EURAMET

Impact of the EMRP

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European Metrology Research Programme

Article 169

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Impact of the EMRP

(Analysis on data available at the end of 2016)

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EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

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This report represents EURAMET's view of the Impact of the EMRP based on the data available at the end of 2016. It is based on the evidence EURAMET presented to the ex-post evaluation. It presents data against the programme's specific and operational objectives as defined in Part 5 of the Annex to the General Agreement (GA) and summarises the evidence against the evaluation criteria of effectiveness, efficiency and European Value-added.

Effectiveness

The programme has delivered against all of its operational and specific objectives.

Specific objectives - contributing to the ERA / creating a Metrology Research Area

Leveraging and consolidating metrology funding in Europe

The programme achieved a significant level of coordination of national public metrology research programmes. 23 European countries participated in EMRP, leveraging national funding of 219.236 M€ – 10 % above the target of 200 M€ – for EMRP activities. The value of the total EMPIR (the successor programme) budget compared to the national metrology research budgets over the same period is 52 %.

The programme enabled widespread collaboration in metrology research, not only among the traditional metrology institutes (the NMIs and DIs) but also with the academic, industrial and public sector communities. The Commission and national funding supported 119 joint research projects with 957 participations from the metrology community (i.e. NMIs and DIs) and 1157 participations from a further 916 organisations the academic, industrial and public sector communities.

Scientific integration

The programme was designed and governed by the participating countries at a number of levels to support scientific integration of metrology research across Europe:

- The programme was guided by a common research agenda developed by the European metrology community under the precursor ERA-NET programme iMERA;
- The programme was designed around themes focused on grand societal challenges (energy, environment, health, industry) as well as supporting important developments in the international systems of units (the SI).
- Call scopes were developed by the EMRP Committee in line with the common research agenda;
- A two-stage call process brought the European metrology community together, along with the academic community and measurement research end-users, to develop and deliver collaborative research projects;
- Project selection was based on an assessment, by the EMRP committee, of alignment with strategic requirements (stage 1) and independent expert review (stage 2). The Interim Evaluation of EMRP and the annual independent observers' reports confirm that this process was independent and robust.

All participating countries could (in most cases, did) participate in all levels of programme and project design and governance.

Projects were conducted by collaborations of NMIs, DIs, academics, industrial and other organisations significantly increasing the level of networking and enabling the flow of ideas, knowledge and people and sharing of metrology research facilities.

Management integration

EURAMET implemented a dedicated and centralised governance and management processes for the programme from the outset, made up of the EMRP Committee, a EMRP Programme Manager and a dedicated Management and Support Unit (MSU). The delivery of the programme has been monitored and reviewed in various ways (annual reports, audits, Interim Evaluation, etc) and no significant problems or issues have arisen. The Interim Evaluation found the programme processes to be of high quality and transparent and in line with the Commission's requirements.

Financial integration

The programme managed 200 M€ of EU funding and coordinated 19 M€ of national metrology research funds using a common approach to financial rules. From the very beginning the programme adopted a model contract and financial approach based on the FP7 model. Guidelines and templates were provided to support project partners who were new to this approach, helping them to cost projects and ensure finances were reported consistently and in accordance with the financial rules.

Specific objective - delivering scientific, economic and social impact

Scientific excellence and impact

The EMRP programme provided a structured process of research collaboration among European metrology institutes (NMIs and DIs). Prior to EMRP (and its predecessor ERA-NET iMERA+) research collaboration was rather ad-hoc, based on goodwill and relationships between individual institutes and researchers. A key benefit of the programme was not only the ability to coordinate resources and skills but the ability to align research timescales. An important example of this being the coordination of European research contribution to the forthcoming redefinition of the international system of units (the SI). EMRP projects under the first SI call became a focal point for European redefinition activity and, for some projects, an international focal point. The pooling of research expertise and the alignment of critical experiments and measurement comparisons has enhanced the European contribution scientifically but also in terms of creating a more coordinated European position in the forthcoming redefinition decision.

EMRP researchers have published 1358 papers in peer-reviewed journals. Bibliographic analysis shows that the publications are above world averages in terms of citations, impact factor and highly cited papers and have been increasing over the period from 2008 to 2015 (i.e. before and during EMRP). In addition, the level of international co-authorship of peer-reviewed papers has increased from 32 % to 47 %.

Economic impact

Accurate traceable measurement, reliable and robust worldwide, underpins trade. Metrology research ensures the international measurement systems are fit for the future and supports the introduction of innovative product and services through the accurate validation of new technologies and ideas. The pathways and timescales for economic impact are not always direct or immediate and most EMRP projects have only recently been completed (and some EMRP projects have not yet finished). Nevertheless, EURAMET has collected evidence of early impact - that is the adoption of EMRP project outputs by measurement users. Early adopters of metrology research are often (but not solely) the instrumentation sector and the accredited laboratory sector who make use the new NMI/DI capabilities or adopt the improved measurement techniques to develop their own new products and services. These sectors are an important bridge to measurement end-users in other businesses sectors and public sector agencies, who use improved measurement capabilities to develop their new products and/or improve processes.

EURAMET conducted surveys of industrial participants in EMRP projects and developed impact case studies. These have demonstrated an economic impact in terms of actual and projected sales of innovative products (as quoted and/or estimated by the early adopters) influenced by the programme of 1,627 M€. Of this figure, the early adopters estimate that 319 M€ is directly attributable to the programme. This figure covers the industrial participants that participated in projects in the first three EMRP calls (covering the Energy, Environment, Industry, Health and New Technology themes) and therefore can be expected to increase as additional surveys are conducted and case studies developed. In addition, the new products sold will contribute to economic benefits for many of the end-users. EURAMET has identified and published 42 case studies demonstrating economic impact.

Social impact

Three of the programme's themes were explicitly focused on social impact via the grand challenges Energy, Environment and Health. Research in these themes addressed the requirements for accurate data and appropriate instrumentation to improve the ability to identify, quantify and better understand problems, and to design and implement effective solutions and/or appropriate regulation. Many of the projects in these themes were directly focused on European regulation supporting issues such as water and air quality, safety of healthcare products and radiation protection. 42 projects (35 % of the total) supported regulation.

As for economic impact, the pathways and timescales for impact are not always direct or immediate (and some projects have not yet finished) but EURAMET has identified and developed 28 case studies to date of social impact in these three themes and more will follow. These case studies provide examples of the adoption of

project outputs by the measurement users and demonstrate that the route to longer-term impact has commenced. Examples include:

- New flow and temperature instrumentation that has been demonstrated to improve efficiency in traditional power plants, leading to reduced carbon emissions and providing financial benefits
- Supporting the introduction of energy efficient lighting in the Italian tunnel network, improving safety and reducing both costs and energy use
- The development and trial of practical reference standards to improve the robustness of roadside emissions monitoring, so protecting human health
- Contributing measurement methods and standards to ESA's next generation Earth observation satellites
- Developing accurate validation of molecular methods to identify and quantify infectious diseases

Operational objectives - key points

Extensive participation from European metrology institutes

There was extensive participation from across Europe in EMRP research activities. 23 countries were formal EMRP participating states (19 EU Member States and 4 non-EU) plus the JRC. A further 21 countries (including five EU Member States) participated in projects as unfunded partners or collaborators. Collaborative research projects involved between 4 and 18 NMI /DI partners.

Extensive participation from the scientific community and metrology end-users

There were 1147 participations in EMRP projects from 916 organisations outside the NMI /DI community. 50 % (570) of participations were from universities and public research organisations and 41 % (474) from industry. The academic and public research community largely participated in the programme via the Researcher Grant mechanism, while industrial participation was largely in the form of unfunded partners or collaboration via an NDA with project partners.

Considerable international participation

There were 140 participations in EMRP research projects by non-European researchers from the NMI/DI, academic and industrial communities either as unfunded partners or collaborators, including NMIs/ DIs from 14 countries (Argentina, Australia, Brazil, Canada, China, Egypt, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, Taiwan, Thailand, United States).

Researcher Mobility

79 mobility grants supported the transfer of staff between institutions to facilitate learning and the development of personal and institutional networks. These grants were heavily used by used by developing NMIs/DIs (60 % of grants were from this group) enabling their researchers to spend time in the more developed NMIs and DIs (97 % of mobility grant destinations were from this group).

Capacity building

Seven of the EMRP participating countries were EU new member states and two are accession /pre-accession states. A further three new member states participated in the programme, two of which formally joined the successor EMPIR programme. Via participation in projects and mobility grants, developing metrology institutes have been able to increase the research skills of their metrologists. Most have been able to increase their research activities where formerly they focused on maintaining national measurement standards and providing calibration services. For example: CMI, the NMI in the Czech Republic, has been able to develop critical mass in research in key areas and create a community of research-focused metrologists. IMBiH, the NMI in Bosnia and Herzegovina, has progressed from mobility grants, to collaborative projects, to being a coordinator of a project under EMPIR. Case studies of capacity building are provided in Figure 19.

Supporting European standardisation and regulation

The design of the programme around key societal challenges ensures strong alignment of the research to the European regulation. Metrology research enables more robust and reliable measurements to support the compliance with, and monitoring of the implementation of, regulation. 42 of the 119 projects funded have direct reference to regulation including, for example, the Renewable Energy Directive, the Water Framework Directive, Air Quality Directive and the Medical Device Directive (a full list is provided in Figure 28).

Project teams have also made (to the end of 2016) 1135 contributions to 486 unique standards committees. Many of these standards committees directly support regulation. Others support the characterisation of innovative technologies, products and processes to facilitate their market adoption.

Extensive dissemination of research results

Project teams have undertaken wide-ranging dissemination activities to share the research outputs with the metrology, scientific and end-user communities in the public and private sectors. Not all projects are completed or have finalised their reporting requirements, but current figures for dissemination activities include:

- 1432 peer-reviewed papers
- 4915 conferences presentations and posters
- 1020 training activities
- 2155 communications and dissemination activities (exhibitions, newsletters, trade press, etc)
- 36 patent applications

Efficiency

The programme objectives and impacts have been delivered efficiently. The costs of administering the programme are expected to be 16 M€. This represents 3.8 % of the total 419 M€ programme budget.

European value-added

Metrology is both a national and international endeavour. In some countries the requirement to hold national measurement standards to support the economy and society is enshrined in law and the international system of metrology ensures that primary measurement standards and the measurements they support are comparable and accepted across the world. However the requirements for research to ensure measurements are fit for the future are increasing. Meeting ever-growing demands for new measurement standards in emerging areas of technology whilst still meeting the expectations of existing sectors and users places increasing demands on national metrology research budgets, with most countries having similar demands. Conducting research at European level via EMRP has enabled national metrology institutes to pool resources and knowledge and reduce duplication and reach critical mass in key areas.

1 Introduction

This report represents EURAMET's view of the Impact of the EMRP based on the data available at the end of 2016. It is based on the evidence EURAMET presented to the ex-post evaluation. It presents data against the programme's specific and operational objectives as defined in Part 5 of the Annex to the General Agreement (GA) and summarises the evidence against the evaluation criteria of effectiveness, efficiency and European Value-added.

EMRP commenced in 2009 as an Article 169 TEC initiative, later transitioning to an Article 185 TFEU initiative. The programme held annual calls for joint research projects from 2009 to 2013, with projects in the last call finishing in 2017. The programme was preceded by two ERA-NET projects (MERA and iMERA+) that assessed the potential for joint working in metrology research; defined common research areas and piloted an initial joint research call.

2 EMRP objectives

The ex-ante impact assessment set out a set of nested general, specific and operational objectives for EMRP (Figure 1). The general objectives reflect (see below) with the objectives of FP7 and the Lisbon agenda, and the specific and operational objectives were designed to ensure EMRP would contribute to these wider goals.

The EMRP specific objectives S1.1, 1.2 and 1.3 contribute to the creation of the European Research Area (general objectives G1.2 and G1.3): the coordination of metrology research in Europe; aiming to reducing fragmentation and duplication; and removing barriers not just among the national metrology organisations but also with the wider research community, fostering inter-disciplinarity and the latest research in new and emerging technologies.

Specific objective 1.4 explicitly focuses on the impact of the metrology research directly aligned to the Lisbon objectives in three areas: scientific excellence, economic growth and addressing societal challenges (contributing to general objectives G1.1 and G1.4).

Figure 1 General, specific and operational objectives for EMRP

EMRP GENERAL OBJECTIVES	
Over-arching objective: The general policy objectives of the initiative is to enhance the EU's capacity to achieve its high level policy goals and respond to the major challenges it faces in the coming years:	
G1.1	To contribute to the achievement of the objectives of the revised Lisbon Strategy, focussing on four priority areas: (1) concern for citizens, (2) concern for the environment, (3) a more competitive economy, and (4) knowledge and innovation
G1.2	In particular to invest more and better in knowledge for growth and jobs (and to take steps towards the so called "fifth freedom" – the free movement of knowledge within ERA)
G1.3	To contribute to the realisation of the European Research Area (ERA) by implementing a genuine "European Metrology Research Area" (MERA).
G1.4	To help Europe respond more effectively to key societal challenges such as environmental protection, health care, food safety, or public security through research striving for scientific excellence in human potential and institutional resources

EMRP SPECIFIC OBJECTIVES	
Over-arching objective: In order to contribute to achieving the general European policy objectives, it will be necessary to improve the efficiency and effectiveness of public metrology research programming in Europe in areas where it is facing major societal challenges	
S1.1	Structuring the ERA through coordinating and partly integrating national public metrology research programmes to provide solutions to important European societal challenges

S1.2	Improve the efficiency of Europe's fragmented public metrology research approach
S1.3	To remove barriers between national metrology research programmes and to foster sustainable cross-border cooperation e.g. through mobility of young researchers, scientists and academic staff and to open up the national programmes to inter-disciplinary cooperation with researchers and scientists from other fields in particular relating to new and emerging technologies.
S1.4	To increase the impact of these programmes, both S&T impacts (scientific excellence, pooling of resources, data and expertise, achievement of critical mass, facilitating programme optimisation) and economic and societal impacts.

EMRP OPERATIONAL OBJECTIVES	
O1.1	Cross-border public research programme coordination and integration
O1.2	Address the grand challenges (e.g. climate change) and areas with pressing metrology needs (e.g. new and emerging technologies like for example nano- biotech- healthcare- metrology)
O1.3	Enable some "new" MS or candidate countries to build metrology research capacity
O1.4	Open access to unique research infrastructures and facilities
O1.5	Increase generic collaboration between national metrology research programmes with the relevant science community at European level
O1.6	Modernisation in the programming of national and European research priorities
O1.7	Foster mobility of "early-stage" researchers from National Metrology Institutes and Designated Institutes
O1.8	Europe should speak with one voice to strengthen its influence at global level
O1.9	Metrology research has to become a supporting activity for government regulation
O1.10	Support to industry and economic growth through up-front public metrology research

3 Indicators: specific objectives

This section provides data and evidence against the indicators set for the programme's specific objectives as presented in Figure 2 below.

Figure 2 Specific objectives and indicators

EMRP SPECIFIC OBJECTIVES		INDICATORS
Over-arching objective: In order to contribute to achieving the general European policy objectives, it will be necessary to improve the efficiency and effectiveness of public metrology research programming in Europe in areas where it is facing major societal challenges		
S1.1	Structuring the ERA through coordinating and partly integrating national public metrology research programmes to provide solutions to important European societal challenges	**Leveraging investments and co-funding of EMRP by the participating States** • National funding committed and effectively spent on EMRP: the target is EUR 200 million spent by the participating States; identification of the use of the reserve funding capability. **Programme efficiency** • The time required between the closure of the call for EMRP proposals or for researcher grants and the date where information on the outcome of the evaluation is sent to the applicants. **Progress towards the integration of national programmes** *Scientific integration*
S1.2	Improve the efficiency of Europe's fragmented public metrology research approach	
S1.3	To remove barriers between national metrology research programmes and to foster sustainable cross-border cooperation e.g. through mobility of young researchers, scientists and academic staff	

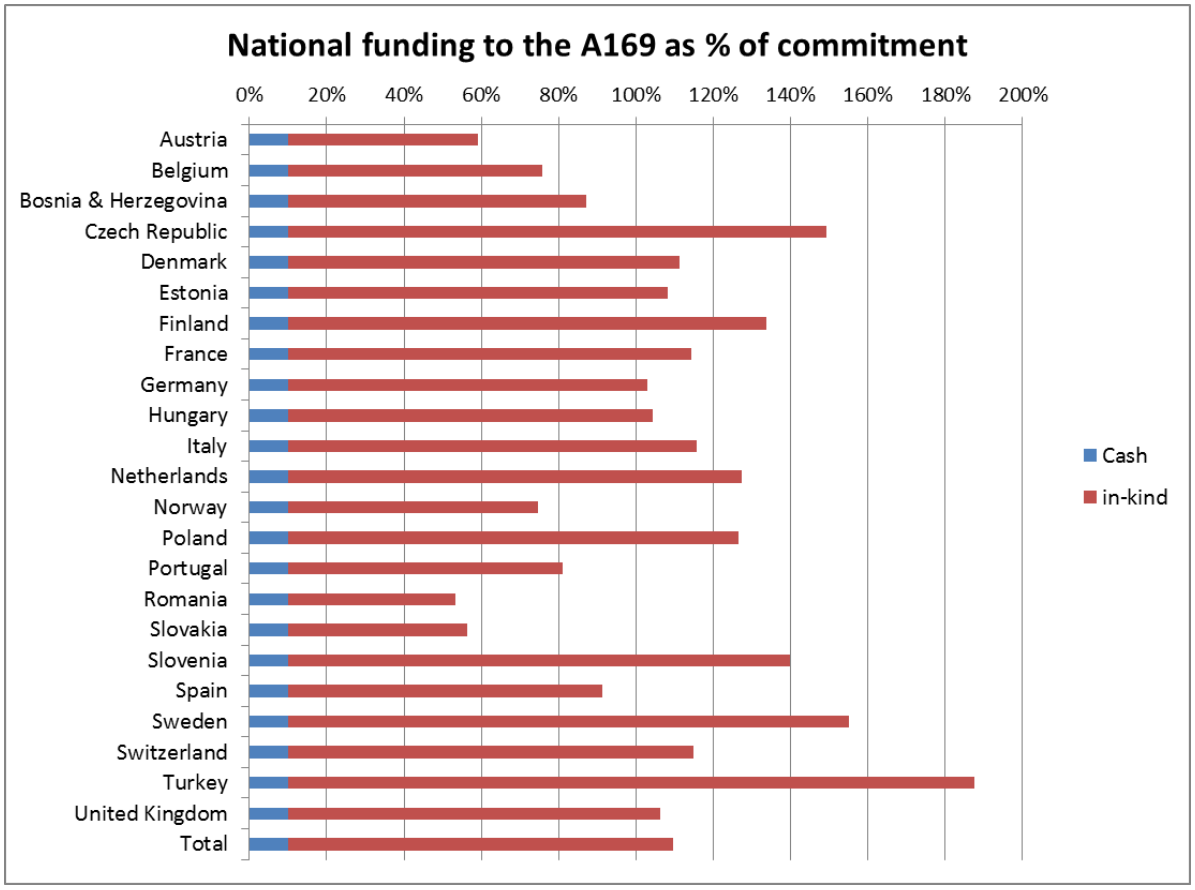
	and to open up the national programmes to inter-disciplinary cooperation with researchers and scientists from other fields in particular relating to new and emerging technologies.	• Common definition of research topics following the EMRP and involving third parties through the call for potential research topics; • Effectively working central evaluation with independent experts, and central selection decision. *Management integration* • The dedicated implementation structure is in place and is effectively implementing EMRP; • The use of a common contract (model grant agreement per category of activity) linking all the fund recipients to EURAMET. *Financial integration* • The projects selected at central level are effectively co-funded by the participating States from their national earmarked budget and the reserve funding capability, according to the order in the ranking list; • The Community contribution is allocated to the projects according to the order of the ranking list; • Progress towards more financial integration through the use of harmonised financial rules (e.g. eligibility of costs, funding rates, ex-post verification).
S1.4	To increase the impact of these programmes, both S&T impacts (scientific excellence, pooling of resources, data and expertise, achievement of critical mass, facilitating programme optimisation) and economic and societal impacts.	*No indicators set but relevant data is provided in this report*

3.1 Leveraging investments and co-funding of EMRP by the participating States (S1.1)

Figure 3: Specific Objectives - Indicator 1

INDICATOR 1	**National funding committed and effectively spent on EMRP: the target is EUR 200 million spent by the participating States; identification of the use of the reserve funding capability**
Data / Evidence	
By the end of 2015, the total national funding committed to EMRP was **219.236 M€**. The target commitment was 200 M€ and therefore 19.236 M€ of reserve funding has been allocated. Figure 4 presents the national target and actual commitment and Figure 4 presents the same data as a chart illustrating the cash and in-kind contributions. Some projects are still in progress and therefore this figure will not be fully spent until the last project ends in 2017.	

Figure 4: National commitments to EMRP – cash and in-kind



Source: EMRP 2015 Annual Report

Figure 5: National commitments to EMRP

	Initial national commitment	Actual national commitment
	k€	k€
Austria	840	495
Belgium	840	637
Bosnia & Herzegovina	100	87
Czech Republic	4,295	6,414
Denmark	2,235	2,486
Estonia	420	454
Finland	8,033	10,748
France	19,014	21,742
Germany	71,473	73,609
Hungary	840	875
Italy	14,081	16,279
Netherlands	10,827	13,772
Norway	1,397	1,044
Poland	420	532
Portugal	840	681
Romania	840	448
Slovakia	2,526	1,423
Slovenia	1,257	1,760
Spain	4,475	4,085
Sweden	2,389	3,704
Switzerland	6,424	7,370
Turkey	1,588	2,978
United Kingdom	44,845	47,611
Total	**200,000**	**219,236**

Source: EMRP 2015 Annual Report

3.2 Programme efficiency (S1.2)

Figure 6: Specific Objectives - Indicator 2

INDICATOR 2	The time required between the closure of the call for EMRP proposals or for researcher grants and the date where information on the outcome of the evaluation is sent to the applicants
Data / Evidence	
The time between call close and the announcement of the outcome to the applicants varied year to year. Between the 2010 and 2013 Calls the average time was 55 days. The timescale of the first call was particularly short as the programme was given approval to commence later than expected. It was possible to achieve this because the call was very small (covering only one theme and 9 funded projects) compared to later calls (that covered two or three themes and ~20-30 funded projects per year).	

Year	Stage 2 close	Stage 2 preliminary results	Days required
2009	02/11/2009	27/11/2009	25
2010	11/10/2010	29/11/2010	49
2011	03/10/2011	28/11/2011	56
2012	01/10/2012	28/11/2012	58
2013	01/10/2013	25/11/2013	55

For Researcher Grants, the time between call close and the communication of results to the applicant was planned to be one month, and this was met in the majority of cases, but as the individual consortia were responsible for the final selection, there were times that this took longer.

3.3 Progress towards the integration of national programmes (S1.3)

3.3.1 Scientific integration

Figure 7: Specific Objectives - Indicator 3a

INDICATOR 3a	Common definition of research topics following the EMRP and involving third parties through the call for potential research topics

Data / Evidence

National commitment of EMRP member states to a common definition of research

At the national level, metrology programme owners supported the common definition of research topics at the European level by relinquishing control over a large proportion of their national programmes (219 M€ - which is a significant proportion of national funding for metrology research) and allowing the research topics to be defined via the processes of the EMRP.

