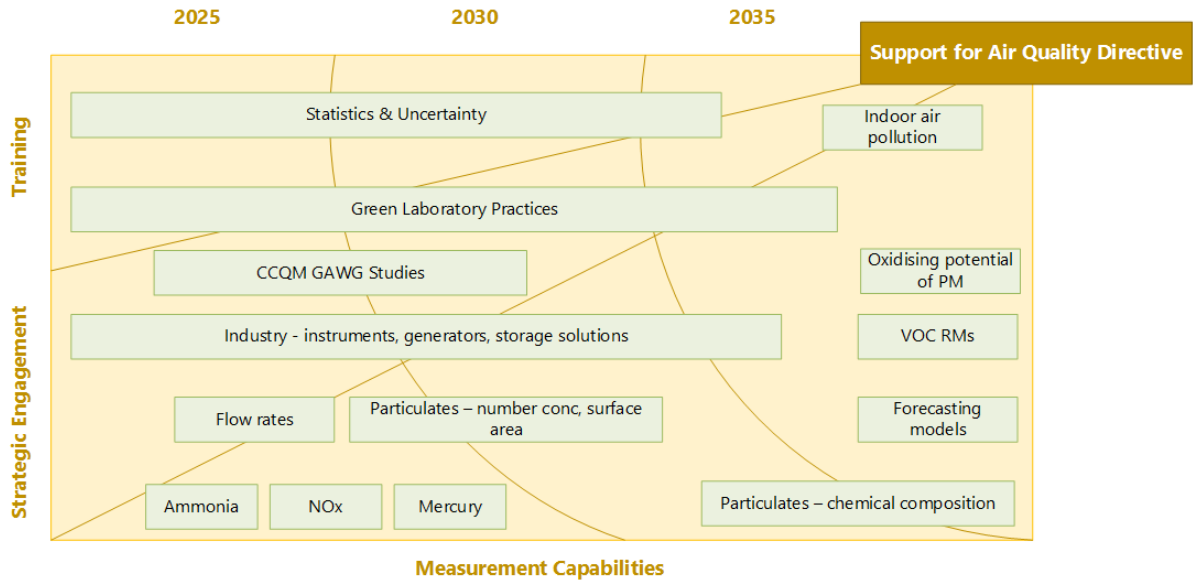

Figure 14: Implementation Roadmap - support for the Air Quality Directive

2.4.2 Smart Specialisation Proposal 2: PFAS

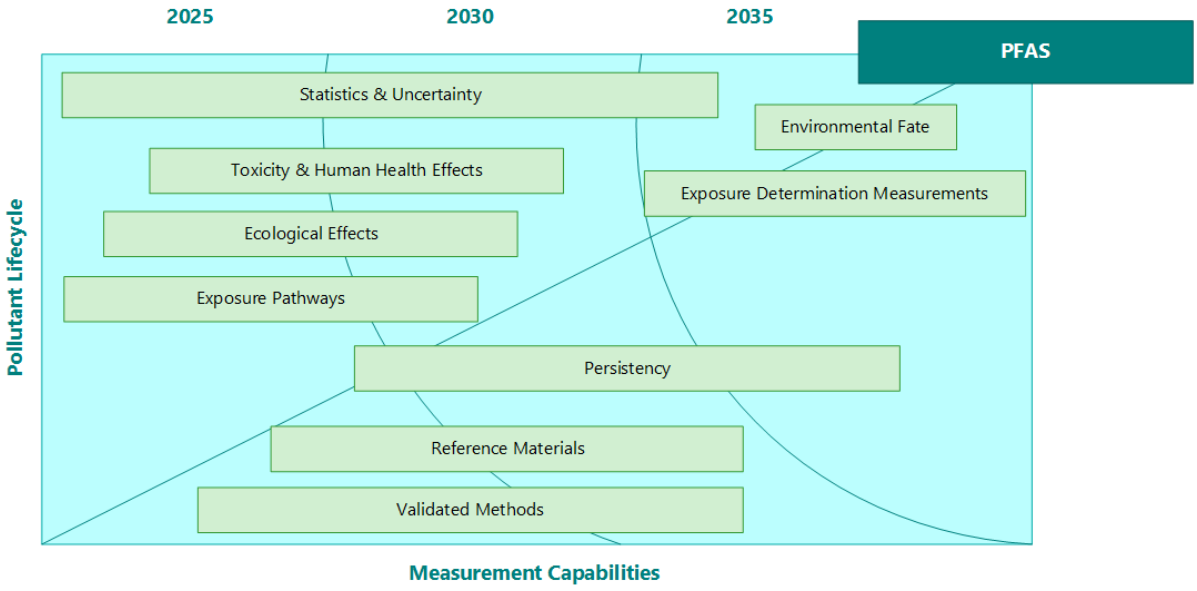

Figure 15: Implementation Roadmap – PFAS

2.4.3 Smart Specialisation Proposal 3: Sensor Networks

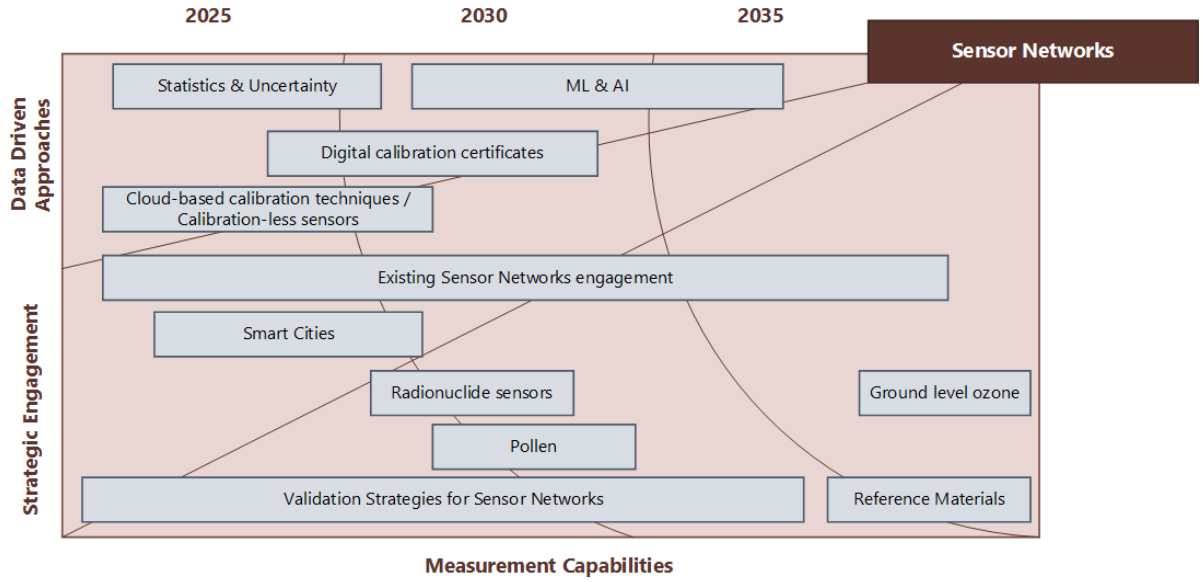

Figure 16: Implementation Roadmap – Sensor Networks

2.4.4 Smart Specialisation Proposal 4: Radionuclides

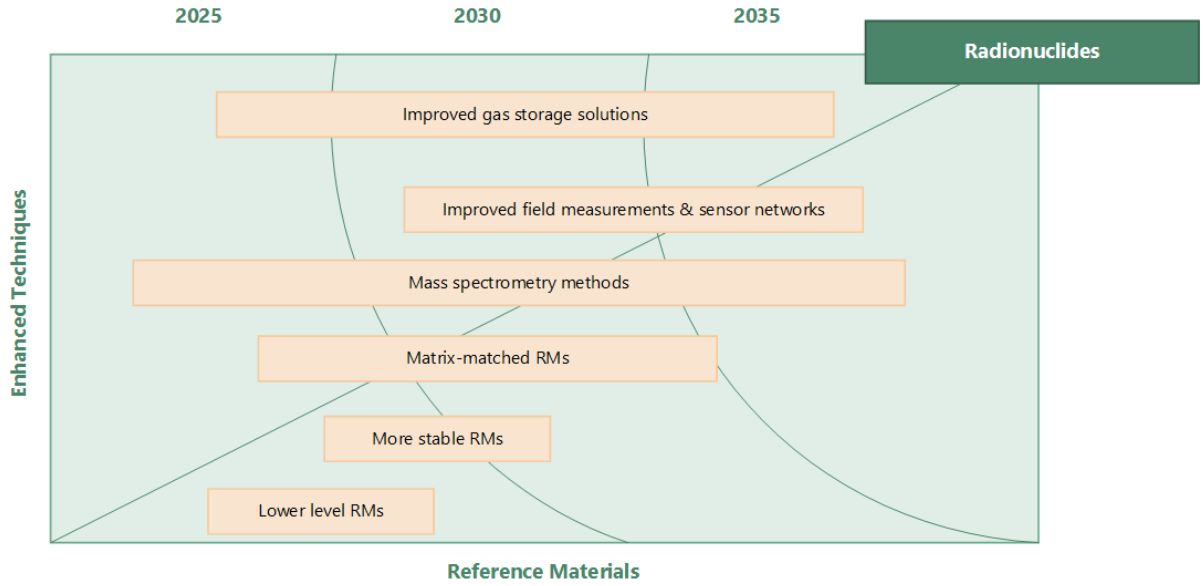

Figure 17: Implementation Roadmap – Radionuclides

2.4.5 Smart Specialisation Proposal 5: Euro 7

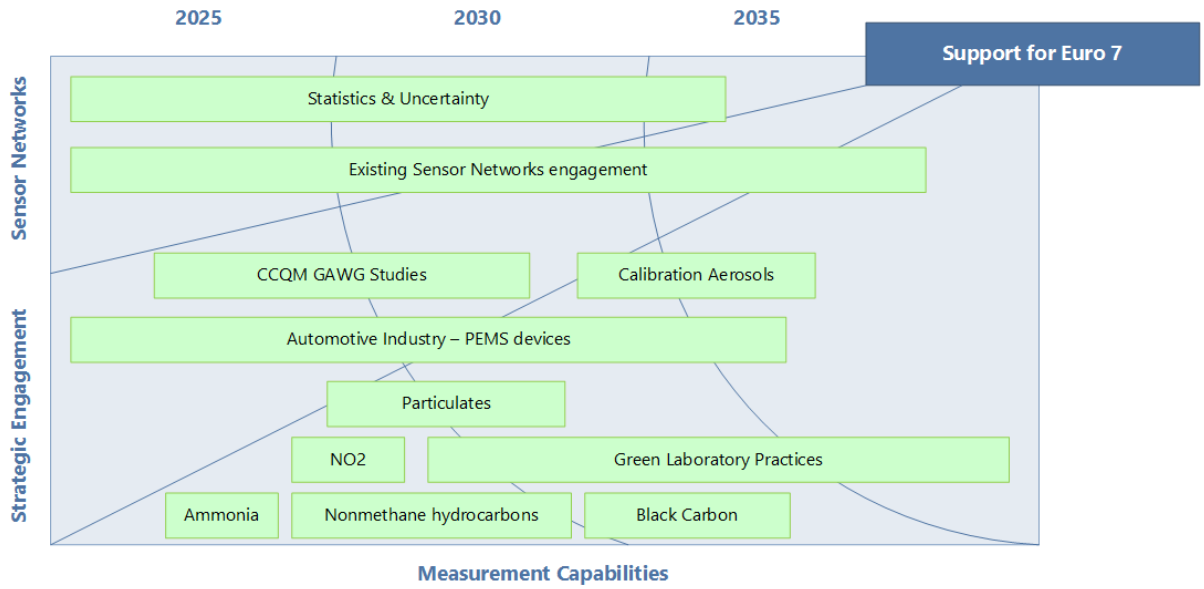

Figure 18: Implementation Roadmap – Euro 7

2.4.6 Smart Specialisation Proposal 6: Support for Industrial Emissions Directive

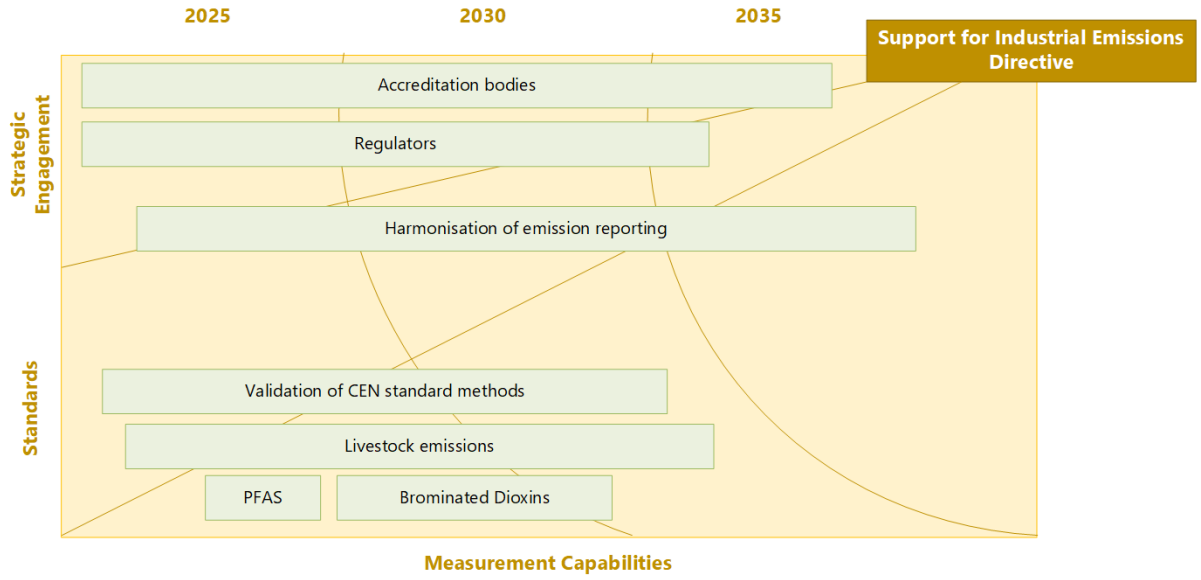

Figure 19: Implementation Roadmap - Support for Industrial Emissions Directive

3 WATER SECTION

3.1 Introduction

This Strategic Research Agenda outlines a critical roadmap for advancing water pollution metrology. It prioritises research efforts to:

- Ensure compliance with key legislative drivers by provision of metrologically rigorous solutions to provide a granular picture of water quality, offering early warning of contamination and tracking the migration of pollutants and biodiversity loss.
- Develop a holistic understanding of water pollutants and their persistence throughout the water cycle. From source to sink: from pharmaceuticals, to microplastics, to PMTs.
- Provide the correct tools and strategies to identify specific sources of contamination both in the laboratory and in the field.
- Develop metrology and QA/QC tools for alternative approaches to water quality monitoring such as environmental DNA, and effect-based monitoring using bioassays.
- Support global efforts against climate change by providing robust data about water quality and quantity to equip policymakers and stakeholders with the information they need to implement effective regulations and prioritize water management efforts.

These broad principles are based on the measurement challenges faced by stakeholders in water pollution monitoring (see 3.2 Current Needs, strategies to address these; 3.3 Smart Specialisation proposals; and roadmaps and strategies for their implementation, i.e. 3.4 Implementation Roadmaps & Prioritisation).

3.2 Current Needs

What are the challenges currently facing stakeholders in water pollution monitoring?

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/ current EURAMET Projects?
		EMN Members	Stakeholders		
1	Compliance with requirements of **key EU directives** including **UWWD**[18] and **WFD**[13]. Priority analytes include those identified in Table 2 of the UWWD (total phosphorus & total nitrogen), and those in Annex X of the WFD[83]. Both EMN members and Stakeholders identified these directives as the most important legislative drivers in pollution monitoring across all sections. Where enforcement of water protection legislation used the concept of 'pollution units' as a basis for taxation, a traceability chain will need to be established.	Yes Noted that methods with lower limits are needed.	Yes	Under evaluation	Yes ENV08, 18NRM01
2	Development of **mass spectrometry** methods for **radionuclides**, for both established pollutants and emerging pollutants (e.g. novel medical radionuclides). **Calibration materials** are needed to support new MS methods. As methods are developed, **interlaboratory comparisons** and **training** will also be needed.	Yes	Yes Priorities include Tc-99, I-129, Cs-135, Cs-137, Sr-90 & Am-241/Np-237.	Legacy radiochemical techniques rather than MS.	Limited 15SIB10, 21GRD09

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/ current EURAMET Projects?
		EMN Members	Stakeholders		
3	**Environmental DNA (eDNA).** eDNA is genetic material released by organisms into the environment, such as dead cells, skin flakes, or excrement. It is of particular concern with regard to Antimicrobial Resistance (AMNR) as eDNA from resistant bacteria can persist in the environment for longer than the live bacteria, acting as a reservoir for resistance. eDNA is also used to track biodiversity loss in the context of climate change. eDNA **validation protocols** and **comparisons with biological indices** are needed to begin to address these challenges.	Yes	Further engagement with stakeholders in this space required.	Only 1 NMI currently reports specific methods for eDNA.	Limited Research to date has been of a more fundamental than applied nature. See SIB54, 15HLT07 (AMR).
4	Lack of **validated methods**, **reference materials**, and **interlaboratory comparisons** to underpin **PFAS** environmental compartmentalisation and lifecycle modelling. Monitoring strategies for these 'forever chemicals' will be needed to define categories of PFAS and to establish persistency and toxicity. In the longer term, a greater understanding on the universe of PFAS is needed including sources of environmental contamination, exposure pathways, and human health and ecological effects.	Yes Ultrashort PFAS identified as a priority.	Yes	Only 2 NMIs currently report capability.	Not specifically