Common research agenda

Before the Programme started there was considerable work in the precursor ERA-NET projects (MERA, iMERA) to define common areas of interest that would be suitable to define call areas under EMRP (and the pilot call under iMERA+). Detailed roadmaps were developed and one of the iMERA outputs was further refined to become a published “outline” to define the priorities for the Programme.

At the end of the EMRP this process was repeated resulting in the publication of EURAMET’s Strategic Research Agenda (http://www.euramet.org/research-innovation/sra-survey/) that informs the research conducted under EMPIR.

Themed calls

A key element of the common research agenda in the EMRP Outline and the subsequent EURAMET Strategic Research Agenda was (and is) a thematic structure with a strong focus on metrology to address the grand challenges rather than the traditional metrology approach of themes based on technical areas and/ or SI units. EMPR calls were designed around the themes (referred to as TPs (Targeted Programme) in EMRP) and the call scopes were based on the EMRP Outline. The programme was strongly focused on the grand challenges with five of the seven themes (and 78 % of the funding) focused on the **Environment, Health, Energy, Industry, New Technologies** themes.

Common definition research topics via the call process

The greatest integration of the national metrology programmes comes through the construction of the Selected Research Topics (SRT) and the proposals in response to those. Over the life of the programme nearly half the total metrology research in the EMRP member states is funded through the Programme. This provides a great focus for the scientists working in the National Metrology Institutes - to see their work funded they need to engage in collaboration across Europe.

The process started long before a call was announced. Each Technical Committee (TC) in EURAMET met at least annually to discuss plans for future EMRP calls. Contact Persons from each member state discuss their future plans, stakeholder needs in their countries, and outline work they would like to do to address those

needs. Where a consensus emerged in a TC that a need was significant enough to be best addressed collaboratively and it was in line with the call scope then interested parties refined the idea and submitted a Potential Research Topic (PRT) when the call was announced. Where the need was best addressed nationally then it was left for individual national responses. To ensure PRTs were focused on the needs of industry, public services and policy-makers and engaged with the wider research base, there was strong encouragement from the EMRP Committee to develop PRTs with those outside the NMI/DI community with measurement users. For example in the 2011 call, 153 PRTs were submitted written by a total of 1069 co-authors, 29 % of whom were from outside the NMI/DI community.

At the next stage, the submitted PRTs are prioritised and converted into SRTs by the EMRP Committee to become the basis of a competitive process for research proposals. The EMRP Committee undertook a higher level of research integration by bringing a more strategic view of both national capabilities and priorities and stakeholder needs and potential benefits. The committee constructed SRTs designed to bring about change in the metrology community, requiring different technical areas to cooperate to achieve an objective where this would not happen naturally due to organisational boundaries, or requiring the active engagement of industry, regulators or standards bodies throughout a project where the technical community would prefer merely to present the final results.

In addition, by setting the indicative budgets by theme the EMRP Committee took a joint strategic view on priorities for metrology research across Europe. In 2010, for example, following the decision on the SRTs, the Committee took the view that a greater need had been identified in the Industry TP than in the Environment TP and moved 3 M€ from Environment to Industry. In 2011 a similar decision was initially made to move budget from SI to Health. These decisions are not about individual projects but strategic direction and feed through to national programmes and resource allocations within the NMIs.

Although national programme owners had given control over a large proportion of their national programmes to EMRP, they had influence over the national response to the research topics identified (in the SRTs) by the EMRP Committee. As proposals were developed in response to the SRTs they could choose how to spread their resources across the proposals being prepared. In theory they could withdraw from a bid at the end of that process, although this was rare as it would cause some damage to the relationship with their partners and affect other proposals. But, once the proposal was submitted they relinquished control and the result was in the hands of the independent referees. In general, half the proposals were funded with scoring based on scientific excellence, relevance, potential impact, and quality.

Research projects of critical mass

The relatively large size of the funded JRPs (typically 3 M€) reduced fragmentation and duplication. Critical mass was brought to bear on clear objectives, with agreed project plans and enhanced stakeholder engagement. What could have been 20 independent research teams working on a smaller scale in a similar research area and with enhanced stakeholder engagement.

Figure 8: Specific Objectives - Indicator 3b

INDICATOR 3b	Effectively working central evaluation with independent experts, and central selection decision
Data / Evidence	
The call was transparent with all processes, procedures and documents publicly available on the website managed by the EURAMET Management and Support Unit (MSU). The MSU managed a review conference for each call where independent experts reviewed and scored each proposal received. An Independent Observer was appointed by the Commission to review and report on the review conference process. The Independent Observers were satisfied and complementary. For example the Independent Observer at the Review Conference for the last EMRP call in 2013 stated:	

"*The main conclusions that I can draw from attendance at the 2013 EMRP Review Conference and related documents are:*

- *The selection of the Referees and design of the evaluation processes leading to the Single Ranked List was carried out in accordance and compliance with the rules established in the Decision and General Agreement*
- *The Review Conference was organised in a highly professional and transparent manner*
- *The Single Ranked List for each of the two Targeted Programme was approved by all of the Referees and has subsequently been accepted by the EURAMET EMRP Committee*

One of the most impressive features of the EMRP is the culture of continuous improvement. Further refinements had clearly been implemented for the 2013 Call, including some that were derived from consideration of 2012 recommendations."

3.3.2 Management integration

Figure 9: Specific Objectives - Indicator 3c

INDICATOR 3c	The dedicated implementation structure is in place and is effectively implementing EMRP

Data / Evidence

Programme level

EURAMET implemented governance and management processes at the start of EMRP. These processes provide an integrated approach to governing the strategic direction of the programme, selecting research projects to be undertaken and managing the programme's funding. As a significant proportion of national metrology research funds are coordinated via the programme this represents a significant level of management coordination of metrology research in Europe.

EURAMET put in place an EMRP Committee, Programme Manager and dedicated Management and Support Unit (MSU) to govern and manage EMRP. All EMRP processes are governed by the EMRP Committee and delivered via the Programme Manager and the MSU. The delivery of the programme has been monitored and reviewed in various ways and no significant problems or issues have arisen:

- All EMRP annual reports submitted to the Commission have been be accepted.
- The Interim Evaluation found the EMRP processes to be of high quality and transparent and in line with the Commission's requirements "*The Panel was most impressed by the quality and efficiency of the governance and operational systems that had been established by EURAMET, the EMRP Committee and the operational management units in Germany and the UK. These are all in accordance with the General Agreement.*" and concluded that "*EMRP is a well managed joint European research programme that has already achieved a relatively high level of scientific, management and financial integration*. "The Commission reiterated this in a press release on the Programme that stated "*EMRP is a well managed and progressively more and more integrated European programme. It has transformed a specialised and fragmented community into a successful public-public partnership confirming the advantages of the European Research Area*."[1]

Project level

While the management culture and processes at individual NMIs/DIs are highly varied the programme has developed a common understanding of suitable project management practices for research projects. EURAMET had a poor history of delivering collaborative (self-funded) projects to time and this needed to change to ensure the delivery of EMRP projects with defined timescales and budgets. Initially this required considerable direction from the Programme Manager and MSU through the implementation of fairly prescriptive EMRP templates for the project plans and reporting. As the programme progressed, the level of detail required in the project plans and reports has been continuously reduced as the community needs less

[1] The Interim Evaluation report is publicly available at:
https://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/mtr_report_final.pdf

supervision from EURAMET. Under EMPIR, the successor programme, the guidance to project coordinators is much less prescriptive. Project coordinators and partners are advised to plan at a level of detail appropriate to the size of the project and only maintain documentation within the consortium as necessary, and they report less frequently and in less detail to EURAMET. This progress has only been possible because of systematic training of potential coordinators over the years both from EURAMET and in individual partner organisations. EURAMET has held, and continues to hold, training events for those considering PRT submissions, potential coordinators, project support providers (concentrating on technical reporting) and financial support staff (concentrating on financial reporting and the financial rules).

The final step of management integration occurs in the EURAMET ex-post audit process. This consists of both a financial audit based on EC practices from FP7 and a technical audit assessing "the scientific/technical management and control systems relating to the proper execution of the JRP and the JRP-Contract". This later part includes:

- the degree of fulfilment of the JRP-Protocol
- the resources planned and utilised in relation to the achieved progress, particularly regarding the principles of economy, efficiency and effectiveness
- the management procedures and methods of the project
- the plan for the use and dissemination of Foreground IP
- the auditee's contribution and integration within the project
- the claimed potential impact in scientific, technological, economic, competitive and social terms

Figure 10: Specific Objectives - Indicator 3d

INDICATOR 3d	**The use of a common contract (model grant agreement per category of activity) linking all the fund recipients to EURAMET**
Data / Evidence	
The same model contract is used for all joint research projects. Similarly there is a standard model contract for each type of Researcher Grant (one each for: Researcher Excellence Grant, Researcher Mobility Grant and Early Stage Researcher Mobility Grant). They are available at the same link as for the joint research project contract.	

3.3.3 Financial integration

Figure 11: Specific Objectives - Indicators 3e & 3f

INDICATOR 3e	**The projects selected at central level are effectively co-funded by the participating States from their national earmarked budget and the reserve funding capability, according to the order in the ranking list**
INDICATOR 3f	**The Community contribution is allocated to the projects according to the order of the ranking list**
Data / Evidence	
The proposed joint research projects are scored and ranked (against the standard FP7 criteria) by independent experts at a Review Conference. Projects are then formally selected for funding by the EMRP Committee according to the order in the ranked lists. The funded projects are listed on the EURAMET website: https://www.euramet.org/emrp-calls	

Once selected for funding, the projects are co-funded by the Commission allocation to EMRP and the national programmes' commitment to EMRP. The national commitment is demonstrated by the commitment data in Figure 5.

Figure 12: Specific Objectives - Indicator 3g

INDICATOR 3g	Progress towards more financial integration through the use of harmonised financial rules (e.g. eligibility of costs, funding rates, ex-post verification)
Data / Evidence	

The programme manages EU funding and coordinates national metrology research funds using a common approach to financial rules.

From the start the programme adopted a model contract and financial process based on FP7 rules. There were no national deviations beyond those allowed in FP7. EURAMET did publish its own Financial Guidelines (http://www.emrponline.eu/downloads/Financial_Guidelines.pdf) but these were not deviations from FP7, merely specific advice tailored to the contract rather than other options in the FP7 generic documents that were not relevant to this programme. Guidelines and templates were provided to support project partners to cost projects at the outset and to ensure finances were reported consistently and in accordance with the financial rules.

The final step of financial harmonisation occurs in the EURAMET ex-post audit process as described under **Specific indicator 3c.** The audits identified a number of common observations in the EMRP community that are fairly similar to those found across FP7 projects such as: inconsistency among professional auditors; some organisations underestimating overhead rates; a general view that organisations and their auditors found the FP7 guidelines insufficiently clear, and in some places contradictory, leading to confusion on, and different interpretations of, the financial rules.

The Full Economic Cost (FEC) model required under FP7 was implemented in EMRP. As project costing methods and financial management processes varied greatly among the NMI/DI institutions, the move to the FEC approach was a significant change for many NMIs/DIs.

3.4 Scientific, economic and social impact (S1.4)

Figure 13: Specific Objectives – indicator 4a

INDICATOR 4a	Scientific impact
Data / Evidence	

Scientific excellence

The programme focused on research excellence - project selection was a competitive process based on external peer review.

1375 papers have been published to date across a range of journals, reflecting the breadth of the research. In addition 607 peer-reviewed papers were published in conference proceedings and 33 contributions made to books. Bibliographic analysis shows that the EMRP publications are above world averages in terms of citations, impact factor and highly cited papers (figure below).

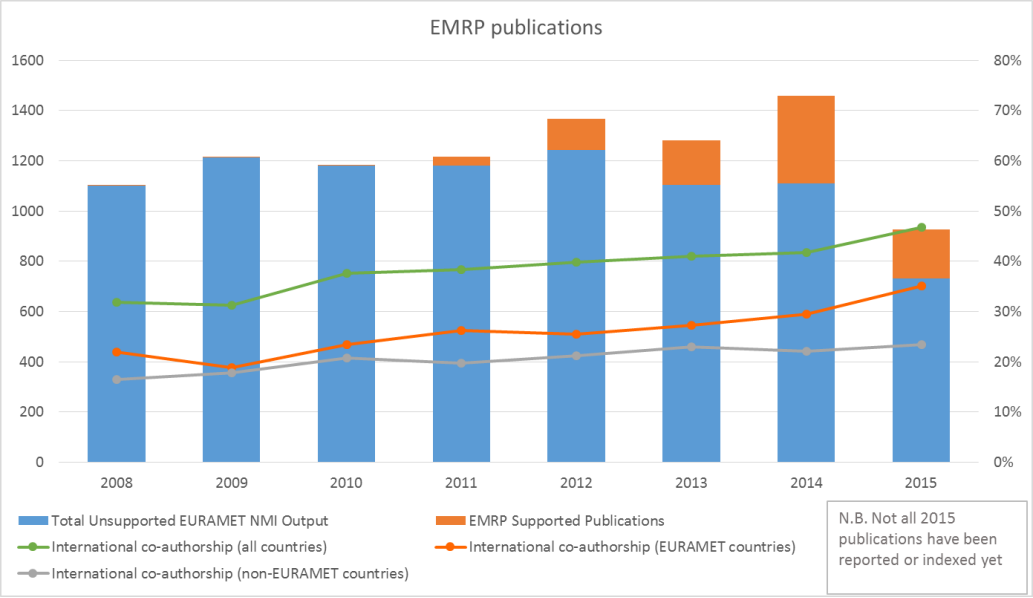
In addition, the annual number of scientific publications from the European metrology community has increased as a result of EMRP (figure below) and there are early indicators from a bibliometric analysis to suggest that citation scores and journal impact factors are increasing compared to international comparator metrology institutes. The figure also shows that the level of international co-authorship with other NMIs and academics, particularly among EURAMET countries, is increasing.

Scientific performance of EMRP supported (2012–2015)

Number of papers, yearly trend in output, highly cited publications (HCP 10%), citation distribution index (CDI), citation distribution charts (CDC), average of relative citations (ARC)

	Total Papers in the analysis	Scientific impact			
		ARIF	CDI	$HCP_{10\%}$	ARC
Supported	843	1.02	8.10	12%	1.15

N.B. the bibliographic analysis is based in a smaller number of papers than the number reported in the paragraph above.[2] The definitions of the bibliographic indicators used are provided in Annex E.



A complete bibliographic dataset for EMRP will not be available until publications from projects in the last call are published and indexed (this will be in 2018 or 2019). Nevertheless, the data to date shows that the proportion of total NMI publications arising from EMRP supported research has increased as the programme progressed. In 2014 publications resulting from EMRP supported research were 33 % of total publications and for 2015 (where a complete bibliographic dataset is not yet available) the figure is 31 %.

Pooling of resources / critical mass

EMRP enabled the pooling and coordination of resources across European metrology institutes. Prior to the Commission supported programmes, research collaboration was rather ad-hoc, based on goodwill and relationships between individual institutes and researchers. A key benefit of the programme was not only the ability to coordinate resources and skills but also the ability to align research timescales. For example, EMRP has played an important role in the European contribution to the forthcoming redefinition of the international system of units (the SI). The first call for projects under the SI Theme was predominantly focused on research supporting the redefinition.

The redefinition is a major milestone for the international metrology community - nothing on this scale has never been undertaken before. The comparison of data from metrology experiments in different laboratories is essential to establishing new SI definitions and agreeing methodologies for realising primary standards. EMRP provided a focal point and project management structure to the European contribution to an international endeavour. It has enabled the world-class European NMIs to work collaboratively to share skills,

[2] This is for two reasons: (i) some of the published papers had not yet been indexed in Scopus at the time of the analysis; and (ii) the bibliometric analysis was based on the publications from the NMI in each EMRP participating country due to the difficulty of identifying DIs in the bibliographic dataset (most DIs are located within a larger research institution and cannot be unambiguously identified). As NMIs were the recipients of around three-quarters of the EMRP budget this enabled a useful analysis to be undertaken.

undertake key experiments and share results in a coordinated manner, and make a more coordinated European contribution to the international decision processes required to agree the details of the redefinition.

The EMRP projects were highly visible internationally with NMIs outside Europe joining the projects as unfunded partners or collaborators.

The EMRP collaborations have led to the start of longer-term coordination activities in European metrology research. This is a considerable achievement for the NMI and DI community in Europe and it is intended that that this type of activity will increase in future. Networks of centre of excellence are being investigated or are in the early stages of development in a number of areas:

- MATHMET: the European Centre for Mathematics and Statistics in Metrology
- Metrology for Smart Grids
- Metrology for Earth Observation

Impact on the scientific community

The EMRP research community collaborated widely with the academic and public research community. The Researcher Excellence Grant (REG) mechanism was the main instrument that supported formal collaboration, but academic groups also joined projects as formal unfunded partners and as collaborators (signing a Non-Disclosure Agreement with the project team to be able to access the research and it outputs while it was in progress). While REGs were primarily designed to ensure that metrology research could draw on the best available scientific inputs from the academic and public research community, they also enabled a two-way flow of expertise, knowledge and skills that is has had and will continue to have an impact on academic research. Examples include:

- The outputs of an industry project addressing accurate metrology of large volume objects (such as aircraft) have been used to assess the alignment of accelerator systems at CERN and has wider applications in other large research facilities such as European Synchrotron Radiation Facility and ITER.
- An industry project focused the metrology of magnetic materials for electronics lead to the development of an instrument that is being used to assess the magnetic cleanliness of the ESA's LISA Pathfinder mission. This mission will test the concept of gravitational wave detection and pave the way for future more extensive missions.
- The outputs of an industry project investigating dielectric properties of materials are being used in graphene research at Imperial Collage and in a method for label-free detection of tumours
- The accurate spectroscopic data arising from an environment project is being used a research group at University College, London to support theoretical modelling of molecular line spectra for atmospheric gases. These are used in predictive modelling of atmospheric gas concentrations in the Earth's atmosphere for climate change studies.

There were 285 participations in EMRP projects via the REG mechanism from 146 academic and public research organisations across Europe (these are listed along with all the REGs in Annex A). Over the period 2008 to 2015 co-authorship of publications between NMIs and academic organisations increased from 47 % to 68 %.

Figure 14: Specific Objectives – indicator 4b

INDICATOR 4b	Economic impact
Data / Evidence	
Metrology research's contribution to economic impact: Accurate measurement supports economic impact in two ways: • **Supporting trade**. Measurements traceable to national metrology standards ensure that measurements are the same in any location and at any time. This gives confidence throughout supply chains, across borders and to consumers that products and components are what they say they are and perform as specified.	

- **Supporting innovation.** Accurate measurements enable the performance of novel products, techniques and processes to be tested and validated, so supporting business growth and productivity improvements.

Metrology research improves the accuracy of measurement at the highest level, extends accurate measurement to new technical areas or measurement ranges, and develops new and improved measurement techniques and instrumentation. These new capabilities flow to first-tier measurement users in industry in a number of ways: via improved calibration services at NMIs/DIs and at commercial accredited calibration and test laboratories; via improved performance of commercial measurement and test instrumentation; and by direct sharing of knowledge and skills with a wide range of sectors (manufacturing sectors in particular).

Therefore the early adopters of metrology research are often (but not solely) the instrumentation sector and the accredited laboratory sector who make use of the new NMI/DI capabilities or adopt the improved measurement techniques to develop their own new products and services. These sectors are an important bridge to measurement for end-users in, for example, the automotive, aerospace, oil and gas sectors and public sector agencies, who use improved measurement capabilities to develop new products and/or improve processes.

In addition, NMIs and DIs interact directly with sophisticated measurement end-users during research activities - developing measurement techniques to solve industrial problems and sharing knowledge and skills.

Finally, improved measurement contributes to economic impact via the indirect economic effects of addressing social challenges such as improved health and a better environment.

The EMRP strongly encouraged industrial participation in the research projects. Industry engaged directly with projects as either 'unfunded partners' where they made a direct contribution to the projects or as 'collaborators' where they signed a Non-Disclosure Agreement with the project team to be able to access the research and it outputs while it was in progress.

In total, there were 745 industrial participations from 653 organisations in the EMRP projects.

Industrial participation	No. of participations	No. of unique organisations
Unfunded partners	92	76
Collaborators	653	585

In addition, projects shared their research outputs with a much larger group of organisations via their extensive communication and diffusion activities (see **Indicator 10d**).

Early impacts of EMRP research

The MSU collects evidence of 'early impact'. By this we mean, the examples of the early adoption (relatively soon after projects are completed) of project outputs by measurement users in the public and private sector. This early adoption demonstrates that the route to impact has started and therefore that longer-term impact is much more likely to occur.

Timescales for economic impact from metrology research vary, depending on the nature of the research undertaken and the measurement user group. Highly industrial focused metrology research can result in innovation within the instrumentation sector, for example, relatively quickly. Impact case studies and a survey of industrial participants in the EMRP projects funded in the first three calls (2009-2011) found that early adopters of project outputs were the companies (mostly instrumentation manufacturers) who participated in research projects. As a result of participation, they were able to develop and/or validate innovative products or utilise new measurement methodologies soon after the projects ended. Survey respondents and case studies companies provided data on early sales achieved to date and projected sales for the next 10 years. In total the EMRP projects in the first three calls:

- **Influenced total sales of innovative products of 1,627 M€**
- **Of which 319 M€ was attributable to the EMRP supported research**
- These figures cover the industrial participants that participated in projects in the first three EMRP calls (covering the Energy, Environment, Industry, Health and New Technology themes) and therefore can be expected to increase as additional surveys are conducted and case studies developed.

- Over longer-time periods these innovative products will go on to provide economic benefits for their end-users. This effect is not captured in the data above as it is too soon for any significant effects to have occurred (at the present most sales of the innovative instrumentation are projected).

  (The 'influenced' figure is the total value of actual and projected sales of the innovative products whose development was influenced by the EMRP research. The 'attributed' figure is the portion of the 'influenced' figure that the company estimated to be directly related to the EMRP research. For example if the product could not have been developed at all without the EMRP research the 'influenced' and 'attributed' figure would be the same. If the product was developed more quickly as result of the EMRP research the company might estimate a 10 % attribution to the research.)

The **Industry theme** was strongly focused on meeting industrial measurement needs. 30 research projects addressed a wide range of industrial measurement needs and this theme was the largest contributor to the impact figure presented above.

A number of examples of early impact from the Industry theme are presented below (more examples are provided in Annex C). These include examples focused on impact for instrumentation and process equipment manufacturers, as well as end-users and the adoption of project outputs to support the development of emerging technologies (such as quantum technologies). Case studies of early adoption of the research outputs are provided on the EURAMET website[3] and summarised in the Industry Impact Report (covering the completed projects in the first Industry theme call).[4]

1. Instrumentation innovation – gas analysis

INFICON, a Swiss manufacturer of instruments for gas analysis, used the new NMI vacuum metrology system to demonstrate that its innovative gauge for dynamic pressure responded twenty times faster than the previous model. This offers opportunities to their customers in the semiconductor sector to reduce the processing time for manufacturing steps conducted in vacuums.

2. Instrumentation innovation – automation equipment

Tetra, a manufacturer of automation and robotic equipment, developed a novel optical sensor for a high performance friction test system at a metrology institute. This sensor has since been used to improve their own high-end positioning system making it one of the best on the market and supporting new sales.

3. Instrumentation innovation – fluxgate sensors

Bartington Instruments, a manufacturer of high-performance fluxgate sensors, used the new metrology facilities for magnetic measurements to validate the performance of its sensors across a wide temperature range. These sensors have been used to prepare navigational instruments for the European Space Agency's (ESA) Solar Orbiter mission, scheduled for launch in 2018.

4. Instrumentation innovation – dynamic pressure sensors

Kistler Instruments AG, a leading manufacturer of dynamic pressure sensors was one of the first users of a new calibration facility designed to test the performance of pressure sensors under dynamically changing pressure conditions. They are proposing to use the new facility to support the development of new prototype sensors that be able to perform effectively under extreme conditions in automotive R&D. This will support the development of engines with higher efficiency and reduced emissions.

5. Accurate analytical measurements for innovative materials

Advanced analytical instrumentation based on a range of atomic and spectroscopic effects offer the ability to understand and assess the characteristics and performance of a wide range of innovative materials. These instruments are used in a wide range of sectors – such as electronics, optoelectronics, aerospace, medical devices – where the chemical and physical structure of surfaces and thin films is critical to the functionality and performance of devices and components. Establishing traceability for these instruments increases their value to product and process innovation as it provides reliable quantitative assessments of material structure and performance. EMRP project teams developed reference materials and transfer standards for a range of analytical instrumentation that are being used by instrumentation manufacturers to validate their products, provide traceability to their customers and support instrument R&D. Examples include:

[3] https://www.euramet.org/industry-case-studies

[4] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-industry/

Bruker Nano Analytics has used certified reference materials to improve its Energy Dispersive X-Ray Spectroscopy (EDS) instruments that support innovation in catalysts for car exhaust systems and coatings for faster and more durable microelectronics. Kratos Analytical, manufacturer of high-value x-ray photoelectron spectroscopy (XPS) instrumentation, has used reference materials to improve the performance of their XPS instruments for innovation in biomaterials, polymers, catalysts.

6. Better heat-treatment process control

ALOtec, a German provider of materials processing services to the manufacturing sector, has improved the performance of its laser-hardening process. Laser hardening is a heat-treatment technique and precise temperature monitoring is required to control the process to ensure high-quality products and minimal waste.

Working with the EMRP project High temperature metrology for industrial applications (>1000 °C), ALOtec tested the portable 'fixed-point' temperature device developed in the project on its laser-hardening system, demonstrating its suitability as an in-situ calibration tool to correct the thermometers that control the process. Testing revealed that the device could correct for large deviations from the ideal processing temperature, where a deviation of 10 °C above or below the required temperature can cause faulty parts. The information gained enabled ALOtec to optimise its laser-hardening process and provide an improved service to its customers in the machine building, automotive and power generation sectors and mould and tool making industries.

7. Supporting development of for fuel-efficient vehicles

Improvements in the accuracy of pressure measurements at the highest metrological levels are helping the automotive industry to design and manufacture the next generation diesel engines. To meet consumer demands and comply with emissions regulation, engines need to be more fuel efficient. A key element in fuel efficiency is the use of higher pressures in the fuel injection process. EMRP research has developed improved metrology in high pressure and dynamic pressures that are supporting European engine research and development. Working closely with the automotive and instrumentation sectors, the metrology community is also helping to ensure the measurement instrumentation for high-pressure manufacturing processes and in-line process control equipment are being developed. HBM, for example, have used the facility to calibrate one of its high pressure sensors, P3MB Blue Line Top Class transducer©, creating a highly accurate in-house standard which allows them to calibrate all the sensors it sells and provide reliable high pressure measurement services to its customers who develop high pressure technologies. Maximator used the facility to verify its autofrettage systems, which use high pressure to strengthen materials. This has provided assurance to its automotive customers that its systems meet the pressures required for industrial strengthening processes for new, lower emissions diesel engines. This is helping those customers meet new EU emissions standards and so remain competitive.

8. Advancing quantum communications

Toshiba has used the results of an EMRP project in the first public demonstration of a prototype communications system secured using Quantum Key Distribution (QKD). QKD, which shares encryption keys using single photons, and offers a level of security beyond that possible with classical communication techniques.

The measurement capabilities developed as part of the EMRP project Metrology for industrial quantum communication technologies were used to characterise Toshiba's laser system, a crucial element in the prototype communications system. After this performance validation, Toshiba had confidence in the laser's use as a single-photon transmitter, and it was used as part of the first public demonstration of a QKD system using commercially-available components on a standard fibre optic network.

The success of this demonstration, conducted at BT in the UK, provides validation of this next-generation communications technology and is an important step towards the widespread implementation of QKD networks for secure data transmission.

9. Building trust in quantum technologies

Micro Photon Devices (MPD), a research establishment of Microgate Srl, a leading producer of professional timing systems has used the new detector characterisation facility developed within the EMRP project Metrology for industrial quantum communication technologies to improve the accuracy of its single-photon counters specifications.

Single-photon detectors are the key components underpinning many new and emerging photonic technologies. MPD produces single-photon counters based on these detectors, specifically designed and

optimized for applications requiring low-noise and low-power measurements, such as space-earth communications or atmospheric sensing. Precise characterisation at the new facility gives MPD's customers in the research and development sector greater confidence in the performance of its detectors.

Reliable specifications for the components underpinning quantum communications will build end-user confidence and accelerate the introduction of next-generation quantum technologies.

10.High-performance thin film technologies

Plasma Quest, a developer of thin film materials and deposition technology for customers in the electronics industry, has developed a new, cost-effective production technique for the high-performance barrier layers used to protect advanced thin-film products.

Plasma Quest used a new facility established by an EMRP project to test the effect of different production techniques on the quality of barrier layers in thin films. This enabled the company to successfully demonstrate a new technique that enables high-volume production of barrier layers unhampered by dust in the production environment.

The ability to create effective barrier layers without the expense of maintaining clean room conditions will significantly reduce production costs without any reduction in product performance, supporting the development of durable thin film devices, reducing costs and opening new markets. Plasma Quest has already received enquiries from several manufacturers of mobile phone screens looking to implement the new technique.

Figure 15: Specific Objectives – indicator 4c

INDICATOR 4c	Social impact
Data / Evidence	

Metrology research's contribution to social impact:

Accurate measurement underpins the society's ability to address grand challenges in a number of ways. It provides the ability to accurately and effectively identify and quantify problems and monitor the progress and effectiveness of actions taken to solve or mitigate those problems. For example:

- Accurate measurements enable the quantification of pollutants in air, water and soil to identify where action is needed and support relevant policy-making. Accurate measurement also enables public agencies to monitor the effectiveness of policies and enforce regulation aiming to reduce emissions;
- Accurate measurements underpin the accuracy of diagnostic tests in healthcare and ensure that therapies and treatment are safe and effective e.g. accurate measurement of dose delivered during radiotherapy;
- Robust measurements assess the performance of new technologies and instrumentation required to address social challenges e.g. assessing the performance of low carbon technologies, sustainable fuels, or emissions monitoring instrumentation.

Metrology research contributes to solving societal challenges in a number of related ways:

- It improves the accuracy (and therefore the robustness and comparability) of measurement data used to make decisions about the environment, healthcare provision, etc;
- It contributes knowledge on robust measurement methods to regulatory and standardisation organisations;
- It supports innovation in the development of appropriate measurement instrumentation to enable effective and efficient implementation of regulation.

Early impacts of EMRP research

The link between metrology research and quantifiable social impact is complex. Accurate measurement is one aspect of the many and diverse social processes required to bring about change. Furthermore, the timescales between metrology research and quantifiable social impact are often long – 5 to 10 years and longer in some cases. Nevertheless the EMRP research in the Energy, Environment and Health themes (in particular) was focused on very practical problems and a wide range of research outputs have already been

adopted by standards developing organisations (CEN, ISO, etc), instrumentation manufacturers and end-users.

As the data reported against **Operational Indicator 9b** demonstrates, the EMRP research community engaged widely with the standards developing organisations: making (to end the end of 2016) 1135 contributions to 486 unique standards committees resulting in contributions to 126 published or draft standards. In addition **Operational Indicator 9a** shows that at least 37 projects have direct references to regulations in the description of their research.

The MSU collects evidence of 'early impact'. By this we mean, the examples of the early adoption (relatively soon after projects are completed) of project outputs by measurement users in the public and private sector. This early adoption demonstrates that the route to impact has started and therefore that longer-term impact is much more likely to occur.

The **Energy theme** had a strong focus on research to support the Commission's Renewable Energy Directive, developing improved measurement accuracy and techniques to characterise renewable energy sources and low carbon technologies and support modernisation of the electricity infrastructure. Case studies of early adoption of the research outputs are provided on the EURAMET website[5] and summarised in the Energy Impact Report (covering the completed projects in the first Energy theme call).[6] The case study summaries are also provided in Annex C.

Examples of early impact include:

1. Enabling implementation of smart grids

Smart grids that proactively manage highly variable supply and demand of electricity are a key component in the energy infrastructure needed to meet Europe's target of 20 % of energy consumption from renewable sources by 2020. As smart grids are managed by radically different instrumentation and control processes to traditional grids, they require the development of an appropriate measurement infrastructure. Phasor measurement units (PMUs) are expected to be the 'life-support monitor' for the smart grids of the future. Installed throughout the grid, PMUs assess and compare the power signals across the network, enabling grid operators to monitor and control these complex systems. EMRP research developed calibration equipment, software and processes that enable PMUs to be validated against traceable measurement standards for the first time in Europe. Tests of PMUs in operational grids in Greece and Sweden resulted in best practice guidelines for PMU use, which have been incorporated into a revision of the relevant IEEE Standard used by the industry and supported the development of PMUs and commercial equipment to calibrate PMUs. The best practice guide has also supported a pilot a 'smart energy cluster' in the outskirts of Dublin, which links small-scale renewable energy generators with local consumers through a smart grid.

2. Improved efficiency of power plants - reducing CO_2 emissions

Increased efficiency of existing fossil fuel and nuclear power plants is part of the solution to reduced CO_2 emissions and will also lower the cost of energy for consumers. EMRP research developed better methods for temperature and flow measurements to support process control in power plants. KROHNE, a leading manufacturer and supplier of industrial process instrumentation, has used the new methods to demonstrate the accuracy of an innovative ultrasonic flow meter that can also simultaneously measure temperature. A trial of the new flowmeter in a nuclear power plant against existing measurement methods has indicated that deployment of the flowmeter across the plant would lead to operational efficiencies - of the order of 60 MW, equivalent to the electricity required to power 10,000 extra homes. This is a significant improvement in plant efficiency, and given Europe's dependence on large-scale power plants for the foreseeable future, an important contribution to the efforts to reduce Europe's carbon footprint.

3. Implementing low energy lighting in the transport network

The EU has committed to cutting its greenhouse gas emissions by at least 20 % by 2020 compared to 1990 levels and to improving energy efficiency by 20 %. With 14 % of the EU's total electricity consumption used for lighting, more efficient lighting technologies can make a significant contribution towards meeting these targets. Solid state lighting (SSL), which uses LEDs as the light source, is the most energy-efficient lighting technology available and offers good quality light and visual performance and is an ideal candidate for safe and efficient road lighting. However, our eyes work very differently under the low light (or mesopic) conditions

[5]https://www.euramet.org/energy-case-studies

[6]https://www.euramet.org/metrology-for-societys-challenges/metrology-for-energy/

experienced in road tunnels and many other important lighting applications and standards were needed to improve the accuracy of light intensity measurements in these conditions. EMRP research develop a novel mesopic luminance meter and accompanying low light measurement method. Project researchers worked with Autostrade per l'Italia to study Italian highway tunnels with LED lighting and determine safety critical design parameters. The outputs contributed to an Italian standard to support the safe introduction of LED lighting into Italian road tunnels. It has enabled a significant reduction in the consumption of electrical power for tunnel lighting. LEDs operating at the new safe lighting levels identified within the project have contributed a further 33 % saving in electricity consumption. With LED lighting already introduced into approximately 95 % of Italy's 1,500 km of highway road tunnel network, this standard will lead to safer roads with significantly reduced power consumption and associated CO_2 emissions.

The **Environment theme** was focused on measurement research to improve our understanding and assessment of climate change and ensuring a safe and clean environment by improving measurements to support environmental regulation in areas such as air and water quality. Case studies of early adoption of the research outputs are provided on the EURAMET website[7] and summarised in the Environment Impact Report (covering the completed projects in the first Environment theme call).[8] The case study summaries are also provided in Annex C.

Examples of early impact include:

1. Enabling compliance with the European Water Framework Directive (WFD)

The WFD specifies very low permitted levels of pollutants that present a significant risk to or via the aquatic environment. Toxic pollutants such as tributyltin (TBT), polybrominated diphenylether (PBDE) and selected polycyclic aromatic hydrocarbons (PAH) are particularly harmful as they are liable to accumulate in the food chain and endanger a wide range of living organisms. However the primary measurement methods did not exist to support compliance with the low levels permitted by the WFD. EMRP research developed validated primary reference methods (traceable to the SI units) and reference materials for the analysis of these pollutants in real-world water samples at the low levels required. These methods allow the robustness of measurements made in public and commercial labs to be validated and enable regulators to have confidence in assessments of water quality. The methods are already being deployed in a number of European regions and have enabled the CEN Technical Committee on Water Analysis to develop standards on the analysis of TBT, PBDE and PAH.

2. Improved roadside pollution monitoring

Improving air quality requires accurate measurements of pollutants at the low concentrations permitted by European regulation. EMRP research developed preparation methods for calibration gases for SO_2, NO and NO_2 at or near the limit values of the regulation and a practical portable NO_2 generator for cost-effective calibration of air quality sensors in the field. The NO_2 generator has been used by the City of Zürich Health and Environment Department to calibrate its installed air quality sensors, enabling it to evaluate its pollution reduction strategy and maintain its lead in reducing city centre pollution.

3. Enabling compliance with the European regulation on vehicle emissions

Particulates are classified as carcinogenic by the World Health Organisation and each generation of the European emissions regulation reduces the levels permitted in vehicle exhausts. Euro 6, the latest version of the regulation, introduces a limit on particle number as well as particle mass. EMRP research developed a new validated aerosol for calibrating the condensation particle counters used to type-test and certify new engines and ensured its uptake through incorporation of measurement best practice in the relevant ISO standard. The new facilities at NMIs have enabled two companies to validate and/or improve instrumentation used to assess automotive exhausts and therefore enable compliance with the tighter regulation and contribute to reduced harmful emissions.

4. Improved data for Essential Climate Variables

EMRP research has made significant developments towards the goal of an 'NMI in space' that will calibrate and validate the climate data from Earth observation satellites. The metrology community worked closely with the European Space Agency and climate scientists to develop and test high-level metrology instrumentation for the space environment. The instrument, a primary radiometer, is capable of a radiometric accuracy of

[7] https://www.euramet.org/environment-case-studies

[8] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-environment/

0.3 %, a factor of 10 improvement on previous traceability methods. The instrument is the key component of the planned TRUTHS mission (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) that will establish an NMI in space.

The **Health theme** focused on measurement research to improve the diagnosis and treatment of health conditions via both improved accuracy of chemical and biological analyses and more effective therapeutic methods and technologies. Case studies of early adoption of the research outputs are provided on the EURAMET website[9] and summarised in the Health Impact Report[10]. The case study summaries are also provided in Annex C.

Examples of early impact include:

1. Enabling the introduction of next generation MRI scanners

Next generation MRI scanners with improved image resolution will enable clinicians to make more accurate and effective diagnoses. These scanners, already in use as research tools, work at higher magnetic field strengths and the safety of both patients and healthcare professionals must be demonstrated before the new scanner can be adopted in clinical practice. EMRP research developed tools and techniques to accurately assess patient and operator exposure in the higher magnetic fields. The project outputs contributed to international guidelines from International Commission on Non-Ionizing Radiation Protection (ICNIRP) as well as international and national standards, all of which are essential to the type-approval of MRI scanners. The project also worked closely with European MRI manufacturers enabling them to assess their products effectively and ensure compliance with the relevant standards and regulation. This supports both a faster market introduction of innovative products and ensures the most effective technology is available to patients.

2. More effective therapeutic ultrasound

High intensity therapeutic ultrasound (HITU) is able to destroy cells with minimal damage to surrounding tissue and has been approved by some countries to treat a range of specific medical conditions such as prostate and liver cancer. However there was no metrological infrastructure in place to accurately assess the dose given to patients and ensure they are treated effectively (not given too low a dose) and treated safely (not given too high a dose) and this uncertainty creates risks for patients and hinders wider uptake of the technique. Accurate dose measurements are also essential to creating robust personalised treatment plans for individual patients. EMRP research (building on research started under EMRP's precursor programme - iMERA+) developed a metrological infrastructure HITU that enables consistent and robust measurements of ultrasound dose and contributed to the key international standards that support the implementation of the European Medical Device Directive in this technological area and is also referred to by the US Food and Drug Administration. The project team has also supported European manufacturers developing HITU equipment via new calibration services and consultancy, ensuring they can provide equipment and components that will comply with regulation and provide effective treatment.

3. Enabling effective diagnosis and management of infectious diseases

Infectious diseases account for over 20 % of human deaths globally and 25 % of all morbidity. Accurate and rapid methods to diagnose and manage infectious diseases are critical to protect public health. Infectious pathogens can be present in samples at very low levels and accurate and consistent assessment methods are needed to identify and quantify pathogens. Molecular methods such as digital PCR and nucleic acid sequencing (NGR), offer the potential to establish the highest-order metrological methods as well as improve the identification and quantification of pathogens in clinical practice. Traceability to international systems of measurement is in its infancy in biological realm and EMRP research developed highly accurate methods that are moving towards SI traceability and used them to evaluate new and emerging molecular approaches for the surveillance and monitoring of infectious diseases. The higher-order methods will support the development of reference materials used to assure the quality of analyses made in end-user laboratories and so support robust and effective identification and monitoring of infectious diseases.

4. Improving medical implants

Implantable medical devices improve quality of life for millions of people, but the rates of complication, infection and device failure are unacceptably high. Novel materials, surfaces and antibacterial and drug-

[9] https://www.euramet.org/health-case-studies-diagnosis
https://www.euramet.org/health-case-studies-therapies
[10] https://www.euramet.org/metrology-for-societys-challenges/metrology-for-health/

releasing coatings can improve the biocompatibility of implants, reducing infections and complications. These require accurate assessment of physical and chemical surface features at the molecular level to support product development and quality assurance during manufacture. EMRP research developed analytical tools to validate the near-surface chemistry of implantable medical devices. It advanced the traceability of the highest-order measurement techniques (complex, expensive and slow methods conducted in a vacuum) and assessed and improved 'ambient' methods suitable for the manufacturing environment. The project team worked with both implant manufacturers and academic researchers to assess failure mechanisms and identify sources of contamination on a production line.

4 Indicators: operational objectives

This section provides data and evidence against the indicators set for the **programme's operational objectives** as presented in Figure 16 below.

Figure 16 Operational objectives and indicators

EMRP OPERATIONAL OBJECTIVES		INDICATORS
O1.1	Cross-border public research programme coordination and integration.	Number of Member States involved in EMRP and national programmes actively coordinated
O1.2	Address the grand challenges (e.g. climate change) and areas with pressing metrology needs (e.g. new and emerging technologies like for example nano- biotech- healthcare- metrology).	Number of research projects which build on the specific strength of NMI and DI and their infrastructures and their impact on primary standards
O1.3	Enable some "new" MS or candidate countries to build metrology research capacity.	Number of new Member States building up metrology capacities Increase in metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development
O1.4	Open access to unique research infrastructures and facilities	Number of research infrastructures jointly used in RTD projects
O1.5	Increase generic collaboration between national metrology research programmes with the relevant science community at European level.	Number of research organizations (not being NMI of DI) involved in EMRP projects Level of participation in the programme by outside researchers and research institutions Total PhDs trained in metrology
O1.6	Modernisation in the programming of national and European research priorities.	List of advanced technologies employed in the developments of primary standards can and should be transferred to new and challenging research activities
O1.7	Foster mobility of "early-stage" researchers from National Metrology Institutes and Designated Institutes	Number of mobility grants implemented
O1.8	Europe should speak with one voice to strengthen its influence at global level	Number of generic cooperation activities with non-European research actors
O1.9	Metrology research has to become a supporting activity for government regulation.	Number of EMRP projects with direct references to regulation Number of presentations at standardisation technical committees or working groups
O1.10	Support to industry and economic growth through up-front public metrology research.	Number of publications, patents granted, presentations at congresses, dissemination activities Number and quality of training activities
	ADDITIONAL INDICATOR (specified in Annex to the General Agreement)	Total number of metrology researchers involved in EMRP projects by age, class and seniority level

4.1 Cross-border public research programme (O1.1)

Figure 17: Operational Objectives - Indicator 1

INDICATOR 1	Number of Member States involved in EMRP and national programmes actively coordinated

Data / Evidence

23 national metrology research programmes were actively coordinated via EMRP. Each country had formally made a commitment to participate in EMRP as specified in the EMRP Decision (No 912/2009/EC) of the European Parliament and Council.

These 23 countries were the EMRP '*participating states'* and were 19 EU Member States plus four non-EU European states and the EU Joint Research Centre (JRC):

EU Member States participating in EMRP		Non-EU Member States participating in EMRP
Austria	Netherlands	Bosnia and Herzegovina*
Belgium	Poland	Norway
Czech Republic	Portugal	Switzerland
Denmark	Romania	Turkey
Estonia	Slovakia	
Finland	Slovenia	
France	Spain	
Germany	Sweden	
Hungary	United Kingdom	
Italy		

* Bosnia and Herzegovina joined the programme in 2013

Additional information

In addition to the participating states, organisations from five other EU Member States and 16 non-EU countries have formally participated in EMRP projects as unfunded partners in JRPs and/or funded partners via EMRP researcher grants:

EU: Bulgaria, Croatia, Greece, Ireland, Latvia
Other Europe: Liechtenstein, Montenegro, Serbia

Rest of the world: Australia, Brazil, Canada, China, India, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, Taiwan-Province of China, Ukraine, United States.