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/ current EURAMET Projects?
		EMN Members	Stakeholders		
5	Lack of **RMs** for **emerging organic pollutants** such as **pyrethroids**, **novel pharmaceutical compounds** (and associated metabolites), **biocides** and **pesticides**, and novel flame retardants (e.g. **organophosphate esters**).	Yes	Yes.	Only 2 NMIs report capability, and these are not current used to value assign RMs.	Not specifically
6	**Quality Assurance of non-targeted screening**. Where screening techniques are used to monitor water quality these are geared towards single analytes rather than the multicomponent 'chemical cocktails' more often found in the real world. **Multi-analyte calibration standards** are needed to ensure traceability.	Yes	Further engagement with stakeholders in this space required.	Not specifically	Not specifically
7	**Water quantity & climate change**. Metrological validation of **continuous-monitoring sensors** used to measure reservoir levels is needed. As global temperatures rise due to climate change, methods are needed to determine the effect of elevated temperatures on fresh water quality. **Satellite monitoring** data may have a role to play here, but it requires **validation**. Fundamentally, the challenges posed by climate change will necessitate better monitoring of the whole water cycle.	Yes	Further engagement with stakeholders in this space required.	Not specifically	Not specifically

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous/ current EURAMET Projects?
		EMN Members	Stakeholders		
8	**Microplastics** (>1 µm <1 mm) and nanoplastics (<1 µm) are acknowledged as pollutants of emerging concern. A comprehensive and robust metrological framework is needed to **characterise** and **quantify** (identification, size, size distribution, number and mass concentration) microplastic pollution and to better understand longer term effects such as **bioaccumulation**. Harmonised measurand definition, CRMs, harmonised sampling protocols, and inter-laboratory comparisons are needed.	Yes	Yes Definition of the measurand highlighted as a fundamental need.	3 NMI reported capabilities currently in development	Limited Research to date has been of a more fundamental than applied nature. See NEW03, 14IND12, 17NRM04, 21GRD07.

3.3 Smart Specialisation proposals

How can the European metrology community most effectively address the measurement challenges faced by stakeholders in water pollution monitoring?

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
1	Develop the metrology required to support current enforcement and future development of WFD and UWWD, and other key EU directives. • This includes established chemical and radionuclide pollutants, and emerging chemical, radionuclide, biological, and particulate contaminants (especially microplastics). • Engage with relevant groups at CCQM (OAWG, IAWG, IRWG) to ensure future interlaboratory comparison studies align with legislative drivers. • Engage with relevant standardisation committees to ensure future standards development aligns with legislative drivers.	• EU Commission • National Regulators • CCQM • CCRI • IMPEL[1] • ISO-TC 147 • CEN-TC 230 • WE[2] • WWQA[3] • EURAMET TC-F	1, 2, 3, 4 5, 8
2	Holistic approach to characterising the nature of pollution from PFAS (and other 'forever chemicals'). Research is needed to understand environmental contamination, exposure pathways, and human health and ecological effects. Whereas this is certainly an important challenge for the water section, PFAS is a topic which must also be addressed cross-sectionally. See Cross Sectional Smart Specialisation proposals.	• National regulatory bodies • EURAMET TC-MC • NORMAN[4]	4, 5, 6

[1] European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) - https://www.impel.eu/en
[2] Water Europe (WE) - https://watereurope.eu/
[3] World Water Quality Alliance (WWQA) - https://www.unep.org/explore-topics/water/what-we-do/improving-and-assessing-world-water-quality-partnership-effort
[4] Network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances (NORMAN) - https://www.norman-network.net/

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
3	Begin to develop metrological approaches to characterise release and persistence of eDNA. • 2024 Green Deal Call PRT: ○ Developing metrology capacity for better quality assurance of eDNA based monitoring. • Engage and align with efforts already underway at national levels (e.g. Finland[84], Germany[85]), and European level (e.g. DNAqua-Net).[86]	• UBA • UDE • CEN TC 230 WG25 (eDNA) • DNAqua-Net • CCQM NAWG	1, 3
4	Begin work to develop the next generation of reference materials for priority chemicals and radionuclides in water. • Produce materials that have lower levels, enhanced stability, and better matrix matching (e.g. wastewater, surface water). • Better matrix matching will help to bridge the gap between measurements made in ideal conditions in the lab and those made in the field. • Multi-analyte materials must be considered a priority.	• Industry (RM & PT providers) • CCQM • CCRI • ISO REMCO	1, 2, 4, 5, 6, 7
5	Support climate initiatives by: • Providing the water quantity metrology needed to accurately monitor the water cycle. • Metrological support for constant measurement-sensors, and the possibility of 'calibration-less' sensors. • Validation of novel techniques for assessing water quality (e.g. satellite monitoring). • Support taxation based on 'pollution units' by establishing metrological traceability for these novel measurement systems.	• EURAMET TCs-IM, F, & IM • EMN COO • Sensor manufacturers • NORMAN	1, 6, 7

3.4 Implementation Roadmaps & Prioritisation

The following section presents Implementation Roadmaps for each of the Smart Specialisation proposals presented in 3.3 Smart Specialisation proposals. Key themes within each proposal are grouped and presented in a timeline to 2030. Long term goals / topics of interest for 2030+ are presented towards the far right of each roadmap.

These roadmaps provide a reference point against which future progress can be measured.

3.4.1 Smart Specialisation Proposal 1: Support for key EU Directives (WFD & UWWD)

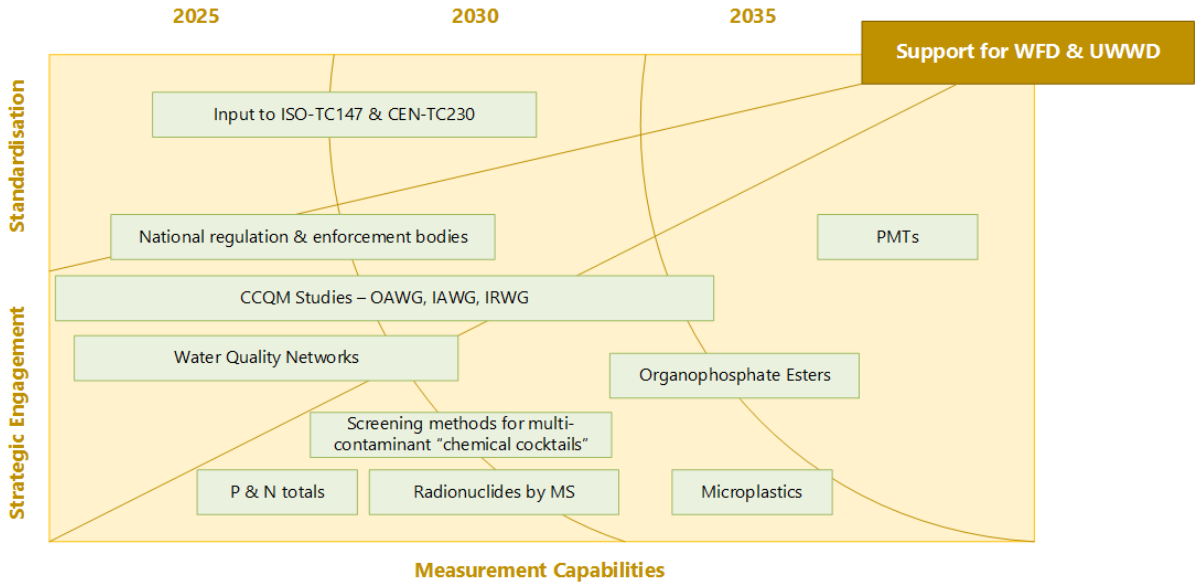

Figure 20: Implementation Roadmap - Support for key EU Directives (WFD & UWWD)