4.2 Address grand challenges (O1.2)

Figure 18: Operational Objectives - Indicator 2

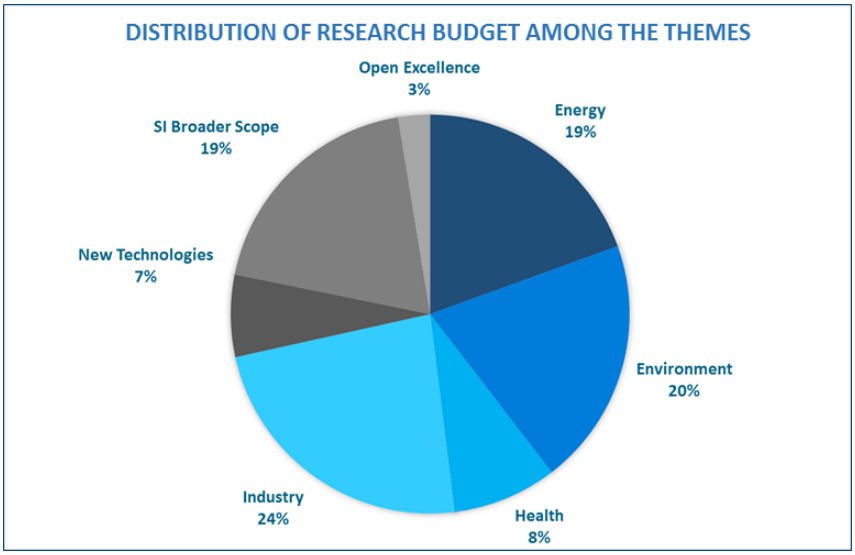
INDICATOR 2	Number of research projects which build on the specific strength of NMI and DI and their infrastructures and their impact on primary standards

Data / Evidence

All 119 EMRP projects were designed to build on the specific strengths of NMIs and DIs. The projects supported improved and developed this expertise to ensure that the European metrology infrastructure provides traceability to primary standards in areas important to the European economy and society.

Projects addressed both the accuracy of the underpinning SI units and metrology to address the grand challenges.

- The SI Broader scope theme (TPs: SIB1 & SIB2) was specifically focused on the coordinated development of primary standards of the SI units at the highest level – contributing to the international effort to redefine the SI units(SIB1) and extending traceability of measurements to SI units into new areas (SIB2). 24 projects were supported under the two calls in this theme.
- The projects in the grand challenges themes: **Environment, Health, Energy, Industry, New Technologies** took a coordinated approach to developing improved traceability to primary standards, establishing traceability where it did not previously exist or made traceability to primary standards more accessible. 78 % of the programme budget was allocated to research focused on the grand challenges:



4.1 Building capacity in New Member States (O1.3)

Figure 19: Operational Objectives - Indicator 3a

INDICATOR 3a	Number of New Member States building up metrology capacities

Data / Evidence

Seven of the EMRP participating states are New Member States. These seven countries have participated in joint research projects funded under EMRP enabling them to collaborate in metrology research projects with more experienced Member States to develop their metrology capabilities:

EU New Member States participating in EMRP
Czech Republic
Estonia
Hungary
Poland
Romania
Slovakia
Slovenia

Three additional New Member States have also participated in EMRP projects via Researcher Grants: Bulgaria, Croatia, Latvia. During the later stages of EMRP, Bulgaria and Croatia (and accession state, Serbia) made the decision to be full participating members of the successor programme (EMPIR) demonstrating their

commitment to European metrology research and their desire and capacity to participate in joint research projects.

New Member States (and accession states) made considerable use of researcher mobility grants (as reported under **Indicator 7**)**.** The majority of the recipients of mobility grants (60 %) were from New Member States and accession states.

Figure 20: Operational Objectives - Indicator 3b

INDICATOR 3b	Increase in metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development

Data / Evidence

Participation in EMRP processes and projects enabled countries in new member states and accession /pre-accession states with developing NMIs and DIs to increase and improve their metrology capacities and their research skills. Six capacity building case studies are provided below.

Czech Republic

Overview

The Czech Metrology Institute, CMI, is the cornerstone of the national metrology system in the Czech Republic responsible for legal metrology, maintenance of national measurement standards and the provision of calibration services to end-users. CMI is an independent public organisation, reporting to the Ministry of Trade and Industry.

The EMRP and EMPIR programmes have played a central role in increasing the scale and quality of the metrology research undertaken at CMI. Prior to EMRP and EMPIR the activities of CMI were focused predominantly on the maintenance of Czech national metrology standards and the delivery of calibration services to Czech industry, with research only representing approximately 20 % of CMI's activities. The EU funding from EMRP leveraged additional matched funding from the Czech government research, increasing research to approximately 40 % of CMI's activities. This new funding has enabled CMI to establish a critical mass of research activities and has supported strategic investments in research staff and facilities. As a result there is now a community of research-focused metrologists at CMI with at least one full-time person dedicated to research in each technical department. This would not have been possible without the EMRP support, in terms of both funding and access to the expertise of the wider NMI community made possible by the programme.

CMI has focused its participation strategically, targeting the Industry, Energy, Environment and New Technologies themes of the programmes (as well as the SI theme) as these align most closely with their goals and the needs of Czech industry and society.

Capacity building impact

The research collaboration and researcher mobility activities have significantly increased the skills and knowledge base enabling CMI to develop high quality primary national facilities in technical areas where traditionally Czech national standards were traceable to the national standards in other countries**.** The skills also enable CMI to offer a wider range of R&D problem-solving skills to Czech industry over and above the more straightforward calibration services. Collaboration has also enabled CMI to deepen its relationships with the European NMI community and establish formal agreements to access national standards and services in other countries to meet user needs where it makes sense to do so. New national capabilities and facilities, developed in part via EMRP, include:

- CMI has made a step-change in its capabilities in time and length metrology, developing an optical clock that will create services to support precision manufacturing, electronics, defence, security. Working with the European NMI community via EMRP is enabling CMI to learn from their experience and 'jump a stage' in the development in atomic clocks.

- CMI's contribution to the development of an electrical resistance standard based on graphene (and the Quantum Hall Effect) will result in a more cost-effective primary standard that will enable CMI to provide increased accuracy to the electronics sector in the Czech Republic.
- CMI has established a new laboratory to assess thermal protection materials at high temperatures that is not only widely used by industry in the Czech Republic but also by businesses in neighbouring countries.
- CMI has increased its ability to support high-tech industries such as semi-conductors and nanotechnology by investing in new complex analytical instrumentation to characterise surfaces and materials at the micro and nano-scale.
- CMI has developed a low magnetic measurements laboratory to meet demand from Czech industry for lower uncertainties and calibrations matched to local magnetic conditions. Customers of the service include automotive, geology and surveying and the military.

The new skills and facilities developed via the EMRP and EMPIR programmes is enabling CMI to better support Czech industry and society. While CMI has a long tradition of providing calibration services to industry its new capabilities is enabling it to provide more complex R&D problem-solving services for businesses in, for example, the automotive, instrumentation and electronics sectors, so supporting product and process innovation. Examples include:

- The knowledge gained in making accurate temperature measurements in the real-world conditions of power plants has been used by a Czech manufacturer to design temperature sensors that can operate in high vibration environments.
- Improved facilities in high pressure and dimensional measurements are supporting automotive manufacturers and their suppliers in the Czech Republic.
- The new facilities to assess materials at the micro and nano-scale have been used to support the innovation processes of a range of companies developing new and improved products that include new hard-wearing coating for car headlights and the surfaces of novel coloured solar–cells.
- CMI contributed to the development of a tabletop TeraHertz spectrometer that has the potential to be commercialised to offer a smaller and most-effective device for security applications.

Turkey

Overview

Turkey committed approximately 1.6 M€ at the start of EMRP, a relatively small share compared to its peers in EURAMET. By the end of the programme, however, the value of Turkey's contribution via participation in 37 JRPs, is expected to total 2.8 M€, which can be viewed as an indicator that the Turkish National Metrology Institute (TUBITAK UME), considers EMRP to be a success.

TÜBİTAK UME is a young, medium-sized NMI with capabilities that expanded rapidly from the mid-1990s into the early 2000s through significant investments made by the Turkish government and the implementation of two successive World Bank funded projects. Before iMERA+ programme (the precursor programme to EMRP) its main focus was on building up capability for primary level calibration and measurement services to cover the unmet needs of the rapidly expanding and industrializing Turkish economy. What little research activity did exist consisted mostly of efforts to resolve measurement problems encountered by industrial customers and public agencies, to set up primary level standards similar to those available in other NMIs, and smaller scale applied research projects undertaken within the technical committees of EUROMET. In preparation for participation in iMERA+ and EMRP, TÜBİTAK UME's designation was changed from "service facility" to a "research and development institution" by its governing body, signalling a reorientation of priorities and allowing engagement in large scale, externally funded R&D.

Capacity building impact

TÜBİTAK UME's participation in EMRP projects has been broad based and fairly well distributed across the themes. However, there is a somewhat higher concentration of projects in Energy (9) and SI Broader Scope (11). The first is reflection of a national priority given to the issues of energy security and diversification and electrical grid improvements, and the second, of TÜBİTAK UME's concern with keeping abreast of developments pertaining to technical implications of the expected redefinition of some SI units and efforts to

establish traceability in emerging areas of measurement so as to ensure that it will maintain and improve its ability to provide primary level services in these areas.

In general, TÜBİTAK UME's engagement in EMRP has delivered a number of important benefits. First and foremost, it has allowed the institute to engage in state-of-the-art research and access knowledge at the cutting edge of metrology, bringing its knowledge base closer to that of the top tier of metrology institutions in Europe than would have otherwise been possible at this point. In parallel, TÜBİTAK UME's researchers have gained significant experience working in high level research in collaboration with other researchers across Europe, some of whom are among the best in their fields, contributing to a general elevation in personnel skill sets and knowledge and an enhancement in the quality of their scientific output. Furthermore, participation in EMRP projects has been instrumental in transforming TÜBİTAK UME's stance vis-a-vis stakeholders. Whereas it was once primarily reactive to stakeholder demands, seeking to build capacity to meet fully materialised and urgent needs, it is now able to build capabilities that anticipate demands for metrology services expected to emerge in the future and stimulate the adoption of more advanced technologies in the economy.

Examples of the capabilities gained by TÜBİTAK UME through specific EMRP projects and their benefits to stakeholders include:

- Participation in the SIB64 METefnet (Metrology for Moisture in Materials) allowed TÜBİTAK UME to develop high-level skills in measurement of moisture in materials, which is particularly important to agricultural concerns and was a demand that TÜBİTAK UME could not previously meet. Calibration and measurement services in the area are expected to be initiated in 2017. Materials are also in preparation for new training courses on the subject.
- Through SIB10 Noted (Novel Techniques for Traceable Temperature Dissemination), TÜBİTAK UME's developed capabilities in the production and characterization of reference thermocouples.
- The SIB01 InK (Implementing the New Kelvin) project allowed TÜBİTAK UME to expand the range of its temperature measurements and calibration capability into high temperatures (>1000 °C), which is important for a number of industries
- As a result of IND12 Vacuum (Vacuum Metrology for Production Environments), a dynamic vacuum system, a gas mixture preparation system and a set-up for the secondary calibration of leak standards, used for the characterization of quadrapole mass spectrometers (QMS) were gained by the Vacuum Laboratory of TÜBİTAK UME. New services were initiated in the calibration of leak standards, for which customers were previously referred to other NMIs in Europe.
- Work undertaken within the SIB56 SoundPWR (Realisation, dissemination and application of the unit watt in airborne sound) project resulted in the realization of a primary level reference standard for sound power in the Acoustics Laboratory, used to now offer new services to industry. New methods developed within the project have eliminated the need for measurements of sound power to take place in purpose-built environments, reducing the cost of such measurements.
- Expertise and experience gained through participation in various projects within the Health theme catalysed the establishment of a Medical Metrology Laboratory at TÜBİTAK UME, addressing a significant deficit in the metrology infrastructure in Turkey.
- As the coordinator of SIB58 Angles (Angle Metrology), TÜBİTAK UME became one the leading institutes in angle measurements, significantly reducing uncertainties and extending the range of angle measurements that can be performed at the nano-radian scale. Skills and knowledge gained have been used in joint projects with stakeholders.
- Participation in ENG04 Smartgrid (Metrology for Smart Electrical Grids) resulted in the development of much needed standards for power quality measurement parameters as well as methods for the calibration of instruments that measure power quality. New skills and services led to the implementation of a project to enhance the calibration capabilities and measurement infrastructure of the national electric distribution company, ultimately contributing to greater electrical grid stability.
- Through HLT03 DUTy (Dosimetry for Ultrasound Therapy), TÜBİTAK UME became one of four institutes in Europe with the necessary metrological infrastructure to characterize high intensity focused ultrasound (HIFU) systems that have widespread medical applications.

Bosnia and Herzegovina

Overview

As relatively young country, Bosnia and Herzegovina has a young and developing national metrology system. The Institute of Metrology of Bosnia and Herzegovina (IMBiH) was legally established in 2004 and became operational in 2007. It is an independent administrative organization directly responsible to the Council of Ministers of Bosnia and Herzegovina. IMBiH is responsible for establishing and maintaining the whole metrology system in Bosnia and Herzegovina including scientific, industrial and legal metrology. This includes: developing, declaring and maintaining the base of national standards of legal units and ensuring their traceability to the International Standards of the SI system; prescribing metrological requirements for standards, reference materials and measuring instruments, recognising standards as national standards, performing conformity assessment including the pattern evaluation and pattern approvals of measuring instruments. IMBiH maintains two laboratories and currently has 53 employees.

As a young NMI in a country that is a potential candidate country for EU membership, IMBiH has accessed a range of support mechanisms to assist its development. For example, EU IPA (Instrument for Pre-Accession Assistance) funding has enabled labs to be equipped in the field of chemical, electrical, thermal and mechanical quantities and a calibration lab in ionising radiation to be established. IMBiH achieved associate membership of EURAMET in 2005 and full membership since 2009, with representation on ten of EURAMET's 12 Technical Committees.

Capacity building impact

EMRP provided IMBiH with the opportunity to develop the metrology research skills of its staff as well as improve their metrology skills more generally, complementing the equipment acquired via other support mechanisms. Bosnia and Herzegovina became the 23rd participating country in EMRP towards the end of the programme in 2013. Prior to that it had participated in seven researcher mobility grants. This enabled the IMBiH and its staff to engage with the programme and gain first-hand experience in more developed NMIs in Germany, the UK, Italy, the Netherlands and Turkey. On joining the programme in 2013 IMBiH became a partner in four research projects – three in the Energy theme and one in the Environment theme.

Key capacity building achievements resulting from EMRP include:

- IMBiH participation in researcher mobility grants (including early-stage researchers) has enabled knowledge transfer and ensured sustainability of cooperation between IMBiH and other NMIs. The opportunity to work on these projects as mobility grant researchers helped gain experience and knowledge for the career development of IMBiH scientists, and prepared the ground for participation in EMRP research projects. IMBiH's participation in collaborative research projects continues - to date it is a partner in six EMPIR projects. A key achievement being that an IMBiH ESRMG/RMG researcher (under EMRP) has gained necessary experience to be able to coordinate an EMPIR research project (15RPT03 HUMEA - Expansion of European research capabilities in humidity measurement). This was the first time that an EMRP or EMPIR project has been instigated and led by an NMI from an emerging country
- Institute staff has further confirmed their competences through publication of papers in peer reviewed journals and other technical magazines.
- IMBiH has increased its entries (and has new entries pending) in the BIPM Calibration and Measurement capabilities (CMC) database – the key database that demonstrates the equivalence of national metrology systems worldwide. Methods on primary and secondary level of calibration were developed in IMBiH in different fields; laboratories successful implemented a quality management system according to international standard for metrology: EN ISO/IEC 17025 and IMBiH took part in different inter-comparisons to support their CMCs in relevant fields.
- IMBiH designs its research and laboratory development activities to address the needs of environmental agencies, the electronics, automotive, pharmaceutical and medical device sectors, secondary calibration laboratories, manufacturers of sensors and accreditation institutes at the national level. The improved CMCs and research capabilities are helping to improve the quality of calibration laboratories, with ultimate beneficiaries being the companies and public agencies that use the calibration services. For example:

- Validated calibration procedures and associated uncertainty formulations developed by the projects will be directly used by calibration laboratories in Bosnia and Herzegovina in order to ensure traceability of measurements. Measurement results will be reported with the associated measurement uncertainty, which will enable a transparent comparison of measurement results and issuance of valid calibration certificates. This will have a large impact on calibration laboratories; the recommendations will be presented to the accreditation authorities in Europe as well as to end users and manufacturers. This will give the accredited laboratories opportunity to improve their measurement uncertainties in different metrology areas, and consequently to improve scopes and measurement capabilities for their accredited services.
- Testing capabilities of the Laboratory for Chemistry have been improved by publishing CMCs and has enabled further development of chemistry department in the field of reference measurements and assignment of reference values for proficiency testing (PT) samples. The Laboratory for chemistry is active in the field of development of reference methods for testing impurities in gas matrices in accordance with European normative documents.
- Benefit to the industrial companies that rely on such calibration services; workshops at the national level will be held to share the project's outputs and engage with the target user communities.

Poland

Overview

The national metrology institute, the Central Office of Measures (GUM) is the NMI in Poland. It was established on the basis of the Decree on Measures of February 8, 1919 and the President of GUM the central authority of the state administration in matters of measurement and hallmarking, reporting to the Minister of Economy. In addition there are two designated institutes in Poland - the Institute of Low Temperature and Structure Research of the Polish Academy of Sciences (INTiBS) and the Laboratory of Radioactivity Standards, located at the Radioisotope Centre (RC) POLATOM, the National Centre for Nuclear Research.

Capacity building impact

Poland's metrology system has a relatively small research activity and therefore its EMRP participation was focused on areas of most importance to the country – in the SI theme to develop Poland's metrology system and in the Industry and Environmental themes. GUM, as the NMI, was the most frequent participant in EMRP activities, plus additional participation from public or academic research groups such as the Polish National Centre for Nuclear Research.

Key capacity building achievements resulting from EMRP include:

- New metrological services in the Laboratory of the Electricity Department at GUM in contactless measurements of the electrical properties of materials for applications in electronics and electrical products.
- Establishment of a direct traceability route for AC resistance and a measurement system for small values of resistance at acoustic frequencies.
- The extension of scope for GUM's force measurements. This resulted in a collaboration with a producer of force transducers.
- GUM made important contributions to the Large Volume Metrology project (focused in particular on the aerospace industry), in refractive index of air measurements and preparation of a 50m interferometer for a testing campaign.
- Improved research skills and measurement capabilities in angle measurements and temperature and humidity measurements.

Estonia

Overview

AS Metrosert is the NMI in Estonia, responsible for the majority of national standards. It is supported by a designated institute, theTesting Centre of the University of Tartu. The national metrology system of Estonia is described in the Estonian Metrology Act and was established in 2004. Estonia was a founding member of both EMRP and its precursor programme iMERA+. The EMRP funding supports research activities (mainly

researcher time) and as such has complemented EU Structural Funds that have supported the acquisition of equipment and facilities for metrology.

Capacity building impact

As a very small country with a small NMI, Estonia's participation was focused on the unique technical skills and needs of the country. Their participation in research projects was primarily focused on radiometry/ optics/ quantum optics (three projects plus a project under iMERA+), plus practical industrial dimensional measurements, measurements of biofuels and measurement of ocean parameters.

Key capacity building achievements resulting from EMRP include:

- Development of metrology capabilities in radiometry (e.g. in low photon flux measurements, low photocurrent measurements, fibre-optic measurements) including the development of new services for industrial users in electrical and optical measurements, plus skills in silicon technologies and semi-conductor physics. The capabilities and skills gained by the NMI are important for supporting Estonian industry in precision mechanics and optoelectronics and enabling Estonian industry and service providers to meet the recommendations of ITU (International Telecommunication Union).
- The research collaboration in in-process dimensional measurement has significantly increased the skills and knowledge base in industrial dimensional measurements generally, including 3D measurements of workpieces in laboratory conditions and in the workshop environment; accurate assessment of machine tools and their measurement capabilities; and the influences of environmental conditions in workshop environment. These new capacities enable better understanding of cost effective production of accurate workpieces and the provision of better NMI (AS Metrosert) measurement services for industry.

Slovenia

Overview

Although the current metrology system in Slovenia is fairly young, it is based in a long history of regulation related to weights and measures, and Slovenia has been an active participating country in the EU-supported metrology research activities since their inception in 2002 – from the ERA-NETs (MERA, iMERA and IMERA+) all the way through to the EMRP and EMPIR programmes. As one of the smallest countries in the programmes their financial contribution is small, nevertheless Slovenian metrology institutes have participated in 23 joint research projects and five researcher grants.

Slovenia's participation had a strong focus on projects in the Environment and Industry themes to support Slovenian industry and develop its expertise in a range of environmental measurements. Projects have also addressed smart grids for future energy supply and managing radioactive materials. Slovenia also participated in projects developing the SI system and widening SI traceability at the highest level to ensure it can meet future needs for accurate measurement.

Capacity building impact

Slovenia has a distributed metrology system making best use of metrology expertise in a number of institutes and universities across the country and many of them participated in EMRP.

Key capacity building achievements resulting from EMRP include:

- The Slovenian Institute of Quality and Metrology participated in a range of projects in the Energy, Industry and SI themes, developing new skills and measurement capabilities in power quality for smart grids, EMC assessment, the assessment of the performance of dielectric materials and assessments of complex waveforms. Together these are supporting Slovenian industry, such as the instrumentation sector and public utilities.
- The Department of Biotechnology and Systems Biology at the National Institute for Biology has significantly increased its skills and knowledge in quantitative PCR and digital PCR to support diagnostics of human pathogens. This has not only led to many high quality publications but will ultimately support improved public health. This work brought together research funding and PCR equipment acquired via European Structural funding (ESIF).
- The Environmental Sciences and Low and Medium Energy Physics group at the Jozef Stefan Institute contributed to projects in the Environment theme, developing skills and new calibration capabilities

for trace elements in air, water, soil and food to support implementation of the Air and Water Quality Directives in Slovenia plus traceable measurements for radioactive quantities to support the management of nuclear waste (the latter brought together research funding and PCR equipment acquired via European Structural funding).

- The Faculty of Electrical Engineering / Laboratory of Metrology and Quality at the University of Ljubljana developed and improved their facilities for the calibration of meteorological moisture sensors that support improved understanding of the atmosphere and measurements of Essential Climate Variables.
- The Faculty of Mechanical Engineering / Laboratory for Production Measurement and the Institute of Metals and Technology / Laboratory of Pressure Metrology improved and extended their capabilities in a range of dimensional and mechanical measurements that underpin the calibration chain for a wide range of manufacturing sectors.

4.2 Open access to research infrastructures (O1.4)

Figure 21: Operational Objectives - Indicator 4

INDICATOR 4	Number of research infrastructures jointly used in RTD projects
Data / Evidence	
The metrology infrastructure in each country is a research infrastructure – the NMIs and DIs in each country provide both specialist facilities and expertise to conduct metrology research and deliver metrology services to measurement users. Therefore each participation of an NMI or DI in a joint research project constitutes a sharing of research infrastructures. This amounts to 957 research infrastructures jointly used across the 119 EMRP projects. In addition, the researcher mobility grants supported a very direct method of sharing of research infrastructures by enabling the movement of researchers between the national research infrastructures. There were 73 research mobility grants (to date) each involving shared use of metrology facilities for joint research (see **Operational indicator 7**).	

4.3 Increase cooperation between NMI/DIs and science community (O1.5)

Figure 22: Operational Objectives - Indicator 5a

INDICATOR 5a	Number of research organisations (not being NMI of DI) involved in EMRP projects
INDICATOR 5b	Level of participation in the programme by outside researchers and research institutions
Data / Evidence	

In addition to participation from NMI and DIs, there were 1147 participations in EMRP projects from 916 organisations.

50 % (570) of participations were from universities and public research organisations and 41 % (474) from industry.

They participated as:

- Unfunded project partners - i.e. full project partners providing a defined contribution to the projects
- Grant recipients - providing additional funded contributions to projects
- Collaborators - signing a Non-disclosure Agreement with the projects to enable them to contribute to the project and network with project partners

The data is illustrated in the figure below.

Industrial participation was largely in the form of collaboration via a Non-disclosure Agreement or as unfunded partners. University and public research organisations participated via the Researcher Grant mechanisms or as collaborators.

A list of participants is provided in Annex A.

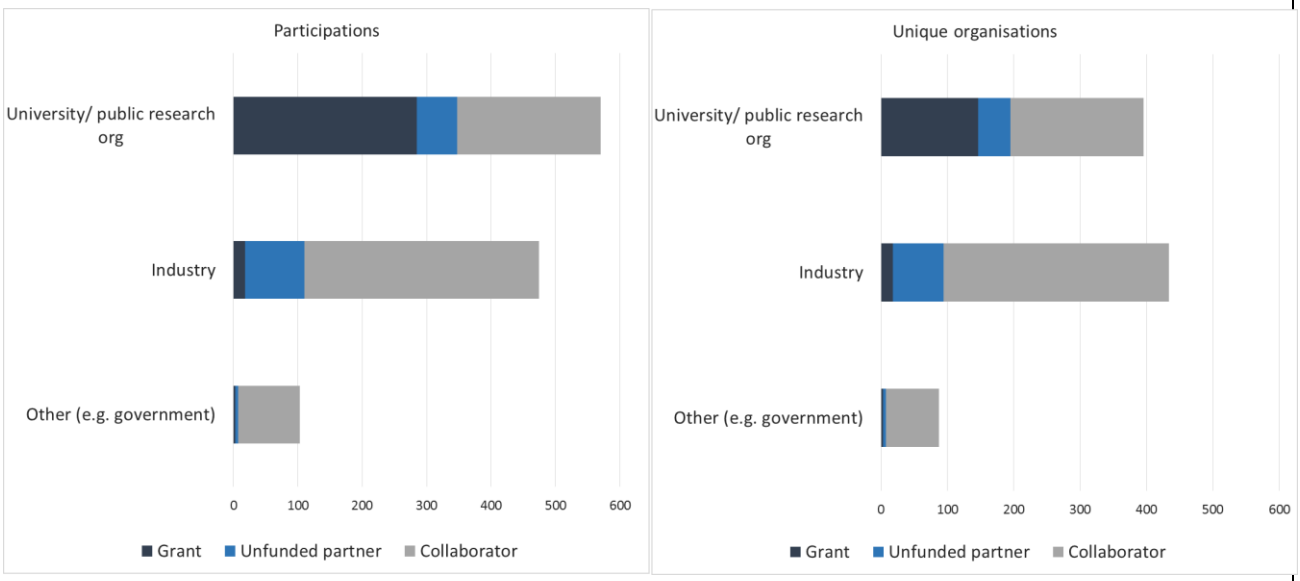


Figure 23: Operational Objectives - Indicator 5c

INDICATOR 5c	Number of PhDs trained in metrology
Data / Evidence	
25 PhDs in metrology have been published.	

4.4 Modernisation in programming (O1.6)

Figure 24: Operational Objectives - Indicator 9

INDICATOR 6	List of advanced technologies employed in the developments of primary standards which can and should be transferred to new and challenging research activities
Data / Evidence	
Metrology research makes use of advanced technologies to develop next generation techniques for realising primary measurement standards and, in the process of developing primary measurement standards, advances technologies, tools and techniques that may be applied to challenging research activities. Examples from EMRP projects include: **Graphene** An EMRP project investigated the use of graphene as a practical quantum resistance standard. Graphene characterisation methods were enhanced by the project and are already being used in various laboratories where graphene films are grown for research or for applications development (e.g. in the field of electronics). The ultimate goal of a graphene based quantum resistance standard will not only improve primary electrical standards but will also enable accurate assessment of resistance in academic ad industrial R&D.	

Single photon technologies

A number of EMRP projects have been developing single photon sources and detectors to improve the primary standards for the measurement of light (radiant power, etc.) but also to ensure that such devices can be accurately characterised for use in quantum cryptography and quantum computing.

Single electron technologies

A project developed state-of-the-art Single Electron Transport (SET) devices - known as SET pumps – to support future realisation of the SI unit the ampere. These pumps move a single electron at a time and offer the opportunity to investigate fundamental electronic phenomena and develop applications such as single-electron-based information processors and highly sensitive scanning probes.

Atomic and optical clocks

The metrology community has been at the forefront of the development of atomic and optical clocks for accurate time measurement. EMRP projects not only advanced the development of practical atomic clocks for wider industrial and space applications but advanced the ion-trap technologies and techniques for future optical clocks. The ion-trap techniques have applications in quantum physics and quantum information and communications research.

Large volume metrology

An EMRP project developed state-of-the-art techniques and instrumentation of the accurate dimensional measurement of large objects such as aircraft and spacecraft during manufacture. The techniques have wider applicability to large-scale research facilities that require accurate alignment of components and systems such as CERN (the project team is already working with CERN), European Synchrotron Radiation Facility and ITER.

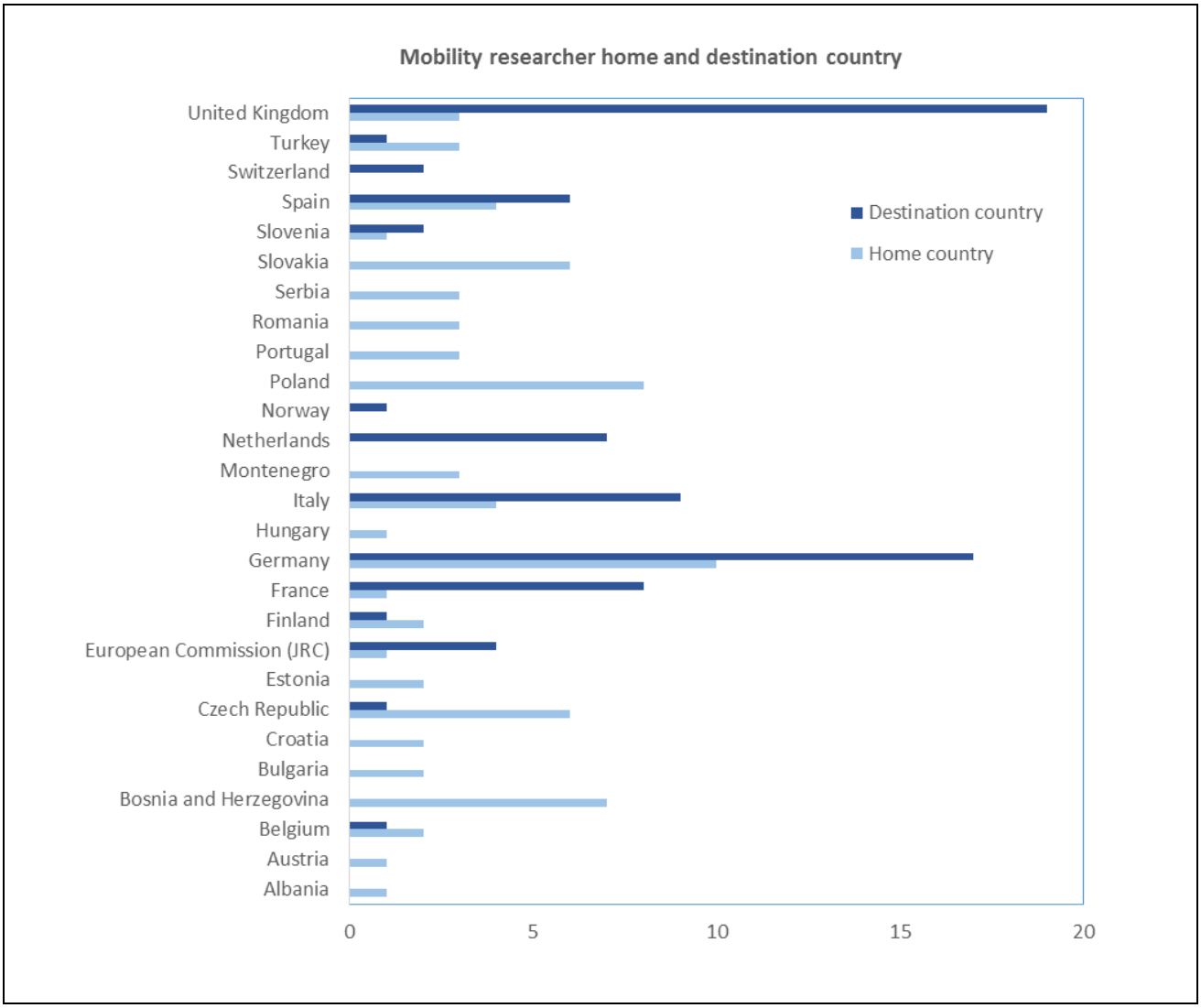
Advanced spectroscopic techniques

A number of EMRP projects improved the accuracy of high-performance spectroscopic techniques such as energy dispersive X-ray spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS) atomic force microscopy (AFM), secondary ion mass spectrometry (SIMS), etc. These have wide application in materials research (in particular) with more accurate techniques enabling the research base to make better quantitative assessments of new materials.

4.1 Mobility (O1.7)

Figure 25: Specific Objectives - Indicator 7

INDICATOR 7	Number of mobility grants implemented
Data / Evidence	
79 mobility grants were implemented. These enabled researchers to spend time at other institutions. 30 % of the mobility grants were for early stage researchers. The home and destination countries are shown in the chart below illustrating the use of mobility grants for capacity building. 60 % of the home countries of mobility grant recipients were in New Member States and accession states, while 82 % of the destination NMI and DIs were in the larger most experienced NMIs and DIs in Germany, UK, France, Netherlands, Italy and Spain. Lists of the mobility grant recipients are provided in Annex B.	



4.2 Strengthen European influence (O1.8)

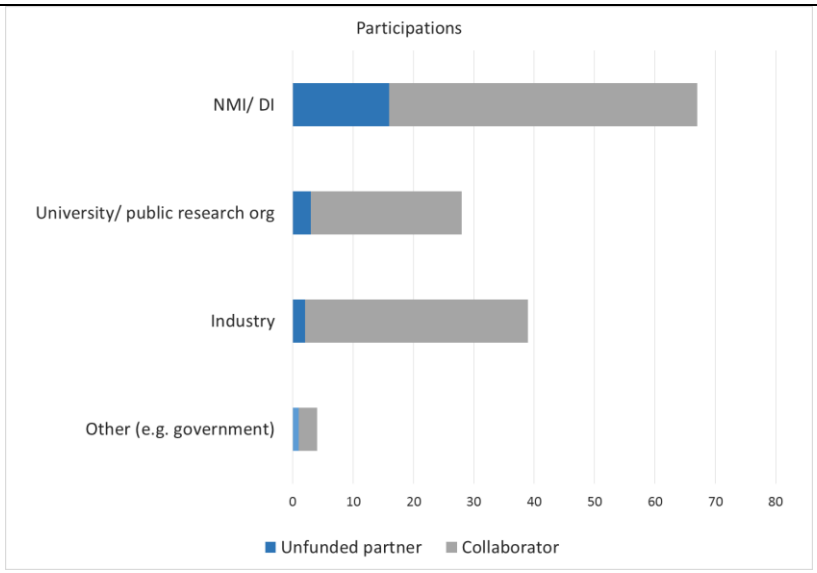
Figure 26: Operational Objectives - Indicator 8

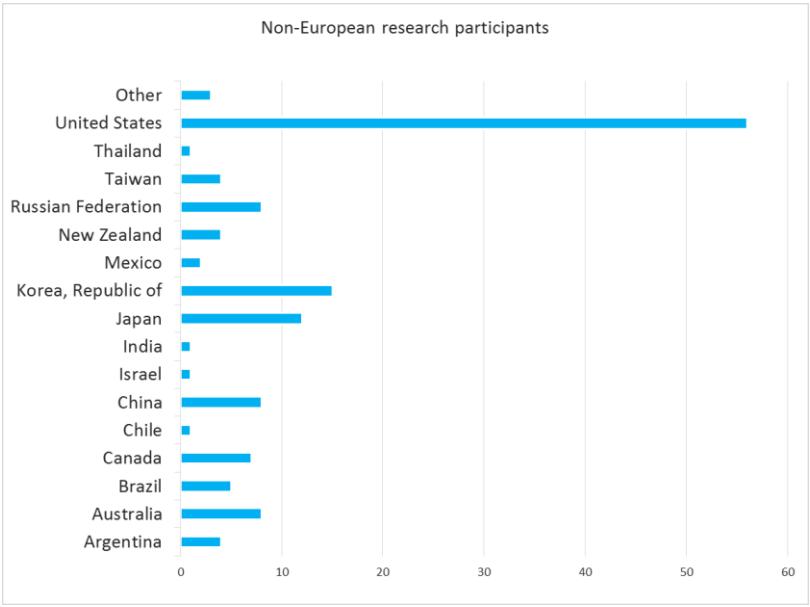
INDICATOR 8	Number of generic cooperation activities with non-European research actors

Data / Evidence

There has been significant participation from non-European research actors in the programme. There were 140 participations in EMRP projects by non-European research actors from the NMI/DI, academic and industrial communities either as unfunded partners or collaborators, illustrated in the chart below. The most frequent non-European actors were the NMI /DI community, with participation from NMIs/ DIs in 14 countries participated in EMRP projects (Argentina, Australia, Brazil, Canada, China, Egypt, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, Taiwan, Thailand, United States).

No generic cooperation activities with non-European research actors have yet been established but as the second chart below shows, there has been significant levels of interaction with NMI in the USA (NIST) and other important NMIs in Japan, Korea and China. The EMRP projects addressing the research for the forthcoming redefinition of the SI have played an important focal point for international activity, bringing together the European expertise and international NMIs via the unfunded partner and collaborator mechanisms.





4.3 Supporting regulation (O1.9)

Figure 27: Operational Objectives - Indicator 9a

INDICATOR 9a	Number of EMRP projects with direct references to regulation
Data / Evidence	
The EMRP Energy, Environment and Health themes have a strong focus on regulation with many projects addressing regulatory issues. A number of projects in other themes (such as Industry and SI Broader scope) also address regulation. In total 42 projects (out of the 119 funded) have direct reference to regulation (see Figure 28).	
Additional information	
Energy theme The Energy theme is predominantly focused on metrology to support Europe's climate and energy targets.	

Twelve projects make a direct reference to the Renewable Energy Directive (2009/28/EC). The directive has set a target that at least 20 % of Europe's total energy needs fulfilled by renewables by 2020. The projects focused on:

- Accurate measurement techniques needed to characterise and quantify renewable fuels to support their development and trade
- Accurate measurement techniques required for the smart grids and high voltage transmission systems that are being developed to ensure electricity generated from renewable sources can be managed and distributed safely and cost-effectively.

Three Energy projects also supported the development of low carbon technologies to support Europe's target for increased energy efficiency (Energy Efficiency Directive 2012/27/EU).

- Two projects focused on the accurate measurements required to characterise and assess on low energy lighting (LED, OLEDs, etc). This supports both the Energy Efficiency Directive and the Eco-design Directive (2009/125/EC)

  One project addressed the measurements required to characterise and assess energy harvesting technologies that will reduce energy use and may potentially reduce use of small batteries. This supports both the Energy Efficiency Directive and the Batteries Directive (2008/98S/EC)

Two projects on liquid natural gas (LNG) also supported the EU Directive concerning common rules for the internal market in natural gas (2003/55/EC), the Measuring Instruments Directive (2014/32/EU) and the Sulphur Directive (2012/33/EU (amendment on Directive 1999/32/EC)) that regulates sulphur emissions from ships.

Environment theme

Ten projects in the Environment theme focus on the measurements required to robustly analyse and quantify pollutants and other hazardous substances to support air and water quality regulation and therefore directly refer to the:

- Water Framework Directive (WFD-2000/60/EC) and the related directives: the Drinking Water Directive (98/83/EC); the Directive on Technical Specifications for Chemical Analysis and Monitoring of Water Status (2009/90/EC); Directive on environmental quality standards in the field of water policy (2008/105/CE) and Directive relating to restrictions on the marketing and use of certain dangerous substances and preparations (organostannic compounds) (2002/62/EC)
- Ambient air quality and cleaner air for Europe Directive (2008/50/EC) and related directives such as Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)
- The Euro series of emissions regulations for type-approval of motor vehicles and engines: for light duty vehicles (cars and vans) (No 715/2007) and for heavy duty vehicles (No 595/2009) and related directives on regular emissions testing
- Industrial Emissions Directive (IED) (2010/75/EU) that sets out limits on the emissions from a range of industrial processes.
- Directive on national emission ceilings for certain atmospheric pollutants (NEC) (2001/81/EC) regulates ammonia emissions in the Member States
- Directives focused on reducing mercury in the environment: Restriction of Hazardous Substances RoHS) in Electrical and Electronic Equipment Directive (2002/95/EC) and the Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)

In terms of broader environmental challenge climate change, a project focused on issues related to the measurement of environmental parameters to assess climate change addressing the INSPIRE Directive (2007/2/EC) – to establish an Infrastructure for Spatial Information in the European Community for the purposes of EU environmental policies and policies.

Three environment projects addressed measurements related to radioactivity. Two projects addressed measurements of radioactive waste during the decommissioning of nuclear power plants, addressing Directive 96/29/EURATOM laying down basic safety standards for the protection of the health of workers and

the general public against the dangers arising from ionising radiation and related IAEA Safety Standards Series. The third project addressed measurements for a radiological early-warning systems in Europe.

Health theme

Seven projects in the Health theme address the provision of accurate measurements to support the implementation of Directives focused on the use of medical procedures and devices. Accurate measurement ensure that healthcare tools and processes are effective and that safety standards are meaningful. Five projects address:

- Medical Device Directive (93/42/EEC) and related directives that cover the conformity assessment of all medical equipment used to diagnose, prevent, monitor and treat medical conditions.
- In-vitro Diagnostics (IVD) Directive (98/79/EC) that regulates devices and accessories used to perform tests on samples for diagnostic, prevention and health monitoring purposes
- Directive on medicinal products for human use (2001/83/EC) and its related directives – that regulate medicinal products such as pharmaceuticals, and the Directive on processing, storage and distribution of human blood and blood components (2002/98/EC)

Two projects in the Health theme addressed the requirements for accurate measurements of ionising radiation to ensure patient safety covered by Directive 97/43/EURATOM health protection on individuals against the dangers of ionising radiation in relation to medical exposure.

A further project addressed the safety of healthcare workers regarding the electromagnetic radiation of MRI scanners as covered by the Physical Agents Directive (2004/40/EC). In this case the issue is accurate measurements to support both healthcare workers and ensure the effectiveness of the MRI as a diagnostic tool.

A project addressed the effects of non-audible sound on humans and potential extensions to the coverage of environmental noise directives: Directive on the assessment and management of environmental noise (2002/49/EC) and Directive on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (2003/10/EC).

Figure 28: List of projects and related directives*

Renewable Energy Directive (2009/28/EC)	
ENG01 GAS	Characterisation of Energy Gases
ENG02 Harvesting	Metrology for Energy Harvesting
ENG04 SmartGrid	Metrology for Smart Electrical Grids
ENG07 HVDC	Metrology for High Voltage Direct Current
ENG09 Biofuels	Metrology for Biofuels
ENG52 SmartGrid II	Measurement tools for Smart Grid stability and quality
ENG53 ThinErgy	Traceable characterisation of thin-film materials for energy applications
ENG54 Biogas	Metrology for biogas
ENG55 PhotoClass	Towards an energy-based parameter for photovoltaic classification
ENG56 DriveTrain	Traceable measurement of drive train components for renewable energy systems
ENG61 FutureGrid	Non-conventional voltage and current sensors for future power grids
ENG63 GridSens	Sensor network metrology for the determination of electrical grid
Energy Efficiency Directive 2012/27/EU) Eco-design Directive (2009/125/EC)	**Batteries Directive (2008/98S/EC) Waste Directive (2008/98/EC)**
ENG02 Harvesting	Metrology for Energy Harvesting
ENG05 Lighting	Metrology for Solid State Lighting
ENG62 MESaIL	Metrology for efficient and safe innovative lighting
IND04 MetroMetal	Ionising radiation metrology for the metallurgical industry

Directive concerning common rules for the internal market in natural gas (2003/55/EC) Measuring Instruments Directive (2014/32/EU) Sulphur Directive (2012/33/EU (amendment on Directive 1999/32/EC))	
ENG03 LNG	Metrology for Liquefied Natural Gas
ENG60 LNG II	Metrological support for LNG custody transfer and transport fuel applications
Water Framework Directive (WFD-2000/60/EC) and associated directives	
ENV08 WFD	Traceable measurements for monitoring critical pollutants under the European Water Framework Directive (WFD-2000/60/EC)
ENV05 Ocean	Metrology for ocean salinity and acidity
ENV51 MeTra	Traceability for mercury measurements
Ambient air quality and cleaner air for Europe Directive (2008/50/EC) The Euro series of emissions regulations for type-approval of motor vehicles and engines	
ENV01 MACPoll	Metrology for Chemical Pollutants in Air
ENV02 PartEmission	Emerging requirements for measuring pollutants from automotive exhaust emissions
ENV52 HIGHGAS	Metrology for high-impact greenhouse gases
ENV56 KEY-VOCs	Metrology for VOC indicators in air pollution and climate change
INSPIRE Directive (2007/2/EC)	
ENV04 MetEOC	European metrology for earth observation and climate
ENV53 MetEOC2	Metrology for earth observation and climate
Directive 96/29/EURATOM	
ENV09 MetroRWM	Metrology for Radioactive Waste Management
ENV54 MetroDecom	Metrology for decommissioning nuclear facilities
ENV57 MetroERM	Metrology for radiological early warning networks in Europe
HLT09 MetrExtRT	Metrology for radiotherapy using complex radiation fields
HLT11 MetroMRT	Metrology for molecular radiotherapy
IND04 MetroMetal	Ionising radiation metrology for the metallurgical industry
Industrial Emissions Directive (IED) (2010/75/EU)	
ENV60 IMPRESS	Metrology to underpin future regulation of industrial emissions
ENV51 MeTra	Traceability for mercury measurements
Directive on national emission ceilings for certain atmospheric pollutants (NEC) (2001/81/EC)	
ENV55 MetNH3	Metrology for ammonia in ambient air
ENV52 HIGHGAS	Metrology for high-impact greenhouse gases
Hazardous Substances RoHS) in Electrical and Electronic Equipment Directive (2002/95/EC) Directive relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (2004/107/EC)	
ENV51 MeTra	Traceability for mercury measurements
Medical Device Directive (93/42/EEC)	
HLT03 DUTy	Dosimetry for ultrasound therapy
IND56 Q-AIMDS	Chemical metrology tools to support the manufacture of advanced biomaterials in the medical device industry

In-vitro Diagnostics (IVD) Directive (98/79/EC)		
HLT04	BioSurf	Metrology for the characterisation of biomolecular interfaces for diagnostic devices
HLT05	Metallomics	Metrology for metalloproteins
HLT08	INFECT-MET	Metrology for monitoring infectious diseases, antimicrobial resistance, and harmful micro-organisms
SIB54	Bio-SITrace	Traceability for biologically relevant molecules and entities
Directive on medicinal products for human use (2001/83/EC) Directive on processing, storage and distribution of human blood and blood components (2002/98/EC)		
HLT10	BiOrigin	Metrology for biomolecular origin of disease
Physical Agents Directive (2004/40/EC)		
HLT06	MRI safety	Metrology for next-generation safety standards and equipment in MRI
Directive on the assessment and management of environmental noise (2002/49/EC) Directive on minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (2003/10/EC)		
HL01	Ears	Metrology for a universal ear simulator and the perception of non-audible sound
EMC Directive (2004/108/EC)		
IND60	EMC	Improved EMC test methods in industrial environments
Construction products regulation (Regulation (EU) No 305/2011)		
SIB52	Thermo	Metrology for thermal protection materials

*Some projects are listed under more than one category of regulation

Figure 29: Operational Objectives - Indicator 9b

INDICATOR 9b	**Number of presentations at standardisation technical committees or working groups**
Data / Evidence	
To the end of 2016, 1135 contributions had been made to 486 unique standards committees. To date this has resulted in contributions to 126 published and draft standards. Many of the technical committees are working on standards that link to the effective implementation of the regulations reported under **Operational Indicator 9a**. Such standards specify measurement methods to be deployed in the field or commercial calibration and test laboratories that provide measurements to assess, for example, air and water quality.	