3.4.2 Smart Specialisation Proposal 2: PFAS

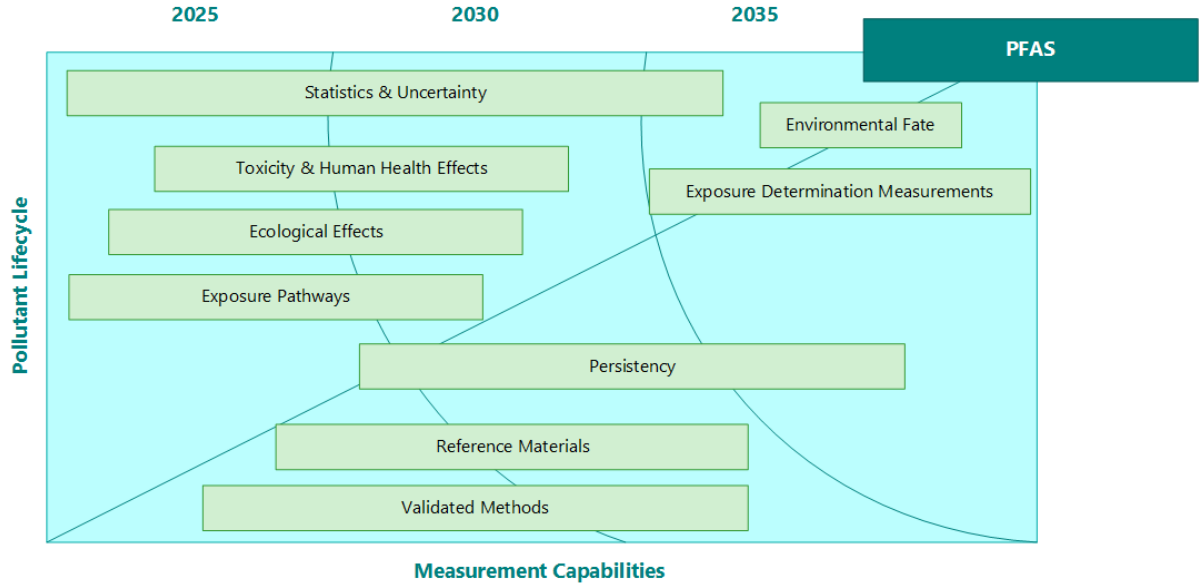

Figure 21: Implementation Roadmap - PFAS

3.4.3 Smart Specialisation Proposal 3: eDNA

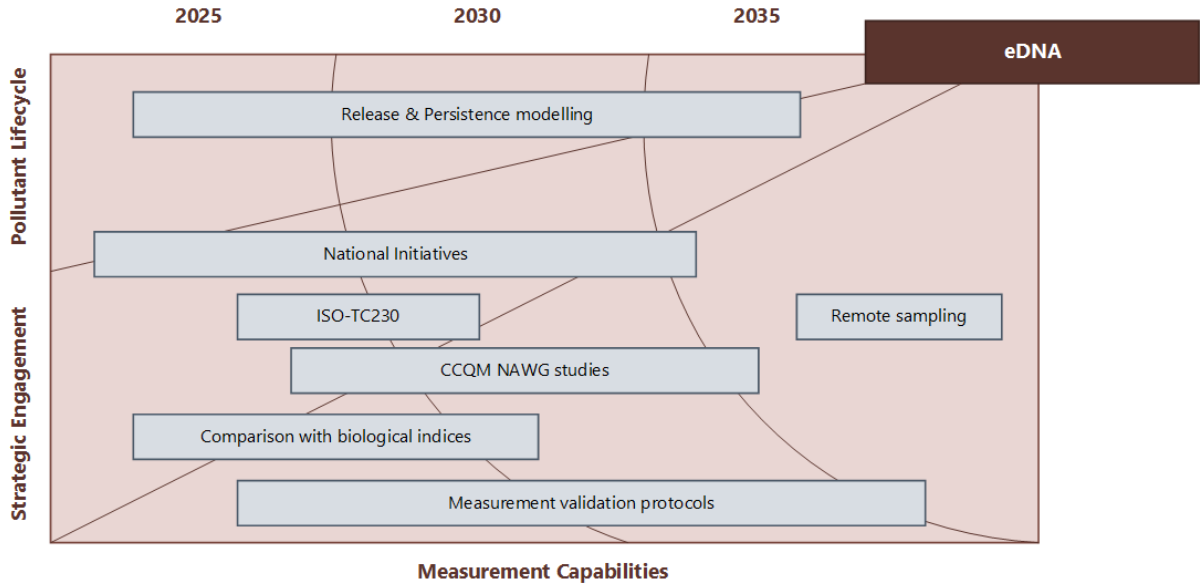

Figure 22: Implementation Roadmap - eDNA

3.4.4 Smart Specialisation Proposal 4: Radionuclides

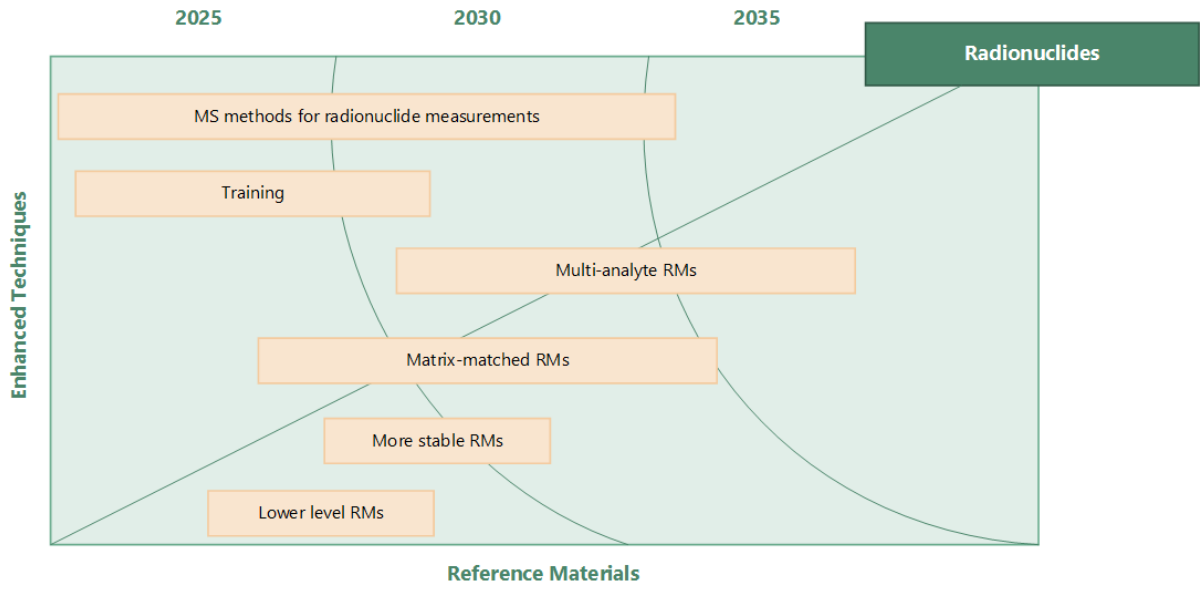

Figure 23: Implementation Roadmap - Radionuclides

3.4.5 Smart Specialisation Proposal 5: Support for climate initiatives

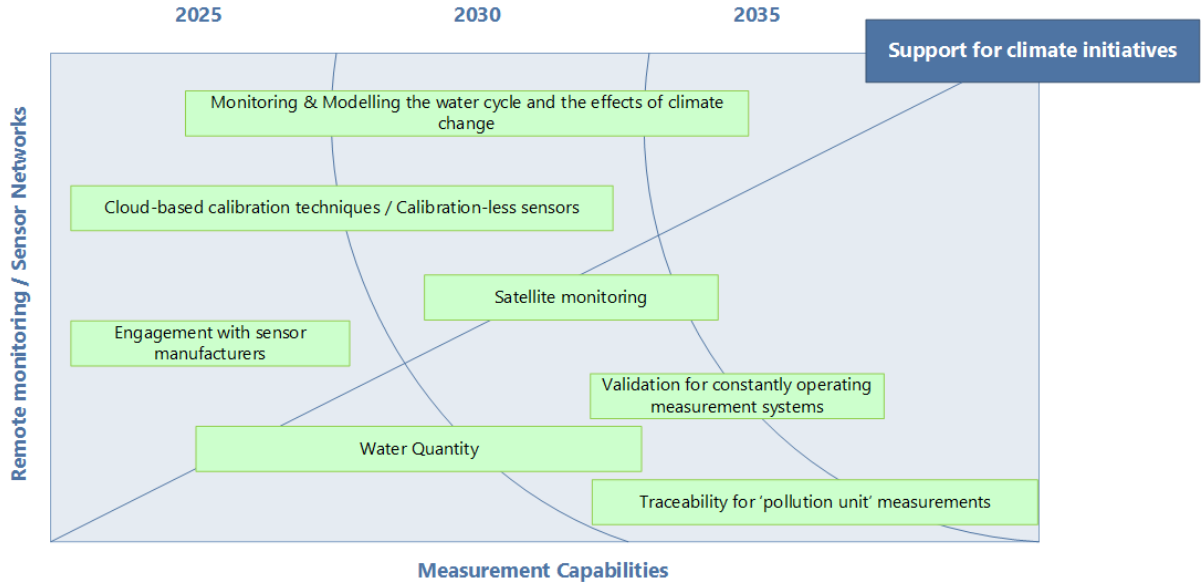

Figure 24: Implementation Roadmap - Support for climate initiatives

4 SOIL SECTION

4.1 Introduction

This Strategic Research Agenda outlines a critical roadmap for advancing soil pollution metrology. It prioritises research efforts to:

- Develop advanced monitoring technologies including screening techniques and innovative real-time solutions, enabling early detection of contamination and continuous monitoring of remediation efforts.
- Develop reference materials to support measurements both in the lab and in the field, and to support the development of new faster techniques for monitoring soil contamination.
- Encourage a holistic understanding of environmental pathways, taking a cross-disciplinary approach across biology, chemistry, and physics, to characterise the complete environmental pathway of multiple contaminants.

These broad principles are based on the measurement challenges faced by stakeholders in water pollution monitoring (see 3.2 Current Needs, strategies to address these; 3.3 Smart Specialisation proposals; and roadmaps and strategies for their implementation, i.e. 3.4 Implementation Roadmaps & Prioritisation).

4.2 Current Needs

What are the challenges currently facing stakeholders in soil pollution monitoring?