4.4 Supporting industry through up front public metrology research (O1.10)

Figure 30: Operational Objectives - Indicator 10a

INDICATOR 10a	**Number of scientific publications**
Data / Evidence	
1375 papers have been published to date. In addition 607 papers were published in conference proceedings and 33 contributions made to books.	

Figure 31: Operational Objectives - Indicator 10b

INDICATOR 10b	Number of presentations at congresses
Data / Evidence	
4915 contributions have been made at conferences - 3394 presentations and 1521 posters.	

Figure 32: Operational Objectives - Indicator 10c

INDICATOR 10c	Number of patents granted
Data / Evidence	
36 patent applications have been made to date. None has yet been granted. It should be noted that not all projects have finished yet and therefore more patent applications may arise.	

Figure 33: Operational Objectives - Indicator 10d

INDICATOR 10d	Number and quality of activities related to metrology communication and diffusion
Data / Evidence	

2155 activities have been undertaken to communicate and diffuse the outputs of EMRP projects. In the majority of cases (89 %) the target audience is measurement users in the industrial, public sector and academic communities. The remainder (11 %) are targeted at the general public.

These include a wide range of activities:

Dissemination activities	Number
Presentation at seminar/workshop etc.	711
Website	238
JRP event / workshop / seminar	209
Article published in trade / professional press	136
Article published in the popular press	98
Exhibition	89
Newsletter, flyer, leaflets	119
Press release	84
Media interview	53
Communication with the public/public report	73
Video /film	12
Email lists, social networking, etc.	22
Other	311
TOTAL	**2155**

Audience size: the dissemination activities are estimated to have reached a total audience of 684,000[11]

[11] Project partners report estimated audience size in ranges (e.g. 50-100, 101-200 people), therefore the total number is an estimate. The estimate does not represent unique numbers of people as people may be targeted by more than one dissemination activity.

Figure 34: Operational Objectives - Indicator 10e

INDICATOR 10e	Number and quality of training activities

Data / Evidence

1020 training activities have been undertaken. Of these:

- 463 were focused on training for the NMI/DI community
- 557 were focused in training of users of metrology

The training took a wide range of formats, appropriate to the audiences being targeted:

	Audience	
Type of training	**Measurement users**	**NMI/DI community**
One-to-one training	42	172
Training course/workshop for external	448	248
Interactive online training course/tool	17	7
Written training material for external (online/paper)	23	28
Other	27	8
TOTAL	**557**	**463**

A further 35 PhDs (see **Operational indicator 5c**) and 25 Masters students have been trained in metrology.

It is estimated that the training activities reached the following audiences.

Measurement user community: an estimated 24,200 people from the measurement user community were trained in small group sessions and workshops.

NMI/DI community: 4,410 people in the NMI/DI community were trained.[12]

Specific Objectives - Indicator 10e

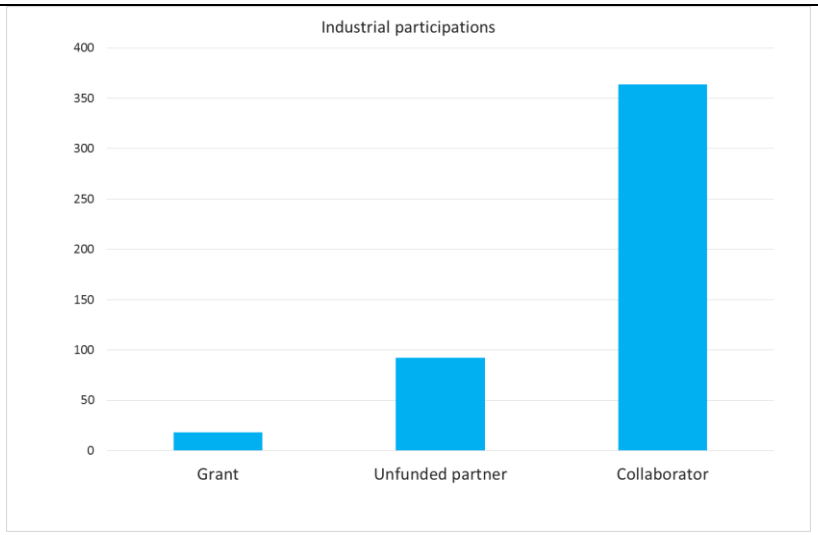
INDICATOR 10e	Number of industrial participants

Data / Evidence

As reported under **Operational indicator 5a**, there was significant participation by industry. There were 474 participations from 434 organisations.[13] The majority (77 %) participated as collaborators, signing a Non-Disclosure Agreement with the project partners enabling them (with conditions) to engage with the project team and access results. A smaller number made formal contributions to the projects as unfunded partners or via Researcher Grants.

[12] Project partners report numbers of attendees at training events in ranges (e.g. 5-10, 11-25 people), therefore the total number is an estimate. The estimate does not represent unique numbers of people as people attending more than one training event will be counted each time they attend.

[13] The actual number of unique organisations is likely to be lower than this due to the way that company names are reported by project partners (particularly for collaborators), where the same company and/or their subsidiaries can be reported under slightly different names.



5 Effectiveness, Efficiency and European value-added

5.1 Effectiveness

The programme has delivered against all of its operational and specific objectives.

Contributing to the ERA / creating a Metrology Research Areas

S1.1 Structuring the ERA through coordinating and partly integrating national public metrology research programmes to provide soutions to European societal challenges

S1.2 Improve the efficiency of Europe's fragmented public metrology research approach

S1.3 To remove barriers between national metrology research programmes and to foster sustainable cross-border cooperation e.g. through mobility of young researchers, scientists and academic staff and to open up the national programmes to inter-disciplinary cooperation with researchers and scientists from other fields in particular relating to new and emerging technologies.

Levering and consolidating metrology funding in Europe

The programme achieved a significant level of coordination of national public metrology research programmes. 23 European countries participated in EMRP, leveraging national funding of 219.236 M€ – 10 % above the target of 200 M€ – for EMRP activities. The value of the total EMPIR budget compared to the national metrology research budgets over the same period is 52 %.

The programme enabled widespread collaboration in metrology research, not only among the traditional metrology institutes (the NMIs and DIs) but also with the academic, industrial and pulic sector communities. The Commission and national funding supported 119 joint research projects with 957 participations from the metrology community (i.e. NMIs and DIs) and 1157 participations from a further 916 organisations the academic, industrial and public sector communities.

Scientific integration

The programme was designed and governed by the participating countries at a number of levels to support scientific integration of metrology research across Europe:

- The programme was guided by a common research agenda developed by the European metrology community under the precursor ERA-NET programme iMERA+
- The programme was designed around themes focused on grand societal challenges (energy, environment, health, industry) as well as supporting important developments in the international systems of units (the SI).
- Call scopes were developed by the EMRP Committee supported by the new themed Task Groups established by EURAMET

- A two-stage call process brought the European metrology community together, along with the academic community and measurement research end-users, to develop and deliver collaborative research projects.
- Project selection was based on an assessment, by the EMRP committee, of alignment with strategic requirements (stage 1) and independent expert review (stage 2). The Interim Evaluation of EMRP and the annual independent observers' reports confirm that this process was independent and robust.

All participating countries could (in most cases, did) participate in all levels of programme and project design and governance.

Projects were conducted by collaborations of NMIs, DIs, academics, industrial and other organisations significantly increasing the level of networking and enabling the flow of ideas, knowledge and people and sharing of metrology research facilities.

Management integration

EURAMET implemented a dedicated and centralised governance and management processes for the programme from the outset, made up of the EMRP Committee, an EMRP Programme Manager and a dedicated Management and Support Unit (MSU). The delivery of the programme has been monitored and reviewed in various ways (annual reports, audits, Interim Evaluation, etc) and no significant problems or issues have arisen. The Interim Evaluation found the programme processes to be high quality and transparent and in line with the Commission's requirements.

Financial integration

The programme managed 200 M€ of EU funding and coordinated 219 M€ of national metrology research funds using a common approach to financial rules. From the very beginning the programme adopted a model contract and financial approach based on the FP7 model. Guidelines and templates were provided to support project partners who were new to this approach, helping them to cost projects and ensure finances were reported consistently and in accordance with the financial rules.

Delivering economic and social impact

S1.4 To increase the impact of these programmes, both S&T impacts (scientific excellence, pooling of resources, data and expertise, achievement of critical mass, facilitating programme optimisation) and economic and societal impacts.

Scientific excellence and impact

The EMRP programme provided a structured process of research collaboration among European metrology institutes (NMIs and DIs). Prior to EMRP (and its predecessor ERA-NET iMERA+) research collaboration was rather ad-hoc, based on goodwill and relationships between individual institutes and researchers. A key benefit of the programme was not only the ability to coordinate resources and skills but the ability to align research timescales. An important example of this being the coordination of European research contribution to the forthcoming redefinition of the international system of units (the SI). EMRP projects under the first SI call became a focal point for European redefinition activity and, for some projects, an international focal point. The pooling of research expertise and the alignment of critical experiments and measurement comparisons has enhanced the European contribution scientifically but also in terms of creating a more coordinated European position in the forthcoming redefinition decision.

EMRP researchers have published 1358 papers in peer-reviewed journals. Bibliographic analysis shows that the publications are above world averages in terms of citations, impact factor and highly cited papers and have been increasing over the period from 2008 to 2015 (i.e. before and during EMRP). In addition the level of international co-authorship of peer-reviewed papers has increased from 32 % to 47 %.

Economic impact

Accurate traceable measurement, reliable and robust worldwide, underpins trade. Metrology research ensures the international measurement systems are fit for the future and supports the introduction of innovative product and services through the accurate validation of new technologies and ideas. The pathways and timescales for economic impact are not always direct or immediate and most EMRP projects have only recently been completed (and some EMRP projects have not yet finished). Nevertheless, EURAMET has collected evidence of early impact - that is the adoption of EMRP project outputs by measurement users. Early adopters of metrology research are often (but not solely) the instrumentation sector and the accredited laboratory sector who make use the new NMI/DI capabilities or adopt the improved measurement techniques to develop their own

new products and services. These sectors are an important bridge to measurement end-users in other businesses sectors and public sector agencies, who use improved measurement capabilities to develop their new products and/or improve processes.

EURAMET conducted surveys of industrial participants in EMRP projects and developed impact case studies. These have demonstrated an economic impact in terms of actual and projected sales of innovative products (as quoted and/or estimated by the early adopters) influenced by the programme of 1,673 M€. Of this figure, the early adopters estimate that 319 M€ is directly attributable to the programme. This figure covers the industrial participants that participated in projects in the first three EMRP calls (covering the Energy, Environment, Industry, Health and New Technology themes) and therefore can be expected to increase as additional surveys are conducted and case studies developed. In addition, the new products sold will contribute to economic benefits for many of the end-users. EURAMET has identified and published 42 case studies demonstrating economic impact.

Social impact

Three of the programme's theme were explicitly focused on social impact via the grand challenges Energy, Environment and Health. Research in these themes addressed the requirements for accurate data and appropriate instrumentation to improve the ability to identify, quantify and better understanding problems, and to design and implementation effective solutions and/or appropriate regulation. Many of the projects in these themes were directly focused on European regulation supporting issues such as water and air quality, safety of healthcare products and radiation protection. 42 projects (35 % of the total) supported regulation.

As for economic impact, the pathways and timescales for impact are not always direct or immediate (and some projects have not yet finished) but EURAMET has identified and developed 28 case studies to date of social impact in these three themes and more will follow. These case studies provide examples of the adoption of project outputs by the measurement users and demonstrate that the route to longer-term impact has commenced. Examples include:

- New flow and temperature instrumentation that has been demonstrated to improve efficiency in traditional power plants, leading to reduced carbon emissions and providing financial benefits
- Supporting the introduction of energy efficient lighting in the Italian tunnel network, improving safety and reducing both costs and energy use
- The development and trial of practical reference standards to improve the robustness of roadside emissions monitoring, so protecting human health
- Contributing measurement methods and standards to ESA's next generation Earth observation satellites
- Developing accurate validation of molecular methods to identify and quantify infectious diseases

5.2 Efficiency

The programme objectives and impacts have been delivered efficiently. The costs of administering the programme are expected to be 16 M€. This represents 3.8 % of the total 419 M€ programme budget.

5.3 European value added

Metrology is both a national and international endeavour. In some countries the requirement to hold national measurement standards to support the economy and society is enshrined in law and the international system of metrology ensures that primary measurement standards and the measurements they support are comparable and accepted across the world. However the requirements for research to ensure measurements are fit for the future are increasing. Meeting ever-growing demands for new measurement standards in emerging areas of technology whilst still meeting the expectations of existing sectors and users places increasing demands on national metrology research budgets, with most countries showing similar demands. Conducting research at European level via EMRP has enabled national metrology institutes to pool resources and knowledge and reduce duplication and reach critical mass in key areas.

6 Annex A: Non-NMI/DI project participants

6.1 Researcher Grants

There were 306 participations by 146 organisations in researcher grants.

Figure 35: Researcher grants

Project	Organisation	Country	Organisation type
ENG01	Politecnico di Torino	Italy	University/ public research org
ENG03	Ruhr-Universitaet Bochum	Germany	University/ public research org
ENG04	Aristotelio Panepistimio Thessalonikis	Greece	University/ public research org
ENG04	University of Strathclyde	United Kingdom	University/ public research org
ENG05	University of Surrey	United Kingdom	University/ public research org
ENG05	University of Surrey	United Kingdom	University/ public research org
ENG05	Technische Universiteit Delft	Netherlands	University/ public research org
ENG06	Technische Universitaet Graz	Austria	University/ public research org
ENG07	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG08	The Chancellor, Masters and Scholars of the University of Cambridge	United Kingdom	University/ public research org
ENG09	Universidad de Oviedo	Spain	University/ public research org
ENG09	Universitaet Rostock	Germany	University/ public research org
ENG09	Universitaet Rostock	Germany	University/ public research org
ENG51	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
ENG51	Centre National de la Recherche Scientifique	France	University/ public research org
ENG51	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
ENG52	Technische Universiteit Eindhoven	Netherlands	University/ public research org
ENG52	École Polytechnique Federale de Lausanne	Switzerland	University/ public research org
ENG52	University of Strathclyde	United Kingdom	University/ public research org
ENG53	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
ENG53	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
ENG53	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
ENG54	Institut national de l'environnement industriel et des risques ineris	France	University/ public research org
ENG54	Fundación General de la Universidad de Valladolid	Spain	University/ public research org
ENG54	Helsingin Yliopisto	Finland	University/ public research org
ENG55	Loughborough University	United Kingdom	University/ public research org
ENG55	Institut für Solarenergieforschung GmbH	Germany	Industry
ENG55	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
ENG56	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
ENG56	Cardiff University	United Kingdom	University/ public research org
ENG56	Rheinisch-Westfälische Technische Hochschule Aachen	Germany	University/ public research org
ENG57	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
ENG58	University of Leeds	United Kingdom	University/ public research org
ENG58	University of Leeds	United Kingdom	University/ public research org
ENG58	Cranfield University	United Kingdom	University/ public research org
ENG59	International Research Institute Of Stavanger AS	Norway	University/ public research org
ENG59	Faculdade de Ciências e Tecnologia Universidade Nova de Lisboa	Portugal	University/ public research org
ENG60	Ruhr-Universitaet Bochum	Germany	University/ public research org

ENG60	Ruhr-Universitaet Bochum	Germany	University/ public research org
ENG60	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG61	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
ENG61	Technische Universitaet Dresden	Germany	University/ public research org
ENG61	University of Strathclyde	United Kingdom	University/ public research org
ENG62	Technische Universiteit Delft	Netherlands	University/ public research org
ENG62	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG62	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	University/ public research org
ENG63	Technische Universiteit Delft	Netherlands	University/ public research org
ENG63	Technische Universiteit Eindhoven	Netherlands	University/ public research org
ENG63	University of Strathclyde	United Kingdom	University/ public research org
ENV01	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
ENV01	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain	University/ public research org
ENV01	Helsingin Yliopisto	Finland	University/ public research org
ENV02	Leibniz Institut fuer Troposphaerenforschung e.V.	Germany	University/ public research org
ENV03	Medizinische Universität Innsbruck	Austria	University/ public research org
ENV03	The University of Manchester	United Kingdom	University/ public research org
ENV03	The University of Manchester	United Kingdom	University/ public research org
ENV03	Health Protection Agency HPA	United Kingdom	Other (e.g. government)
ENV04	Universitaet Zuerich	Switzerland	University/ public research org
ENV04	Universitaet Zuerich	Switzerland	University/ public research org
ENV04	ZiNIR Ltd	United Kingdom	Industry
ENV04	Maanmittauslaitos	Finland	University/ public research org
ENV05	University of Plymouth	United Kingdom	University/ public research org
ENV05	Fundacao da Faculdade de Ciencias da Universidade de Lisboa	Portugal	University/ public research org
ENV06	Stichting Katholieke Universiteit	Netherlands	University/ public research org
ENV07	Aarhus Universitet	Denmark	University/ public research org
ENV07	Karlsruher Institut fuer Technologie	Germany	University/ public research org
ENV07	Universitat Rovira i Virgili	Spain	University/ public research org
ENV07	EV-K2-CNR	Italy	University/ public research org
ENV07	Consiglio Nazionale delle Ricerche	Italy	University/ public research org
ENV08	Universidad de Oviedo	Spain	University/ public research org
ENV08	Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH	Germany	University/ public research org
ENV09	NUVIA a.s.	Czech Republic	Industry
ENV51	Universidad de Oviedo	Spain	University/ public research org
ENV51	Centre National de la Recherche Scientifique	France	University/ public research org
ENV51	Consiglio Nazionale delle Ricerche	Italy	University/ public research org
ENV52	Stichting Katholieke Universiteit	Netherlands	University/ public research org
ENV52	Eidgenoessische Materialpruefungs- und Forschungsanstalt	Switzerland	University/ public research org
ENV53	Universitaet Zuerich	Switzerland	University/ public research org
ENV53	Humboldt-Universität zu Berlin	Germany	University/ public research org
ENV53	Maanmittauslaitos	Finland	University/ public research org
ENV54	NUVIA a.s.	Czech Republic	Industry
ENV55	Natural Environment Research Council	United Kingdom	University/ public research org
ENV55	Helsingin Yliopisto	Finland	University/ public research org
ENV56	Politecnico di Torino	Italy	University/ public research org

ENV56	Universität des Saarlandes	Germany	University/ public research org
ENV56	Deutscher Wetterdienst	Germany	Other (e.g. government)
ENV57	Universitat Politècnica de Catalunya	Spain	University/ public research org
ENV57	Aristotelio Panepistimio Thessalonikis	Greece	University/ public research org
ENV57	NUVIA a.s.	Czech Republic	Industry
ENV58	Università degli Studi di Genova	Italy	University/ public research org
ENV58	Seconda Università degli Studi di Napoli	Italy	University/ public research org
ENV58	Universitat Politècnica de Catalunya	Spain	University/ public research org
ENV59	Universitaet Bremen	Germany	University/ public research org
ENV59	Universidad de la Laguna	Spain	University/ public research org
ENV59	Aristotelio Panepistimio Thessalonikis	Greece	University/ public research org
ENV60	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
ENV60	Technische Universiteit Delft	Netherlands	University/ public research org
ENV60	DCMR Milieudienst Rijnmond	Netherlands	Other (e.g. government)
EXL01	Oesterreichische Akademie der Wissenschaften	Austria	University/ public research org
EXL01	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
EXL01	Crystalline Mirror Solutions GmbH	Austria	Industry
EXL01	Institut d'optique théorique et appliquée IOTA - SupOptique	France	University/ public research org
EXL02	Friedrich-Alexander-Universität Erlangen - Nürnberg	Germany	University/ public research org
EXL02	Universität des Saarlandes	Germany	University/ public research org
EXL02	Danmarks Tekniske Universitet	Denmark	University/ public research org
EXL02	Danmarks Tekniske Universitet	Denmark	University/ public research org
EXL02	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
EXL03	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
EXL03	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
EXL03	Lancaster University	United Kingdom	University/ public research org
EXL03	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
EXL04	The Chancellor, Masters and Scholars of the University of Cambridge	United Kingdom	University/ public research org
EXL04	Universitaet Bielefeld	Germany	University/ public research org
EXL04	Laboratorio Iberico Internacional De Nanotecnologia	Portugal	University/ public research org
EXL04	Laboratorio Iberico Internacional De Nanotecnologia	Portugal	University/ public research org
EXL04	Fyzikální ústav AV ČR, v.v.i.	Czech Republic	University/ public research org
HLT01	University College London	United Kingdom	University/ public research org
HLT01	Max Planck Gesellschaft Zur Foerderung Der Wissenschaften E.V.	Germany	University/ public research org
HLT02	Research Centre for Natural Sciences, Hungarian Academy of Sciences	Hungary	University/ public research org
HLT02	AMC Medical Research B.V.	Netherlands	University/ public research org
HLT02	AMC Medical Research B.V.	Netherlands	University/ public research org
HLT03	University College London	United Kingdom	University/ public research org
HLT03	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
HLT03	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
HLT04	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
HLT04	The University of Nottingham	United Kingdom	University/ public research org
HLT04	Charite - Universitaetsmedizin Berlin	Germany	University/ public research org
HLT04	Technische Universität Berlin	Germany	University/ public research org
HLT05	The University Court of the University of Aberdeen	United Kingdom	University/ public research org

HLT05	Loughborough University	United Kingdom	University/ public research org
HLT05	Universitaet fuer Bodenkultur Wien	Austria	University/ public research org
HLT05	Deutsches Krebsforschungszentrum	Germany	University/ public research org
HLT06	King's College London	United Kingdom	University/ public research org
HLT07	Fachhochschule Lübeck	Germany	University/ public research org
HLT07	Universitair Medisch Centrum Utrecht	Netherlands	University/ public research org
HLT07	Universitair Medisch Centrum Utrecht	Netherlands	University/ public research org
HLT08	Charite - Universitaetsmedizin Berlin	Germany	University/ public research org
HLT08	University College London	United Kingdom	University/ public research org
HLT08	Bolnisnica Golnik Klinicni oddelek za pljucne bolezni in alergijo	Slovenia	University/ public research org
HLT09	Université d'Auvergne Clermont-Ferrand 1	France	University/ public research org
HLT09	Università degli Studi di Roma Tor Vergata	Italy	University/ public research org
HLT10	Charite - Universitaetsmedizin Berlin	Germany	University/ public research org
HLT10	The Chancellor, Masters and Scholars of the University of Oxford	United Kingdom	University/ public research org
HLT10	The University of Edinburgh	United Kingdom	University/ public research org
HLT10	Freie Universitaet Berlin	Germany	University/ public research org
HLT10	Robert Koch-Institut	Germany	University/ public research org
HLT11	Velindre National Health Service Trust	United Kingdom	University/ public research org
HLT11	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
HLT11	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	University/ public research org
IND01	Bayerisches Zentrum für Angewandte Energieforschung ZAE e.V.	Germany	University/ public research org
IND01	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND02	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND02	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND02	Eidgenössische Technische Hochschule Zürich	Switzerland	University/ public research org
IND02	Eidgenössische Technische Hochschule Zürich	Switzerland	University/ public research org
IND04	NUVIA a.s.	Czech Republic	Industry
IND05	Koc University	Turkey	University/ public research org
IND05	Queen Mary University of London	United Kingdom	University/ public research org
IND05	Schwarzer Norbert	Germany	University/ public research org
IND06	Politecnico di Milano	Italy	University/ public research org
IND06	Oulun Yliopisto	Finland	University/ public research org
IND06	ID Quantique SA	Switzerland	Industry
IND07	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND07	Technische Universiteit Delft	Netherlands	University/ public research org
IND07	Technische Universität Berlin	Germany	University/ public research org
IND07	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
IND07	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND08	Universitaet Bielefeld	Germany	University/ public research org
IND08	HITACHI Europe Limited	United Kingdom	Industry
IND10	Universitaet Stuttgart	Germany	University/ public research org
IND10	Technische Universitaet Ilmenau	Germany	University/ public research org
IND10	XPRESS Precision Engineering B.V.	Netherlands	Industry
IND10	Mahr GmbH	Germany	industry

IND10	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND11	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
IND11	University of Southampton	United Kingdom	University/ public research org
IND12	Karlsruher Institut fuer Technologie	Germany	University/ public research org
IND12	Università degli Studi di Genova	Italy	University/ public research org
IND12	Panepistimio Thessalias	Greece	University/ public research org
IND13	Technische Universitaet Ilmenau	Germany	University/ public research org
IND14	The University Court of the University of St Andrews	United Kingdom	University/ public research org
IND15	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
IND16	Technische Universiteit Delft	Netherlands	University/ public research org
IND16	National Instruments Belgium NV	Belgium	Industry
IND17	Technische Universiteit Delft	Netherlands	University/ public research org
IND17	Itä-Suomen yliopisto	Finland	University/ public research org
IND17	JCMwave GmbH	Germany	Industry
IND17	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
IND51	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
IND51	Technische Universiteit Delft	Netherlands	University/ public research org
IND51	Universite de Rennes I	France	University/ public research org
IND52	Katholieke Universiteit Leuven	Belgium	University/ public research org
IND52	Universidad de Alicante	Spain	University/ public research org
IND52	Innventia AB	Sweden	Industry
IND53	Karlsruher Institut fuer Technologie	Germany	University/ public research org
IND53	University College London	United Kingdom	University/ public research org
IND53	University of Bath	United Kingdom	University/ public research org
IND54	The University of Edinburgh	United Kingdom	University/ public research org
IND54	The University of Liverpool	United Kingdom	University/ public research org
IND54	Centre National de la Recherche Scientifique	France	University/ public research org
IND55	Universite de Neuchatel	Switzerland	University/ public research org
IND56	The University of Nottingham	United Kingdom	University/ public research org
IND56	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
IND56	Westfaelische Wilhelms-Universitaet Muenster	Germany	University/ public research org
IND56	Robert Koch-Institut	Germany	University/ public research org
IND57	Universitaet fuer Bodenkultur Wien	Austria	University/ public research org
IND57	Statni ustav radiacni ochrany v.v.i.	Czech Republic	University/ public research org
IND57	Glowny Instytut Gornictwa	Poland	Industry
IND58	University of Bristol	United Kingdom	University/ public research org
IND58	Technische Universitaet Ilmenau	Germany	University/ public research org
IND58	Technische Universitaet Ilmenau	Germany	University/ public research org
IND58	Ústav přístrojové techniky AV ČR, v.v.i.	Czech Republic	University/ public research org
IND59	The University of Nottingham	United Kingdom	University/ public research org
IND59	Friedrich-Alexander-Universität Erlangen - Nürnberg	Germany	University/ public research org
IND59	Loughborough University	United Kingdom	University/ public research org
IND60	Universitat Politècnica de Catalunya	Spain	University/ public research org
IND60	Universiteit Twente	Netherlands	University/ public research org
IND61	Cranfield University	United Kingdom	University/ public research org
IND61	Ricerca sul Sistema Energetico – RSE S.p.A.	Italy	University/ public research org
IND62	Karlsruher Institut fuer Technologie	Germany	University/ public research org

IND62	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
IND63	Politecnico di Torino	Italy	University/ public research org
IND63	The Chancellor, Masters and Scholars of the University of Oxford	United Kingdom	University/ public research org
IND63	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
NEW01	Interuniversitair Micro-Electronicacentrum IMEC VZW	Belgium	University/ public research org
NEW01	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
NEW01	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
NEW02	Eidgenössische Technische Hochschule Zürich	Switzerland	University/ public research org
NEW02	King's College London	United Kingdom	University/ public research org
NEW02	King's College London	United Kingdom	University/ public research org
NEW03	Heriot-Watt University	United Kingdom	University/ public research org
NEW03	Universitaet Hamburg	Germany	University/ public research org
NEW03	Research Centre for Natural Sciences, Hungarian Academy of Sciences	Hungary	University/ public research org
NEW04	Università degli Studi di Torino	Italy	University/ public research org
NEW05	Technische Universitaet Dresden	Germany	University/ public research org
NEW05	Technische Universitaet Chemnitz	Germany	University/ public research org
NEW05	Helsingin Yliopisto	Finland	University/ public research org
NEW06	Westsächsische Hochschule Zwickau	Germany	University/ public research org
NEW06	The University of Huddersfield	United Kingdom	University/ public research org
NEW06	Ostfalia Hochschule fur angewandte Wissenschaften Hochschule Braunschweig Wolfenbuttel	Germany	University/ public research org
NEW06	University of York	United Kingdom	University/ public research org
NEW07	Technische Universität Berlin	Germany	University/ public research org
NEW07	Philipps-Universität Marburg	Germany	University/ public research org
NEW07	Philipps-Universität Marburg	Germany	University/ public research org
NEW07	Centre National de la Recherche Scientifique	France	University/ public research org
NEW08	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
NEW08	Imperial College of Science, Technology and Medicine	United Kingdom	University/ public research org
NEW08	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
NEW08	Helsingin Yliopisto	Finland	University/ public research org
NEW09	University of Leeds	United Kingdom	University/ public research org
NEW09	Cranfield University	United Kingdom	University/ public research org
NEW09	aixACCT Systems GmbH	Germany	Industry
SIB01	Royal Holloway and Bedford New College	United Kingdom	University/ public research org
SIB01	Seconda Università degli Studi di Napoli	Italy	University/ public research org
SIB01	Seconda Università degli Studi di Napoli	Italy	University/ public research org
SIB01	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB02	Akademia Gorniczo-Hutnicza im. Stanislawa Staszica w Krakowie	Poland	University/ public research org
SIB02	University of Southampton	United Kingdom	University/ public research org
SIB02	Consiglio Nazionale delle Ricerche	Italy	University/ public research org
SIB03	Leibniz-Institut für Oberflächenmodifizierung	Germany	University/ public research org
SIB03	Leibniz-Institut für Oberflächenmodifizierung	Germany	University/ public research org
SIB03	Universita Degli Studi Di Cagliari	Italy	University/ public research org
SIB04	Universitaet Siegen	Germany	University/ public research org
SIB04	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB04	University of Sussex	United Kingdom	University/ public research org

SIB04	LZH Laserzentrum Hannover e.V.	Germany	industry
SIB05	Technische Universitaet Ilmenau	Germany	University/ public research org
SIB06	Klinikum rechts der Isar der Technischen Universitat Munchen	Germany	University/ public research org
SIB06	Istituto Nazionale di Fisica Nucleare	Italy	University/ public research org
SIB06	Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento	Portugal	University/ public research org
SIB07	The Chancellor, Masters and Scholars of the University of Cambridge	United Kingdom	University/ public research org
SIB07	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB07	Latvijas Universitate	Latvia	University/ public research org
SIB07	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
SIB08	Technische Universiteit Delft	Netherlands	University/ public research org
SIB08	Università degli Studi di Torino	Italy	University/ public research org
SIB08	BIAS Bremer Institut für angewandte Strahltechnik GmbH	Germany	Industry
SIB09	Universiteit Gent	Belgium	University/ public research org
SIB09	Leibniz-Institut fuer Festkoerper- und Werkstoffforschung Dresden e.V.	Germany	University/ public research org
SIB10	Politecnico di Torino	Italy	University/ public research org
SIB51	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
SIB51	Linköpings universitet	Sweden	University/ public research org
SIB51	Universitaet Bielefeld	Germany	University/ public research org
SIB53	Politechnika Slaska	Poland	University/ public research org
SIB53	Uniwersytet Zielonogorski	Poland	University/ public research org
SIB55	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
SIB56	Politecnico di Torino	Italy	University/ public research org
SIB56	Bundesanstalt fuer Arbeitsschutz und Arbeitsmedizin	Germany	University/ public research org
SIB57	Tallinna Tehnikaulikool	Estonia	University/ public research org
SIB57	Universitetet I Oslo	Norway	University/ public research org
SIB57	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB58	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	Germany	University/ public research org
SIB59	Høgskolen i Sørøst-Norge	Norway	University/ public research org
SIB60	Technische Universiteit Delft	Netherlands	University/ public research org
SIB60	Gottfried Wilhelm Leibniz Universität Hannover	Germany	University/ public research org
SIB60	Rheinische Friedrich-Wilhelms-Universitaet Bonn	Germany	University/ public research org
SIB60	Technische Universitaet Braunschweig	Germany	University/ public research org
SIB61	Universita Degli Studi del Piemonte Orientale Amedeo Avogadro	Italy	University/ public research org
SIB61	Aalto-korkeakoulusäätiö sr	Finland	University/ public research org
SIB61	Fyzikální ústav AV ČR, v.v.i.	Czech Republic	University/ public research org
SIB62	University of Leeds	United Kingdom	University/ public research org
SIB62	Katholieke Universiteit Leuven	Belgium	University/ public research org
SIB62	České Vysoké Učení Technické v Praze	Czech Republic	University/ public research org
SIB62	Forschungsverbund Berlin e.V.	Germany	University/ public research org
SIB64	Oulun Yliopisto	Finland	University/ public research org
SIB64	Università degli Studi di Cassino e del Lazio Meridionale	Italy	University/ public research org

6.2 Unfunded Partners

There were 158 participations by 129 organisations as unfunded partners.

Figure 36: Unfunded Partners

Project	Organisation	Country	Organisation type
ENG01	E + E Elektronik	Austria	Industry
ENG03	Elengy SA	France	Industry
ENG03	E.ON Ruhrgas AG	Germany	Industry
ENG03	Enagas SA	Spain	Industry
ENG04	Technische Universitaet Braunschweig	Germany	University/ public research org
ENG04	Technische Universitaet Clausthal	Germany	University/ public research org
ENG05	Universite Paul Sabatier Toulouse III	France	University/ public research org
ENG05	Technische Universitaet Ilmenau	Germany	University/ public research org
ENG05	Centro per la Conservazione ed il Restauro dei Beni Culturali "LA VENARIA REALE"	Italy	University/ public research org
ENG07	Trench France SAS	France	Industry
ENG51	Keysight Technologies GmbH	Austria	Industry
ENG51	AZUR SPACE Solar Power GmbH	Germany	Industry
ENG51	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
ENG52	Seconda Università degli Studi di Napoli	Italy	University/ public research org
ENG52	Slovenská technická univerzita v Bratislave	Slovakia	University/ public research org
ENG53	PANalytical B.V.	Netherlands	Industry
ENG54	HC Photonics Corporation Limited	Taiwan, Province of China	Industry
ENG55	Scuola Universitaria Professionale della Svizzera Italiana (SUPSI)	Switzerland	University/ public research org
ENG55	TÜV Rheinland Energie und Umwelt GmbH	Germany	Industry
ENG56	Mitutoyo CTL Germany GmbH	Germany	Industry
ENG56	Carl Zeiss Industielle Messtechnik GmbH	Germany	Industry
ENG56	MDM Metrosoft S.r.l.	Italy	Industry
ENG56	Hexagon Metrology GmbH	Germany	Industry
ENG58	KEMA Nederland BV	Netherlands	Industry
ENG58	Shell Global Solutions International B.V.	Netherlands	Industry
ENG58	Industrial Tomography Systems Plc	United Kingdom	Industry
ENG59	Shell Global Solutions International B.V.	Netherlands	Industry
ENG60	Shell Global Solutions International B.V.	Netherlands	Industry
ENG60	Oil & Gas Measurement Limited	United Kingdom	Industry
ENG62	OSRAM GmbH	Germany	Industry
ENG63	Technische Universitaet Clausthal	Germany	University/ public research org
ENG63	Fundacion Circe Centro de investigacion de recursos y consumos energeticos	Spain	University/ public research org
ENV03	CMS Ing. Dr. Schreder GmbH	Austria	Industry
ENV03	Kipp & Zonen BV	Netherlands	Industry
ENV04	Bergische Universitaet Wuppertal	Germany	University/ public research org
ENV04	Deutsches Zentrum fuer Luft- und Raumfahrt eV	Germany	Industry
ENV04	Forschungszentrum Juelich GmbH	Germany	Industry
ENV04	Maanmittauslaitos	Finland	University/ public research org
ENV07	Uniwersytet Wroclawski	Poland	University/ public research org
ENV07	Aarhus Universitet	Denmark	University/ public research org
ENV07	Chalmers tekniska hoegskola AB	Sweden	University/ public research org

ENV08	Istituto Superiore per la Protezione e la Ricerca Ambientale	Italy	University/ public research org
ENV53	Bergische Universitaet Wuppertal	Germany	University/ public research org
ENV53	University College London	United Kingdom	University/ public research org
ENV53	Science and Technology Facilities Council	United Kingdom	University/ public research org
ENV53	Deutsches Zentrum fuer Luft- und Raumfahrt eV	Germany	Industry
ENV53	Forschungszentrum Juelich GmbH	Germany	Industry
ENV53	Maanmittauslaitos	Finland	University/ public research org
ENV54	Agence nationale pour la gestion des dechets radioactifs	France	Other (e.g. government)
ENV54	NUVIA a.s.	Czech Republic	Industry
ENV54	Electricite de France S.A	France	Industry
ENV57	Institut de Radioprotection et de Surete Nucleaire	France	University/ public research org
ENV57	Bundesamt fuer Strahlenschutz	Germany	Other (e.g. government)
ENV58	Service hydrographique et océanographique de la Marine	France	Other (e.g. government)
ENV59	Kipp & Zonen BV	Netherlands	Industry
EXL02	The University System of Maryland Foundation, Inc.	United States	University/ public research org
HLT02	Academisch Medisch Centrum bij de Universiteit van Amsterdam	Netherlands	Industry
HLT03	Hochschule Merseburg	Germany	University/ public research org
HLT03	M V Lomonosov Moscow State University	Russian Federation	University/ public research org
HLT03	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
HLT03	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain	University/ public research org
HLT11	Lunds Universitet	Sweden	University/ public research org
HLT11	University College London	United Kingdom	University/ public research org
HLT11	The Christie NHS Foundation Trust	United Kingdom	University/ public research org
HLT11	Velindre National Health Service Trust	United Kingdom	University/ public research org
HLT11	Istituti Fisioterapici Ospitalieri	Italy	University/ public research org
HLT11	Istituto Superiore di Sanità	Italy	University/ public research org
HLT11	Azienda Unità Sanitaria Locale Latina	Italy	University/ public research org
HLT11	Institute of Cancer Research - Royal Cancer Hospital	United Kingdom	University/ public research org
IND01	Endress + Hauser Wetzer GmbH Co KG	Germany	Industry
IND01	GDF Suez	France	Industry
IND01	Meggitt (UK) Limited	United Kingdom	Industry
IND01	Commissariat à l'énergie atomique et aux énergies alternatives	France	University/ public research org
IND02	Keysight Technologies GmbH	Austria	Industry
IND03	Technische Universitaet Clausthal	Germany	University/ public research org
IND05	CSM Instruments	Switzerland	Industry
IND05	NGF EUROPE Limited	United Kingdom	Industry
IND05	Schwarzer Norbert	Germany	University/ public research org
IND06	AIT Austrian Institute of Technology GmbH	Austria	University/ public research org
IND06	ID Quantique SA	Switzerland	Industry
IND07	PANalytical B.V.	Netherlands	Industry
IND07	Solarprint Limited	Ireland	Industry
IND07	TOTAL S.A.	France	Industry
IND10	Technische Universitaet Ilmenau	Germany	University/ public research org
IND10	XPRESS Precision Engineering B.V.	Netherlands	Industry
IND10	IBS Precision Engineering bv	Netherlands	Industry

IND10	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek TNO	Netherlands	Industry
IND10	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND11	Friedrich-Alexander-Universität Erlangen - Nürnberg	Germany	University/ public research org
IND11	Alicona Imaging GmbH	Austria	Industry
IND11	Teknologian tutkimuskeskus VTT	Finland	University/ public research org
IND12	Danfoss A/S	Denmark	Industry
IND12	INFICON GmbH	Germany	Industry
IND12	INFICON AG	Liechtenstein	Industry
IND12	Lazzero Tecnologie Srl	Italy	Industry
IND12	VACOM Vakuum Komponenten & Messtechnik GmbH	Germany	Industry
IND13	Ecole Nationale Superieure de Mecanique et d'Aerotechnique	France	University/ public research org
IND13	Fraunhofer-Gesellschaft zur Foerderung der angewandten Forschung e.V.	Germany	University/ public research org
IND14	Keysight Technologies Deutschland GmbH	Germany	Industry
IND14	Componentes Hibridos y Laseres de Fibra Optica S.L.	Spain	Industry
IND15	Chalmers tekniska hoegskola AB	Sweden	University/ public research org
IND15	ION-TOF Technologies GmbH	Germany	Industry
IND15	Kratos Analytical Limited	United Kingdom	Industry
IND15	Scienion AG	Germany	Industry
IND15	Specs Surface Nano Analysis GmbH	Germany	Industry
IND15	FOCUS GmbH Geräte zur Elektronenspektroskopie und Oberflächenanalytik	Germany	Industry
IND16	Agilent Technologies UK Limited	United Kingdom	Industry
IND17	Nanocomp Oy Ltd	Finland	Industry
IND51	Keysight Technologies Deutschland GmbH	Germany	Industry
IND51	Dassault Aviation SA	France	Industry
IND53	The University of Sheffield	United Kingdom	University/ public research org
IND53	SIOS Meßtechnik GmbH	Germany	Industry
IND53	Airbus Operations Limited	United Kingdom	Industry
IND54	The University of Liverpool	United Kingdom	University/ public research org
IND55	Muquans	France	Industry
IND56	Medtronic Bakken Research Center B.V.	Netherlands	industry
IND56	Smith & Nephew Medical Limited	United Kingdom	Industry
IND59	Science and Technology Facilities Council	United Kingdom	University/ public research org
IND59	XPRESS Precision Engineering B.V.	Netherlands	Industry
IND59	IBS Precision Engineering bv	Netherlands	Industry
IND59	LEGO System A/S	Denmark	Industry
IND59	Novo Nordisk A/S	Denmark	Industry
IND59	Robert Bosch GmbH	Germany	Industry
IND62	Fundacion Tekniker	Spain	University/ public research org
IND62	Universidad de Zaragoza	Spain	University/ public research org
IND62	Magnicon GmbH	Germany	Industry
IND62	Daimler AG	Germany	Industry
IND62	EMO - Orodjarna d.o.o.	Slovenia	industry
IND62	Gorenje Orodjarna, d.o.o., Velenje, Partizanska 12	Slovenia	industry
IND62	VEPLAS Velenjska Plastika d.d.	Slovenia	Industry
IND62	RollResearch International Oy	Finland	Industry

IND63	HC Photonics Corporation Limited	Taiwan, Province of China	Industry
NEW01	ION-TOF Technologies GmbH	Germany	Industry
NEW02	Naturwissenschaftliches und Medizinisches Institut an der Universitaet Tuebingen	Germany	University/ public research org
NEW02	Indian Institute of Science	India	University/ public research org
NEW06	Hexagon Metrology PTS GmbH	Germany	Industry
NEW06	Mitutoyo CTL Germany GmbH	Germany	Industry
NEW06	Werth Messtechnik GmbH	Germany	Industry
NEW06	Carl Zeiss Industielle Messtechnik GmbH	Germany	Industry
NEW07	ROHDE & SCHWARZ GmbH & Co. Kommanditgesellschaft	Germany	Industry
NEW07	Sensor- und Lasertechnik - Dr. Werner Bohmeyer	Germany	Industry
NEW08	Magnicon GmbH	Germany	Industry
NEW08	Helsingin Yliopisto	Finland	University/ public research org
NEW09	aixACCT Systems GmbH	Germany	Industry
SIB01	Universidad De Valladolid	Spain	University/ public research org
SIB02	CESNET, Zajmove Sdruzeni Pravnickych OSOB	Czech Republic	University/ public research org
SIB03	Leibniz-Institut für Oberflächenmodifizierung	Germany	University/ public research org
SIB03	National Institute of Advanced Industrial Science and Technology	Japan	University/ public research org
SIB06	Politecnico di Milano	Italy	University/ public research org
SIB09	General Secretariat of Information Systems, Hellenic Ministry of Finance	Greece	Other (e.g. government)
SIB10	Universidad De Cantabria	Spain	University/ public research org
SIB53	esz AG calibration & metrology	Germany	Industry
SIB58	Fundacion Tekniker	Spain	University/ public research org
SIB58	Möller-Wedel Optical GmbH	Germany	Industry
SIB58	Fagor Automation S Coop Ltda	Spain	Industry
SIB58	National Institute of Advanced Industrial Science and Technology	Japan	University/ public research org
SIB62	ROHDE & SCHWARZ GmbH & Co. Kommanditgesellschaft	Germany	Industry
SIB62	Keysight Technologies Belgium BVBA	Belgium	Industry

6.3 Collaborators

There were 683 participations by 620 organisations as collaborators.