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous / current EURAMET Projects?
		EMN Members	Stakeholders		
1	Development and validation of **faster methods for radionuclides**, for both established pollutants and emerging pollutants. Capabilities **for monitoring migration** of radionuclides from contaminated soils into foodstuffs (e.g. Sr-90) is a priority and will require **reference materials** to support environmental food contaminant.[87] **Screening methods** are lacking (particularly for gamma emitting elements), and the possibility of using **novel technologies** (e.g. drones) for monitoring radioactivity in soils has not been assessed metrologically.	Yes	Yes Priorities include Cs-137, Sr-90 & I-131.	Laboratory radiochemical techniques rather than rapid/screening methods.	Yes ENV57, 15SIB10, 16ENV04, 19ENV02, 21GRD09
2	Current **reference materials** tend to be single analyte materials. **Multi-analyte** materials are needed to facilitate the multiparameter methods needed to support risk assessments of the dangers of multi-contaminant “cocktails” which may contain a combination of chemical and radiological hazards. This will also require **cross-discipline collaboration** between those working in radionuclide measurements and experts in other contaminants.	Yes	Yes Need for RMs to support new methods highlighted.	Not specifically for multi-analyte analysis.	Not specifically
3	Lack of **validated methods**, **reference materials**, and **interlaboratory comparisons** to underpin **PFAS** environmental compartmentalisation and lifecycle modelling. Monitoring strategies for these ‘forever	Yes	Yes	Only 2 NMIs currently report capability.	Not specifically

	Measurement Challenge	Identified by		Existing Capability within European NMIs?	Addressed by previous / current EURAMET Projects?
		EMN Members	Stakeholders		
	chemicals' will be needed to define categories of PFAS and to establish persistency and toxicity. In the longer term, a greater understanding on the universe of PFAS is needed including sources of environmental contamination, exposure pathways, and human health and ecological effects.				
4	Need for development of improved models for monitoring **complete environmental pathways** of soil contaminants, including multi-contaminant models, accumulation studies, and migration into food production.	Yes Perchlorates & Phthalates identified as a priority.	Further engagement with stakeholders in this space required.	No	No

4.3 Smart Specialisation proposals

How can the European metrology community most effectively address the measurement challenges faced by stakeholders in soil pollution monitoring?

	Smart Specialisation Proposal	Key Stakeholders	Addresses Measurement Challenges
1	Develop faster, non-laboratory screening techniques for monitoring radionuclides in soils. The possibility of new technologies (e.g. drones, data assimilation approaches between different sensors and techniques, and citizen science approaches) should be evaluated from a metrological point of view, and alignment should be sought with existing radiological monitoring networks.	• IAEA • JRC REMON1 & ESDAC2 • Industry • EMN Radiation Protection • IRCM • EURAMET TC-IR WG2 • National regulatory bodies	1, 2
2	Begin work to develop the next generation of reference materials for priority chemicals and radionuclides in soil. • Materials to support the validation of novel methods (above) are needed. • Multi-analyte materials must be considered a priority.	• Industry (RM & PT providers) • CCQM • CCRI • ISO REMCO	1, 2, 3
3	Holistic approach to characterising the complete environmental pathways of soil contaminants including contamination sources, exposure pathways, accumulation, and human health, food, and ecological effects. This is of particular importance with regard to PFAS, although PFAS is a topic which must also be addressed cross-sectionally. See Cross Sectional Smart Specialisation proposals.	• National regulatory bodies • EURAMET TC-MC • NORMAN	3, 4

[1] JRC Radioactivity Environmental Monitoring Network (REMON) - https://remon.jrc.ec.europa.eu/
[2] JRC European Soil Data Centre (ESDAC) - https://esdac.jrc.ec.europa.eu/

4.4 Implementation Roadmaps & Prioritisation

The following section presents Implementation Roadmaps for each of the Smart Specialisation proposals presented in 4.3 Smart Specialisation proposals. Key themes within each proposal are grouped and presented in a timeline to 2030. Long term goals / topics of interest for 2030+ are presented towards the far right of each roadmap.

These roadmaps provide a reference point against which future progress can be measured.

4.4.1 Smart Specialisation Proposal 1: Radionuclides

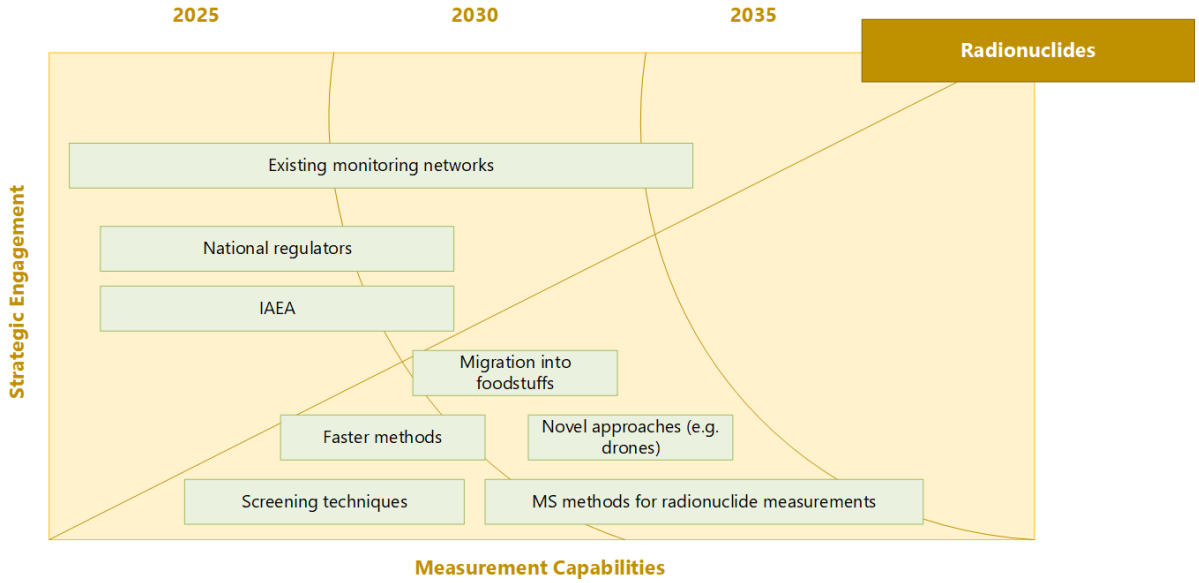

Figure 25: Implementation Roadmap – Radionuclides

4.4.2 Smart Specialisation Proposal 2: Reference Materials

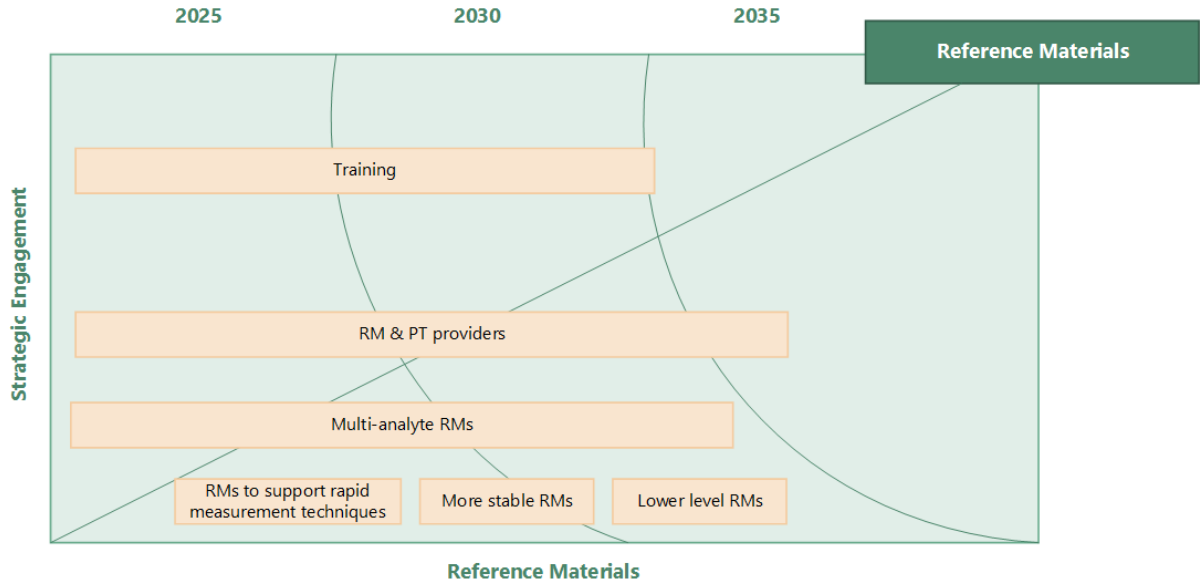

Figure 26: Implementation Roadmap – Reference Materials

4.4.3 Smart Specialisation Proposal 3: Environmental Pathways

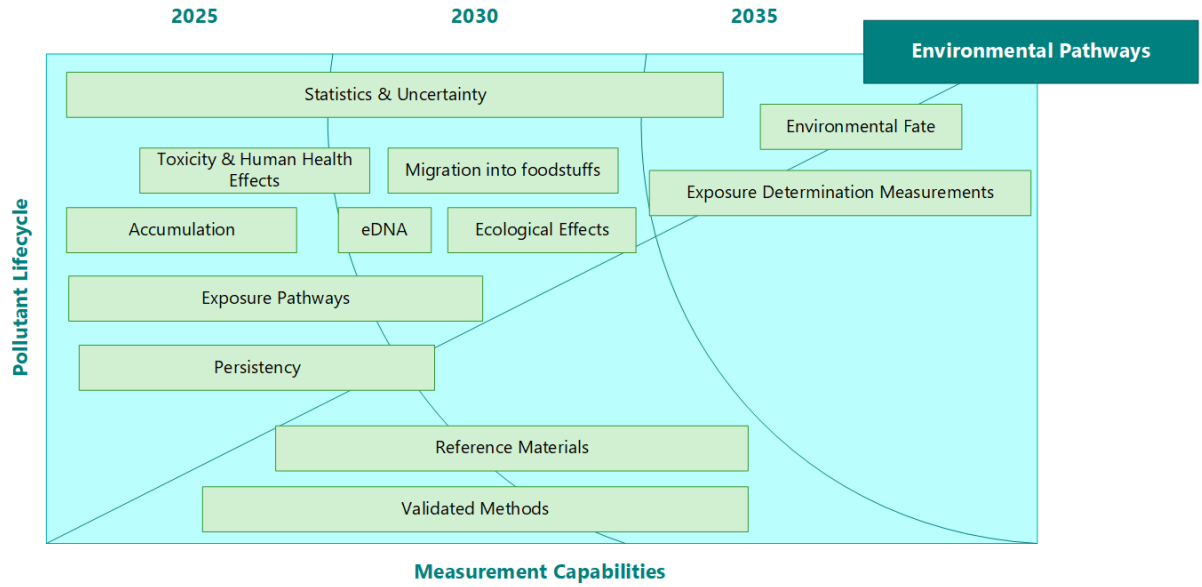

Figure 27: Implementation Roadmap – Environmental Pathways

5 CROSS SECTIONAL

5.1 Introduction

The air, water, and soil sections within the scope of EMN POLMO each represent distinct challenges when considering the strategic direction research should take in the years to come. However, it is evident that there are also significant areas of communality where similar measurement challenges are present across all sections. To this end, it is useful to consider a strategic cross-sectional approach which addresses measurement challenges in a holistic manner and in acknowledgement of the fact that the various environmental compartments are intrinsically linked.

To this end, the following matrix identifies areas in which measurement challenges are common across multiple sections and makes proposals for how these can be addressed in an effective manner. Overarching challenges require overarching solutions, and it is crucial that European measurement institutes take a collaborate and cross-disciplinary approach to addressing these questions.

5.2 Cross Sectional Matrix

✓ Relevant to this section

✕ Requires further evaluation and consultation with stakeholders

	Measurement Challenge	Section			Strategy
		Air	Water	Soil	
1	**PFAS** Stakeholders and EMN members across all sections identified PFAS and other 'forever chemicals' as one of, if not the most, significant measurement challenge facing Europe. Current capabilities are limited and geographically siloed. There is a need to agree on an approach to classification of these substances in order to enable more effective risk assessments.	✓	✓	✓	• Facilitate definition of pollutant categories and measurands. This can be facilitated by interlaboratory studies to encourage method development, refinement, and validation. • Engage with relevant stakeholders (including existing monitoring networks) across all sections to better understand sources of environmental contamination, exposure pathways, and human health and ecological effects. Digital twins could also be used to help develop a holistic understanding of pollutant persistence. • While this topic is not the subject of any PRTs under the Green Deal 2024 call, stakeholder views gathered during the production of this SRA indicate that it should be an important consideration for the next Green Deal call in 2027.
2	**Reference Materials** Stakeholders and EMN members across all sections identified a need for reference materials to facilitate better measurements. Engagement with RM providers has shown the user appetite for reference materials in the environmental sector is increasing, and the metrology community must act to support the growing need.	✓	✓	✓	• The next generation of reference materials across all environmental sectors need better matrix matching and longer-term stability. NMIs involved in RM development should ensure that their material development strategies adhere to these principles. • Multi-analyte materials are also a priority. Whereas in the past, focus has been on single analyte materials, future work should acknowledge that fit-for-purpose multi-analyte materials are what stakeholders currently require.

					• Interlaboratory studies (e.g. via CCQM) can be a vehicle to drive RM development and the needs of stakeholders in pollution monitoring should be considered in this space. • Further work is also needed to understand the types of materials stakeholders need (QC material, RM, CRM). The highest levels of metrological rigour and traceability, while a high priority for the metrology community, may not necessarily be the end user's chief concern.
3	**Radionuclides** Stakeholders and EMN members across all sections identified radionuclides as a pollutant of significant concern, both in terms of well-known contaminants and emerging contaminants. Current methods rely on slow laboratory-based techniques and do not address stakeholders' needs to make high quality field-based measurements.	✓	✓	✓	• This is a further area in which the metrology community should support the development of the next generation of reference materials. • Efforts should be undertaken to move radionuclide measurements outside of the lab by providing the metrological infrastructure to underpin high quality rapid field measurements for both screening and monitoring purposes. • Engage with relevant stakeholders (including existing monitoring networks) to support expansion of their capabilities into radionuclides.
4	**Low cost & constant monitoring sensors** Stakeholders and EMN members across the air and water sections identified a need for metrological validation of novel low cost or constant monitoring sensors which are deployed in the field for pollution monitoring. This is an emerging field, and it is crucial that data gathered via such measurement systems adheres to sound metrological principles,	✓	✓	✗	• Engage with relevant stakeholders (including existing monitoring networks and sensor manufacturers) to embed metrology in the field. • The role of such sensors and sensor networks is not limited to pollution monitoring. Those working in this area should be cognizant of the fact that the data generated by such networks also has important implications for other applications including monitoring climate change. • The emerging fields of ML and AI must not be ignored. Use of these technologies has the potential to be revolutionary

	particularly if it is to be used for applications such as risk assessment of contaminants.				for metrology (e.g. possibility of calibration-less sensors, or advanced measurement networks leveraging the possibility of citizen science). Those involved in pollution monitoring should look to engage with these technologies in a strategic way. • The use of these sensors in soil requires further investigation and stakeholder engagement.
5	**Pollutant mixtures** Stakeholders and EMN members across the soil and water sections highlighted the dangers of considering pollutants in isolation when assessing the risk they pose to environmental or human health. Pollutants need to be considered in combination to understand the real risks posed by so-called “chemical cocktails”.	✗	✓	✓	• Multiparameter risk assessments require both robust measurements of individual analytes and frameworks for understanding the nature of these in combination. As with reference materials (see point 2), emphasis should be placed on multiparameter methods which serve the real-world needs of stakeholders, rather than single parameter approaches which are tied to a laboratory setting. • Pollutant mixtures require further investigation and stakeholder engagement, as does transportation between environmental compartments. Understanding these mechanisms (e.g. oxidation states, chemical forms, leaching).
6	**Greener methods** Although only explicitly identified by stakeholders and EMN members in the air section, the general direction of travel across all laboratory research needs to be towards greener methods in order to align with the goals of the European Green Deal.	✓	✗	✗	• Future laboratory methods for pollution monitoring must ensure alignment with sustainability principles including energy efficiency, water efficiency, and use of reagents which are themselves potential pollutants (e.g. VOCs). • Emerging pollutants from novel ‘green’ technologies should also be considered (e.g. uncommon metals for which standard methods do not exist).
7	**eDNA & Biodiversity**	✗	✓	✗	• Engage with relevant stakeholders (Research Academia, SMEs) to better understand new eDNA methods.

	Although only explicitly identified by stakeholders and EMN members in the water section, eDNA is a powerful tool to monitor biodiversity loss under climate change.				• Develop standardisation to tackle and harmonise quality controls for all compartments. • Develop interlaboratory comparison across Europe, taking into account the regional occurrence and variability in species / taxons. • Investigate the relationship between eDNA methods and classical inventory methods to establish biological indices.

5.3 Future Cross-Sectional Strategy

The topics presented in 5.2 Cross Sectional Matrix represent the EMN's current understanding of cross-section priorities in the short to medium term.

However, there are a number of areas in which the EMN may seek to expand its scope over the coming years. These include indoor air pollution, noise pollution (further details provided below), and light pollution (further details provided below). As new topics are considered, and the pool of relevant stakeholder expands, this SRA will be revised to reflect their inclusion.

5.3.1 Future Cross-Sectional Strategy

Light pollution is characterised by excessive, misdirected, and disturbing artificial light with various negative effects. These include:

- Human health: Disrupted sleep patterns, potential health risks.[88]
- Biodiversity: Disruption of animal behaviour, habitat loss.
- Safety: Glare affecting drivers and cyclists.
- Astronomy: Obscured night sky, hindering observations and tourism.
- Energy consumption: Wasteful use of resources.

Regulations:

- Regulation efforts are underway at both national and EU levels.

Measurement challenges:

- Current methods lack standardisation and comparability.
- Need for research to define standardized measurements.

Possible Future research directions:

- Develop common metrics, measurement methods, and instrumentation.
- Include spectral, spatial, directional, and temporal aspects.
- Address human health and ecological impacts.
- Consider hyperspectral instrumentation.

Overall, light pollution is a growing concern with significant negative impacts. Addressing it requires standardised measurement methods, research on health and ecological effects, and effective regulations. Hence it is a suitable topic for inclusion in subsequent versions of this SRA, pending engagement with the relevant stakeholders.

5.3.2 Urban noise pollution

According to a 2011 report from the World Health Organization (WHO), noise pollution ranks as the second most significant environmental health hazard after air pollution.[89] It contributes to sleep disturbances, stress, cardiovascular issues, and learning disruptions.[90]

For example, a recent major study undertaken by the UK Health Security Agency assessed the impact of noise on health in terms of Disability Adjusted Life Years (DALYs). One DALY represents the loss of one year of good health. It found that 150,000 DALYs were lost in 2018 from road, rail and air traffic noise; a result of severe annoyance and sleep disturbance, leading to stroke, heart disease and diabetes.[91,92]

In its Environment Action Programme to 2030, “A Clean Planet for All”, the European Union committed to significantly decrease noise pollution in the Union, moving closer to levels recommended by the World Health Organisation.[93]

Regulations:

- Environmental Noise Directive (END) (2002/49/EC): Requires member states to assess and manage environmental noise through noise maps and action plans, focusing on urban areas, major roads, railways, and airports.[94]
- EU Machinery Directive (2006/42/EC): includes provisions related to noise emissions from machinery and equipment. It sets out essential health and safety requirements, encouraging manufacturers to design products with noise reduction measures.[95]
- Directive 2000/14/EC: Sets noise emission limits for various machinery types and prescribes testing methods for compliance including CE marking.[96]
- Regulation (EC) No 598/2014: Addresses noise reduction from civil subsonic jet aeroplanes.[97]
- Regulation (EU) No 1304/2014: Sets technical specifications for noise levels produced by trains.[98]

Measurement Challenges:

- Emerging technologies: Acoustic sensor networks, acoustic antennas, and AI for sound event classification lack established calibration methods, standards, and certification programs, compromising data reliability and metrological traceability (ability to relate measurements to national or international standards).
- Spatial sensor networks: Establishing these networks requires addressing challenges like:
    - In-situ calibration: Calibrating a large network of low-cost sensors is expensive and logistically complex, requiring novel methods. The possibility of self-calibrating sensors must also be evaluated.
    - Reducing uncertainties: Ensuring data accuracy and minimizing measurement errors in complex urban environments.
    - Multi-modal sensing: Exploiting correlations between noise and other environmental data (e.g. air quality) from co-located sensors requires advanced data fusion techniques.
    - Big data management: Handling and analysing large datasets generated by dense sensor networks necessitates cloud computing and efficient data processing tools.

Possible Future Research Directions:

- Development of calibration methods, standards, and certification programs to quality of acoustic sensor network and acoustic antenna data.
- AI-processed data: Tools to evaluate the uncertainty, robustness, and quality of data processed through artificial intelligence algorithms (e.g. for determining localisation and classification of noise pollution).[99]
- Investigate and implement in-situ calibration techniques for large-scale sensor networks, minimizing logistical and financial burdens.
- Explore the feasibility and effectiveness of multi-modal and proxy sensing, leveraging existing air quality sensor networks for noise source identification and characterisation.

Urban noise pollution remains a significant public health concern in Europe, despite existing regulations. Addressing the technical challenges associated with novel measurement technologies and pursuing further research are crucial steps towards effective noise management and improving public health outcomes. Hence it is a suitable topic for inclusion in subsequent versions of this SRA, pending engagement with the relevant stakeholders.

5.3.3 Marine noise pollution

Oceans cover >70% of the surface of our planet, constitute more than 95% of the biosphere, provide a substantial portion of the global population with food and livelihoods, and are the means of transport for 80% of global trade.[100] The impact of acoustic noise emanating from human activities poses unprecedented risks for the sustainability of key marine species, biodiversity, ecosystems, and overall ocean health.[101,102] Key marine species use sound for communication and echolocation during foraging, and noise impacts range from physical injury and hearing impairment to chronic masking and habitat displacement.

Regulations:

- EU Marine Strategy Framework Directive (MSFD) (2008): Requires member states to assess the "Good Environmental Status" of their seas, Seismic surveys, construction (e.g. pile driving), dredging, military sonars, decommissioning, and shipping traffic including underwater noise at specific frequencies (63 Hz and 125 Hz).[103]
- EU Habitats Directive (1992): Protects the marine environment in Europe and requires environmental impact assessments for offshore activities, including noise evaluation.[104]
- International Maritime Organization (IMO): Provides guidelines to reduce underwater noise from commercial shipping.[105]

Measurement Challenges:

- Noise-generating activities include seismic surveys, construction (e.g., pile driving), dredging, military sonars, decommissioning, and shipping traffic. Most sound sources emit between 10 Hz and 1 kHz, where traceability (linking measurements to standards) is weakest.
- Lack of metrology infrastructure, both with regard to characterizing sound sources and undertaking long-term monitoring. Metrology for offshore noise measurement is currently lagging behind the rapidly evolving legislative framework.

Future Research Directions:

- Develop traceable measurement standards for both specific sound sources and ambient soundscapes.
- Establish standards for measuring sound particle motion with traceable and validated sensors.
- Address the challenges of deepwater measurements through advancements in acoustic system capabilities.
- Develop methods for ensuring accurate data collection and analysis from digital sensors and recorders.

Marine noise pollution poses a significant threat to marine ecosystems and requires robust metrological solutions and improved measurement capabilities in order to keep pace with regulatory requirements. Hence it is a suitable topic for inclusion in subsequent versions of this SRA, pending engagement with the relevant stakeholders.

6 CONCLUSION

The EMN-POLMO aims to create a sustainable metrology infrastructure to support European and international regulations and directives targeting pollution monitoring, using smart specialisation to maximise outcomes from currently available research resources.

The field of pollution monitoring is a complex landscape encompassing both pressing challenges and exciting opportunities that lie ahead. These challenges and opportunities need to be addressed in a strategic manner in order to derive the greatest value from future research programmes.

It is the vision of the EMN POLMO that this SRA be a valuable resource for anyone who is interested in pollution monitoring research. It provides a comprehensive overview of the key challenges and opportunities in the field, and it sets out a roadmap for future research and development. The SRA will be updated on an annual basis to reflect the latest developments in the field, and it will be a valuable tool for ensuring that pollution monitoring continues to meet the needs of European society.

7 REFERENCES

1. https://ec.europa.eu/commission/presscorner/detail/en/IP_21_4747
2. The European Green Deal, COM/2019/640, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN
3. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Pathway to a Healthy Planet for All EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', COM/2021/400, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827#footnote5
4. https://new-european-bauhaus.europa.eu/index_en
5. Healthy environment, healthy lives: how the environment influences health and well-being in Europe, EEA Report No 21/2019, https://www.eea.europa.eu/publications/healthy-environment-healthy-lives
6. https://environment.ec.europa.eu/strategy/chemicals-strategy_en
7. https://www.iarc.who.int/news-events/iarc-monographs-evaluate-the-carcinogenicity-of-perfluorooctanoic-acid-pfoa-and-perfluorooctanesulfonic-acid-pfos/
8. Zahm et al, Carcinogenicity of perfluorooctanoic acid and perfluorooctanesulfonic acid, The Lancet Oncology, 2023, https://doi.org/10.1016/S1470-2045(23)00622-8.
9. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L 327, 22.12.2000, p. 1–73, https://eur-lex.europa.eu/eli/dir/2000/60/oj
10. https://www.EURAMET.org/research-innovation/search-research-projects/details/project/support-for-a-european-metrology-network-on-pollution-monitoring
11. https://www.euramet.org/download?tx_eurametfiles_download%5Baction%5D=download&tx_eurametfiles_download%5Bcontroller%5D=File&tx_eurametfiles_download%5Bfiles%5D=44062&tx_eurametfiles_download%5Bidentifier%5D=%252Fdocs%252FEMRP%252FJRP%252FJRP_Summaries_2020%252FNetworks%252F20NET03_Publishable_Summary.pdf&cHash=56091b545de4ba110a6816439107bf77
12. http://data.europa.eu/eli/dir/2008/50/oj
13. http://data.europa.eu/eli/dir/2000/60/oj
14. http://data.europa.eu/eli/dir/1986/278/2022-01-01
15. http://data.europa.eu/eli/dir/2004/107/2015-09-18
16. http://data.europa.eu/eli/dir/2008/56/2017-06-07
17. http://data.europa.eu/eli/dir/2006/118/2014-07-11
18. http://data.europa.eu/eli/dir/1991/271/2014-01-01
19. http://data.europa.eu/eli/dec_impl/2013/39/oj
20. http://data.europa.eu/eli/dir/2020/2184/oj
21. http://data.europa.eu/eli/dir/1991/676/2008-12-11
22. http://data.europa.eu/eli/reco/2000/473/2004-05-01
23. http://data.europa.eu/eli/dir/2008/98/2018-07-05
24. http://data.europa.eu/eli/dir/2010/75/2011-01-06

25. http://data.europa.eu/eli/reg/2011/143/2011-02-21
26. http://data.europa.eu/eli/reg/2017/852/2023-10-16
27. http://data.europa.eu/eli/dir/2013/59/2014-01-17
28. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:C2012/327/01
29. https://www.legifrance.gouv.fr/loda/id/JORFTEXT000043388197/
30. https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000045463803
31. https://www.legifrance.gouv.fr/loda/id/JORFTEXT000048347187/
32. https://www.legifrance.gouv.fr/loda/id/JORFTEXT000047826536/
33. https://www.legislation.gov.uk/uksi/2010/1001
34. https://www.legislation.gov.uk/uksi/2010/675
35. https://www.legislation.gov.uk/ukpga/1990/43
36. https://www.gov.uk/government/publications/contaminated-soil-assessing-risks-on-human-health
37. https://www.legislation.gov.uk/ukpga/2021/30/enacted
38. https://www.gesetze-im-internet.de/bimschg/
39. https://www.gesetze-im-internet.de/whg_2009/
40. https://www.gesetze-im-internet.de/bbodschg/
41. https://www.gesetze-im-internet.de/bimschv_39/index.html
42. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Binnengewaesser/nationale_wasserstrategie_2023_en_bf.pdf
43. http://www.gesetze-im-internet.de/bioabfv/BioAbfV.pdf
44. http://www.gesetze-im-internet.de/bnatschg_2009/BNatSchG.pdf
45. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Bodenschutz/5_bodenschutzbericht_2021_bf.pdf
46. https://www.dvgw.de/medien/dvgw/wasser/verordnung/trinkwasserverordnung-2023.pdf
47. https://www.bmel.de/DE/themen/landwirtschaft/pflanzenbau/bodenschutz/schadstoffe.html
48. https://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_18082021_IGI25025005.htm
49. https://www.umweltrat.de/SharedDocs/Downloads/DE/01_Umweltgutachten/2008_2012/2008_Umweltgutachten_HD_Kap06.pdf?__blob=publicationFile&v=2
50. https://www.umweltbundesamt.de/themen/wasser/trinkwasser/trinkwasserqualitaet/toxikologie-des-trinkwassers/trinkwasserleitwerte
51. https://mluk.brandenburg.de/sixcms/media.php/land_bb_test_02.a.189.de/tr_laga2.pdf
52. https://www.umweltbundesamt.de/sites/default/files/medien/359/dokumente/methosa_fu_v1_1_18-11-06_online_laga_fbu.pdf
53. https://rp.baden-wuerttemberg.de/rpk/abt5/ref541/pfc/seiten/landwirtschaft
54. https://www.bundeswehr.de/resource/blob/95768/18bd013558b28fa63a67c59769ee72f2/download-informationen-zu-pfc-leitfaden-data.pdf

55. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Strahlenschutz/avv-imis.pdf
56. https://www.bmuv.de/themen/strahlenschutz/ionisierende-strahlung/ueberwachung-der-radioaktivitaet-in-der-umwelt/messanleitungen
57. https://www.gesetze-im-internet.de/bnatschg_2009/
58. https://www.gesetze-im-internet.de/krwg/
59. https://www.gesetze-im-internet.de/ksg/index.html#BJNR251310019BJNE000101116
60. https://www.sujb.cz/fileadmin/sujb/docs/legislativa/zakony/Act_263_2016_web.pdf
61. https://www.sujb.cz/fileadmin/sujb/docs/legislativa/vyhlasky/Decree_360_2016_web.pdf
62. https://www.sujb.cz/fileadmin/sujb/docs/legislativa/vyhlasky/377_Radioactive_Waste.pdf
63. https://www.mpo.cz/cz/prumysl/chemicke-latky-a-smesi/dalsi-vyhlasky-k-chemickemu-zakonu--105216/
64. https://www.mzp.cz/www/platnalegislativa.nsf/3ED571E252E44B37C12571B0003F53B1/%24file/OL_CHEMZAK_2021.pdf
65. https://www.mpo.cz/assets/dokumenty/27592/33208/349512/priloha004.doc
66. https://www.finlex.fi/en/laki/kaannokset/2006/en20061022.pdf
67. https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/programme-performance-statements/horizon-europe-performance_en#contribution-to-horizontal-priorities
68. https://www.bipm.org/kcdb/cmc/advanced-search?area=8
69. Kortoçi et al, Air pollution exposure monitoring using portable low-cost air quality sensors, Smart Health, Volume 23, 2022, 100241, https://doi.org/10.1016/j.smhl.2021.100241
70. Kuscer et al, An advanced miniature fluidic system in multilayer ceramic technology with precise temperature and flow control for in situ pollution monitoring, Sensors and Actuators A: Physical, Volume 366, 2024, 14946, https://doi.org/10.1016/j.sna.2023.114946
71. Hou et al, A Water Pollution Monitoring System Based on the Internet of Things, Procedia Computer Science, Volume 228, 2023, p 2-13, https://doi.org/10.1016/j.procs.2023.11.002
72. Snyder et al, Environmental Science & Technology 2013 47 (20), 11369-11377, DOI: 10.1021/es4022602
73. European Commission, Pathway to a Healthy Planet for All - 'Towards Zero Pollution for Air, Water and Soil', SWD(2021) 140, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0400
74. UKRI/Met Office Clean Air Strategic Priority programme, A Research Roadmap for Clean Air in the UK, https://generic.wordpress.soton.ac.uk/wp-content/uploads/sites/421/2021/02/A-UK-research-roadmap-for-clean-air_-summary.pdf
75. Defra Air Quality: Open Data Roadmap, https://uk-air.defra.gov.uk/library/reports?report_id=846
76. https://minamataconvention.org/en/documents/minamata-convention-mercury-text-and-annexes

77. https://www.consilium.europa.eu/en/press/press-releases/2023/12/18/euro-7-council-and-parliament-strike-provisional-deal-on-emissions-limits-for-road-vehicles/
78. Oteros, J. et al. Automated and online pollen monitoring. Int. Arch. Allergy Immunol. 167, 158–166. https://doi.org/10.1159/000436968 (2015).
79. Kubera, E. et al, Deep learning methods for improving pollen monitoring. Sensors 21, 3526. https://doi.org/10.3390/s21103526 (2021).
80. Schaefer, J. et al., Towards automatic airborne pollen monitoring: From commercial devices to operational by mitigating class-imbalance in a deep learning approach. Sci. Total Environ. 796, 148932. https://doi.org/10.1016/j.scitotenv (2021).
81. J. Geršl, et al., Flow rate measurement in stacks with cyclonic flow – Error estimations using CFD modelling, Measurement 129, 2018, 167-183, https://doi.org/10.1016/j.measurement.2018.06.032.
82. Knotek, S. et al., (2021). Narrow stack emissions: Errors in flow rate measurement due to disturbances and swirl. Journal of the Air & Waste Management Association, 71(1), 46–59. https://doi.org/10.1080/10962247.2020.1832621
83. https://echa.europa.eu/ann-x-priority-subs-water-dir-2000-60
84. Norros, V. et al, Roadmap for implementing environmental DNA (eDNA) and other molecular monitoring methods in Finland, Reports of the Finnish Environment Institute 20 (2022), http://urn.fi/URN:ISBN:978-952-11-5482-9
85. Leese, F. et al, DNA-basierte Biodiversitätsanalysen im Natur- und Umweltschutz: Welche Optionen haben wir für eine Standardisierung?, BfN-Schriften 666 (2023), https://doi.org/10.19217/skr666
86. Bruce, K. et al., (2021) A practical guide to DNA-based methods for biodiversity assessment. Advanced Books. https://doi.org/10.3897/ab.e68634
87. A.S. Paschoa, F. Steinhäusler, Chapter 3 - Terrestrial, Atmospheric, and Aquatic Natural Radioactivity, Editor(s): A.S. Paschoa, F. Steinhäusler, Radioactivity in the Environment, Elsevier, Volume 17, 2010, Pages 29-85, https://doi.org/10.1016/S1569-4860(09)01703-3.
88. Zhang D, et al., Associations between artificial light at night and risk for thyroid cancer: A large US cohort study. Cancer. 127(9). 1448-1458 (2023). https://doi.org/10.1002/cncr.33392
89. World Health Organization (WHO) (2011), Burden of disease from environmental noise. ISBN:9789289002295, 2011.
90. ANSES. Évaluation des impacts sanitaires extra-auditifs du bruit environnemental. 2013, https://www.anses.fr/fr/system/files/AP2009sa0333Ra.pdf
91. Calvin Jephcote et al. Spatial assessment of the attributable burden of disease due to transportation noise in England. Environment International, Volume 178, August 2023, 107966. https://doi.org/10.1016/j.envint.2023.107966
92. Noise pollution: mapping the health impacts of transportation noise in England. https://ukhsa.blog.gov.uk/2023/06/29/noise-pollution-mapping-the-health-impacts-of-transportation-noise-in-england/
93. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022D0591
94. https://eur-lex.europa.eu/eli/dir/2002/49/oj
95. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006L0042-20190726
96. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32000L0014

97. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32014R0598
98. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.356.01.0421.01.ENG
99. Ministère de la Transition écologique et de la Cohésion des territoires. Radars sonores : une expérimentation en conditions réelles pour lutter contre la pollution sonore. 2022. https://www.ecologie.gouv.fr/radar-sonore
100. United Nations Environment Programme (UNEP), Blue Economy Concept Paper, https://www.unep.org/resources/report/blue-economy-concept-paper
101. World Bank and United Nations Department of Economic and Social Affairs. 2017. The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources, https://www.un.org/en/desa/exploring-potential-blue-economy.
102. The G7 Future of the Seas and Oceans Initiative (FSOI). Working Group Summary Report, 2021, https://www.g7fsoi.org/.
103. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008L0056
104. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:01992L0043-20130701
105. Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life. MEPC.1/Circ.906, International Maritime Organization, 2023. https://www.imo.org/en/MediaCentre/Pages/WhatsNew-1818.aspx

EURAMET e.V.
Bundesallee 100
38116 Braunschweig
Germany

Phone: +49 531 592 1960
Fax: +49 531 592 1969
E-mail: secretariat@euramet.org

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States