Figure 37: Collaborators

Project	Organisation	Country	Organisation type
ENG01	NET4GAS	Czech Republic	Industry
ENG01	Transgaz	Romania	Industry
ENG01	Enagas	Spain	Industry
ENG01	Michell Instruments	United Kingdom	Industry
ENG01	Valdemingómez Technological Park (VTP)	Spain	Industry
ENG01	MBW Calibrations	Switzerland	Industry
ENG01	University of Valladolid	Spain	University /public research org
ENG01	Technical University of Darmstadt	Germany	University /public research org
ENG02	VTT Technical Research Centre of Finland	Finland	Industry
ENG02	Aalto University	Finland	University /public research org
ENG04	Vestas	Denmark	Industry
ENG04	SEPS a.s.	Slovakia	Industry
ENG04	Aidon Oy	Finland	Industry
ENG04	Stenbakken	United States	Industry
ENG04	Mitox Oy	Finland	Industry
ENG04	University of Zaragoza and Foundation CIRCE	Spain	University /public research org
ENG07	ABB High Voltage Cables	Sweden	Industry
ENG07	Schniewindt Gmbh & Co. KG	Germany	Industry
ENG07	Aalto University	Finland	University /public research org
ENG08	CAEN S.p.A.	Italy	Industry
ENG09	Strathclyde University	United Kingdom	University /public research org
ENG51	InPact	France	Industry
ENG51	Scientec	France	Industry
ENG51	Isofoton SA	Spain	Industry
ENG51	Instytut Technologii Materia?ów Elektronicznych	Poland	Industry
ENG51	Naps Systems OY	Finland	Industry
ENG51	Politécnica – Instituto de Energia Solar	Spain	University /public research org
ENG51	University of Jaen	Spain	University /public research org
ENG51	University of Malaga	Spain	University /public research org
ENG51	Instituto de Sistema Fotovoltaicos de Concentracion	Spain	University /public research org
ENG52	FTM - Fabbrica Trasformatori di misura	Italy	Industry
ENG52	Centre for renewable energy sources and saving	Greece	Other (e.g. government)
ENG52	Università di Padova	Italy	University /public research org
ENG52	University of Thrace	Greece	University /public research org
ENG53	Merck Chemicals Ltd.	United Kingdom	Industry
ENG53	LINSEIS Messgeräte GmbH	Germany	Industry
ENG53	von Ardenne	Germany	Industry
ENG53	Semimetrics Ltd.	United Kingdom	Industry
ENG53	Accurion GmbH	Germany	Industry
ENG53	SENTECH Instruments GmbH	Germany	Industry
ENG53	NMI - National Microelectronics Institute	United Kingdom	Other (e.g. government)
ENG53	EMPA	Switzerland	University /public research org

ENG54	Gasum	Finland	Industry
ENG55	Logica E.M. S.A.	Portugal	Industry
ENG55	IKS Photovoltaik GmbH	Germany	Industry
ENG55	Naps Systems Oy	Finland	Industry
ENG55	PV-Engineering GmbH	Germany	Industry
ENG55	solarklima e. K. - Solar-Sachverständigenbüro	Germany	Industry
ENG55	WAVELABS Solar Metrology Systems GmbH	Germany	Industry
ENG56	Rolls-Royce	United Kingdom	Industry
ENG56	ZF Services UK Ltd.	United Kingdom	Industry
ENG56	Schaeffler Technologies AG & Co. KG	Germany	Industry
ENG56	The Timken Company	United States	Industry
ENG56	Allen Gearing Solutions	United Kingdom	Industry
ENG56	Contact Gearing	United Kingdom	Industry
ENG56	Fred Olsen Renewables	United Kingdom	Industry
ENG56	Ludwig Nano Präzision GmbH	Germany	Industry
ENG56	Finnish Wind Power Association	Finland	Other (e.g. government)
ENG56	United Kingdom Accredidation Service	United Kingdom	Other (e.g. government)
ENG56	British Gear Asslociation	United Kingdom	Other (e.g. government)
ENG56	Verband Deutscher Maschinen- und Anlagenbau e.V.	Germany	Other (e.g. government)
ENG56	Verein Deutscher Ingenieure e.V.	Germany	Other (e.g. government)
ENG58	OneSubsea	Norway	Industry
ENG58	Atout Process	United Kingdom	Industry
ENG59	Statoil ASA	Norway	Industry
ENG59	British Petrol Exp Op Co Ltd	United Kingdom	Industry
ENG59	M-I Swaco	Norway	Industry
ENG59	Thermo Electron (Karlsruhe) GmbH	Germany	Industry
ENG59	Brookfield Engineering Laboratories, Inc.	United States	Industry
ENG59	Anton Paar GmbH	Austria	Industry
ENG59	IFP Energies nouvelles	France	University /public research org
ENG59	The Swedish Institute for Food and Biotechnology	Sweden	University /public research org
ENG59	Centro de Ciências Moleculares e Materiais	Portugal	University /public research org
ENG59	Faculty of Sciences and Technology - Centre for Research in Materials	Portugal	University /public research org
ENG60	GE Sensing	United Kingdom	Industry
ENG60	Emerson MM	Netherlands	Industry
ENG60	Enagas	Spain	Industry
ENG60	Gasunie	Netherlands	Industry
ENG60	Kaiser optical systems	United States	Industry
ENG60	Kongsberg	Norway	Industry
ENG60	Krohne	Netherlands	Industry
ENG60	Mustang Sampling	United States	Industry
ENG60	National Grid (UK)	United Kingdom	Industry
ENG60	Gasnaturalfenosa	Spain	Industry
ENG60	E&H	Switzerland	Industry
ENG60	Cameron Caldon	United Kingdom	Industry
ENG60	E.on Ruhrgas	Germany	Industry
ENG63	Sakarya Elektrik (SEDAŞ)	Turkey	Industry
ENV01	Air Liquide	United States	Industry

ENV01	Air Products	United Kingdom	Industry
ENV01	Alphasense	United Kingdom	Industry
ENV01	Praxair	Belgium	Industry
ENV01	Saes Pure Gas	United States	Industry
ENV01	Linde AG, Linde Gas Division	Germany	Industry
ENV01	Airgas Inc.	United States	Industry
ENV01	CAIRPOL	France	Industry
ENV01	IM2NP	France	Industry
ENV01	Sensirion	Switzerland	Industry
ENV01	Unitec	Italy	Industry
ENV01	Picarro	United States	Industry
ENV01	Takachiho	Japan	Industry
ENV01	SilcoTek	United States	Industry
ENV01	TigerOptics	United States	Industry
ENV01	LNI Schmidlin	Switzerland	Industry
ENV01	Environics	United States	Industry
ENV01	Gradko International	United Kingdom	Industry
ENV01	SIAD	Italy	Industry
ENV01	IngenierosAsesores	Spain	Industry
ENV01	Aalto University	Finland	University /public research org
ENV01	University of Barcelona	Spain	University /public research org
ENV02	Robert Bosch GmbH	Germany	Industry
ENV02	Pegasor Oy Ltd.	Finland	Industry
ENV02	Matter Aerosol AG - Testo	Switzerland	Industry
ENV02	TSI GmbH	Germany	Industry
ENV02	MAHA GmbH & Co. KG.	Germany	Industry
ENV03	EKO Instruments Europe B.V.	Netherlands	Industry
ENV03	World Meteorological Organisation (WMO)	Other	Other (e.g. government)
ENV03	ARPA Valle D'Aosta	Italy	Other (e.g. government)
ENV03	Deutscher Wetterdienst (DWD)	Germany	University /public research org
ENV03	Aristotele University of Thessaloniki	Greece	University /public research org
ENV04	Surrey Satellite Technologies Ltd (SSTL)	United Kingdom	Industry
ENV04	Karlsruhe Institute of Technology (KIT)	Germany	University /public research org
ENV04	MET Office: An Executive Agency of the Ministry of Defence (MET office)	United Kingdom	Other (e.g. government)
ENV04	Rutherford Appleton Laboratory (RAL)	United Kingdom	University /public research org
ENV05	SCOR	Other	University /public research org
ENV05	IAPSO	Other	University /public research org
ENV05	IUPAC	Other	University /public research org
ENV05	IAPWS	Other	University /public research org
ENV05	Instituto Hidrografico	Portugal	University /public research org
ENV05	Ifremer	France	University /public research org
ENV05	IOW (Leibniz Institute of Baltic sea research)	Germany	University /public research org
ENV05	MARUM	Germany	University /public research org
ENV05	GEOMAR	Germany	University /public research org
ENV05	University of British Columbia/ Joint Committee on seawater	Canada	University /public research org
ENV05	Leibniz Universität Hannover	Germany	University /public research org
ENV05	SCRIPPS	United States	University /public research org

ENV07	Spanish Meteorology Agency	Spain	Other (e.g. government)
ENV07	ISTI	Other	Other (e.g. government)
ENV07	GRUAN	Other	Other (e.g. government)
ENV07	Climate Consulting	Italy	Other (e.g. government)
ENV07	Royal Meteorological Institute of Belgium	Belgium	Other (e.g. government)
ENV07	ARPA Valle d'Aosta	Italy	Other (e.g. government)
ENV07	ARPAS - Sardegna	Italy	Other (e.g. government)
ENV07	ARPA Lombardia	Italy	Other (e.g. government)
ENV07	Società Meteorologica Italiana	Italy	Other (e.g. government)
ENV07	Slovenia Environment Agency	Slovenia	Other (e.g. government)
ENV07	CERIS-CNR	Italy	University /public research org
ENV07	Ev-K2-CNR	Italy	University /public research org
ENV07	Turkish State Meteorological Service	Turkey	University /public research org
ENV07	Finnish Meteorological Institute	Finland	University /public research org
ENV07	MetOffice	United Kingdom	University /public research org
ENV07	Consiglio Nazionale delle Ricerche-CNR / Istituto per le Macchine agricole e Movimento Terra, IMAMOTER	Italy	University /public research org
ENV07	Osservatorio di Milano Duomo	Italy	University /public research org
ENV07	Istituto di Scienze dell'Atmosfera e del Clima – Consiglio Nazionale delle Ricerche (ISAC-CNR)	Italy	University /public research org
ENV07	C3	Spain	University /public research org
ENV07	University of Reading	United Kingdom	University /public research org
ENV07	National Centre for Atmospheric Science (NCAS) School of Earth and Environment	United Kingdom	University /public research org
ENV07	Università Cattolica del Sacro Cuore - Facoltà Agraria	Italy	University /public research org
ENV07	Dipartimento di Scienze della Terra – Università degli Studi di Torino	Italy	University /public research org
ENV07	Università degli Studi di Torino, Dip. Fisica Generale	Italy	University /public research org
ENV07	Earth Temperature Network- University of Edinburgh	United Kingdom	University /public research org
ENV08	Universidad de Oviedo	Spain	University /public research org
ENV09	Eckert&Ziegler Nuclitec GmbH	Germany	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	Sellafield plc	United Kingdom	Industry
ENV09	VUHZ, a.s.	Czech Republic	Industry
ENV09	Research Centre Rez Ltd	Czech Republic	Industry
ENV09	Research Centre Rez Ltd	Czech Republic	University /public research org
ENV09	UJV Rez a.s.	Czech Republic	University /public research org
ENV09	Faculty of Nuclear Science and Physical Engineering	Czech Republic	University /public research org
ENV52	VICI AG International	Switzerland	Industry
ENV52	SAES Getters	Italy	Industry
ENV52	Lni Schmidlin	Switzerland	Industry
ENV52	Fine Metrology S.R.L.S.	Italy	Industry
ENV52	RHUL	United Kingdom	University /public research org
ENV53	University of Miami	United States	Industry
ENV53	Surrey Satellite Technology Ltd	United Kingdom	Industry

ENV53	Alexander Cede	Austria	Other (e.g. government)
ENV53	Institute for Environment and Sustainability	Italy	University /public research org
ENV53	National Aeronautical and Space Administration	United States	University /public research org
ENV53	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	France	University /public research org
ENV53	Laboratoire d'Océanographie de Villefranche	France	University /public research org
ENV53	Tartu Observatory	Estonia	University /public research org
ENV53	Centre National d'Etudes Spatiales (CNES)	France	University /public research org
ENV53	University of Southampton	United Kingdom	University /public research org
ENV53	UNIVERSITÉ PIERRE ET MARIE CURIE	France	University /public research org
ENV53	University of Leicester	United Kingdom	University /public research org
ENV53	University of Reading	United Kingdom	University /public research org
ENV53	Chinese Academy of Sciences	China	University /public research org
ENV53	Oxford University	United Kingdom	University /public research org
ENV54	CEA-LIST	France	Industry
ENV54	EDU	Czech Republic	Industry
ENV54	Sellafield	United Kingdom	Industry
ENV54	Canberra	France	Industry
ENV54	LLWR	United Kingdom	Industry
ENV54	Canberra	France	Industry
ENV54	Sogin	Italy	Industry
ENV54	Nucleco	Italy	Industry
ENV54	LabLogic Systems Ltd	United Kingdom	Industry
ENV54	UB	Romania	University /public research org
ENV54	FJFI	Czech Republic	University /public research org
ENV55	Tiger Optics	United States	Industry
ENV55	VICI International	Switzerland	Industry
ENV55	Picarro Inc.	United States	Industry
ENV55	LNI Schmidlin SA	Switzerland	Industry
ENV55	AERODYNE Research	United States	Industry
ENV55	Green Grass - Atmospheric Environment Expert Ltd.	Hungary	Industry
ENV55	SilcoTek GmbH	Germany	Industry
ENV55	Los Gatos Research	United States	Industry
ENV55	Gradko Environmental	United Kingdom	Industry
ENV55	Owlstone Ltd.	United Kingdom	Industry
ENV55	LSE Monitors BV, Groningen	Netherlands	Industry
ENV55	Takachiho Chemical industrial Co., Ltd.	Japan	Industry
ENV55	fine metrology S.r.l.s	Italy	Industry
ENV55	ECOPHYSICS AG	Switzerland	Industry
ENV55	SAES Getters	Italy	Industry
ENV55	Staatliches Gewerbeaufsichtsamt Hildesheim	Germany	Other (e.g. government)
ENV55	Fondazione Salvatore Magueri	Italy	University /public research org
ENV55	INRA	France	University /public research org
ENV55	National Research Council - Institute for Agricultural and Forest Systems in the Mediterranean	Italy	University /public research org
ENV55	University of Wuppertal, Physical Chemsitry	Germany	University /public research org
ENV56	Restek	Germany	Industry
ENV56	Linde	Germany	Industry

ENV56	Air Products	Belgium	Industry
ENV56	Air Liquide	United States	Industry
ENV56	SAES	United States	Industry
ENV56	Takachiho	Japan	Industry
ENV56	Silco Tek	United States	Industry
ENV56	FINE Metrology	Italy	Industry
ENV56	Nano Sense	France	Industry
ENV56	Recordum	Austria	Industry
ENV56	Ion Science	Italy	Industry
ENV56	Aeroqual	New Zealand	Industry
ENV56	Gradko	United Kingdom	Industry
ENV56	Markes International	United Kingdom	Industry
ENV56	Entegris	United States	Industry
ENV56	Bentekk	Germany	Industry
ENV56	Schmidlin	Switzerland	Industry
ENV56	CNR-IMM	Italy	University /public research org
ENV56	Department of Physics, Chemistry and Biology at Linköping University	Sweden	University /public research org
ENV57	Saphymo	Germany	Industry
ENV57	LUBW	Germany	Other (e.g. government)
ENV57	Czech Technical University Prague - Faculty of Nuclear Science and Physical Engineering	Czech Republic	University /public research org
ENV58	CAL Power S.R.L.	Italy	Industry
ENV58	AEMET	Spain	Other (e.g. government)
ENV58	Climate Consulting	Italy	Other (e.g. government)
ENV58	ARPA Piemonte	Italy	Other (e.g. government)
ENV58	ARPA Valle d'Aosta	Italy	Other (e.g. government)
ENV58	ARPAS - Sardegna	Italy	Other (e.g. government)
ENV58	ARPA Lombardia	Italy	Other (e.g. government)
ENV58	Slovenia Environment Agency	Slovenia	Other (e.g. government)
ENV58	Società Meteorologica Italiana	Italy	Other (e.g. government)
ENV58	Royal Meteorological Institute of Belgium	Belgium	Other (e.g. government)
ENV58	Osservatorio di Milano Duomo	Italy	Other (e.g. government)
ENV58	ISTI	United States	Other (e.g. government)
ENV58	Slovak Hydrometeorological Institute	Slovakia	Other (e.g. government)
ENV58	GRUAN	Germany	Other (e.g. government)
ENV58	Italian Air Force	Italy	Other (e.g. government)
ENV58	CERIS-CNR	Italy	University /public research org
ENV58	Istituto per le Macchine agricole e Movimento Terra, , Consiglio Nazionale delle Ricerche, IMAMOTER-CNR	Italy	University /public research org
ENV58	Istituto di Scienze dell'Atmosfera e del Clima – Consiglio Nazionale delle Ricerche (ISAC-CNR)	Italy	University /public research org
ENV58	LMD/CNRS, Ecole Polytechnique	France	University /public research org
ENV58	Università Cattolica del Sacro Cuore - Facoltà Agraria	Italy	University /public research org
ENV58	Dipartimento di Scienze della Terra – Università degli Studi di Torino	Italy	University /public research org
ENV58	National Centre for Atmospheric Science (NCAS) School of Earth and Environment	United Kingdom	University /public research org
ENV58	Università degli Studi di Torino, Dip. Fisica Generale	Italy	University /public research org

ENV58	Earth Temperature Network- University of Edinburgh	United Kingdom	University /public research org
ENV59	Arctic Research Center (FMI)	Finland	University /public research org
ENV59	Deutscher Wetterdienst (DWD)	Germany	University /public research org
ENV59	Deutscher Wetterdienst (DWD)	Germany	University /public research org
ENV59	National Oceanic and Atmospheric Administration	United States	University /public research org
ENV59	Czech Hydrometeorological Institute	Czech Republic	University /public research org
ENV59	Agencia Estatal de Meteorologia (AEMET)	Spain	University /public research org
ENV59	Medical University Insbruck	Austria	University /public research org
ENV59	CNRS (Centre National de Research schientifique), UPMC&PSL Research University	France	University /public research org
ENV60	Quantitech Ltd	United Kingdom	Industry
ENV60	Gasmet	Finland	Industry
ENV60	EON New Build and technology Ltd	United Kingdom	Industry
ENV60	Hessisches Landesamt für Umwelt und Geologie	Germany	Other (e.g. government)
EXL02	University of Wurzburg	Germany	University /public research org
EXL02	Terchnical University of Berlin	Germany	University /public research org
EXL04	University of Naples "Federico II"	Italy	University /public research org
EXL04	Hamburg University	Germany	University /public research org
EXL04	Halle-Wittenberg University	Germany	University /public research org
EXL04	TU München	Germany	University /public research org
HLT01	Acoustic Metrology Limited	United Kingdom	Industry
HLT01	Otodynamics Ltd.	United Kingdom	Industry
HLT01	Guymark UK	United Kingdom	Industry
HLT01	HNO Klinik Regensburg	Germany	Other (e.g. government)
HLT01	Marmara University	Turkey	University /public research org
HLT01	Warsaw University of Technology	Poland	University /public research org
HLT01	Royal Liverpool University Hospital	United Kingdom	University /public research org
HLT01	Institute of Technical Acoustics	Germany	University /public research org
HLT01	Royal Free Hampstead NHS Trust	United Kingdom	University /public research org
HLT02	John Radcliffe Hospital	United Kingdom	Other (e.g. government)
HLT02	John Radcliffe Hospital	United Kingdom	Other (e.g. government)
HLT02	Helmholtz-Zentrum Berlin	Germany	University /public research org
HLT03	US Food and Drugs Administration	United States	Other (e.g. government)
HLT04	LGC	United Kingdom	Industry
HLT04	Scienion	Germany	Industry
HLT04	Plasmore	Italy	Industry
HLT04	Orion Diagnostica	Finland	Industry
HLT04	JRC, IHCP, EC	Other	Other (e.g. government)
HLT04	CIN2 CSIC	Spain	Other (e.g. government)
HLT04	Nanotechnology Industries Assocation (NIA)	United Kingdom	Other (e.g. government)
HLT04	International Iberian Nanotechnology Lab (INL)	Portugal	University /public research org
HLT04	NESAC/BIO	United States	University /public research org
HLT04	University of Utah	United States	University /public research org
HLT04	Materials & Surface Science Institute, University of Limerick	Ireland	University /public research org
HLT04	Charité	Germany	University /public research org
HLT04	University of Nottingham	United Kingdom	University /public research org
HLT04	Lausitz University	Germany	University /public research org

HLT05	Aqura	Germany	Industry
HLT05	Instand e.V.	Germany	Other (e.g. government)
HLT05	Instand e.V.	Germany	Other (e.g. government)
HLT06	University Medical Centre of Utrecht	Netherlands	Other (e.g. government)
HLT06	STUK (Radiation and Nuclear Safety Authority)	Finland	Other (e.g. government)
HLT06	Bundesamt für Strahlenschutz (Radiation Safety Authority)	Germany	Other (e.g. government)
HLT06	Deutsches Krebsforschungszentrum (DKFZ)	Germany	University /public research org
HLT06	Politecnico di Torino	Italy	University /public research org
HLT07	B.braun	Netherlands	Industry
HLT07	B.braun	Portugal	Industry
HLT07	Bronkhorst High-Tech	Netherlands	Industry
HLT08	University Clinic of Respiratory and Allergic Diseases	Slovenia	University /public research org
HLT09	Carl Zeiss Meditec AG	Germany	Industry
HLT09	PTW - Freiburg Germany	Germany	Industry
HLT09	IBA	Germany	Industry
HLT09	Tampere University Hospital	Finland	Other (e.g. government)
HLT09	Helsinki University Central Hospital	Finland	Other (e.g. government)
HLT09	UK S-H, campus Kiel	Germany	University /public research org
HLT09	University degli studi di Roma "Tor vergata"	Italy	University /public research org
HLT09	Czech Technical University in Prague	Czech Republic	University /public research org
HLT10	IBM	United Kingdom	Industry
HLT11	Royal Surrey County Hospital	United Kingdom	Other (e.g. government)
HLT11	University Hospital Southampton	United Kingdom	Other (e.g. government)
HLT11	S. Maria Nuova Hospital (ASMN-IRCCS)	Italy	Other (e.g. government)
HLT11	Nuclear Medicine Royal Victoria Hospital	United Kingdom	Other (e.g. government)
HLT11	Belfast Hospitals	United Kingdom	Other (e.g. government)
HLT11	VUMC	Netherlands	Other (e.g. government)
HLT11	Gurutzeta-Cruces Hospital	Spain	Other (e.g. government)
HLT11	Fakultni nemocnice v Motole	Czech Republic	Other (e.g. government)
HLT11	Nemocnice Na Homolce	Czech Republic	Other (e.g. government)
HLT11	Sant' Andrea Hospital (SAH)	Italy	Other (e.g. government)
HLT11	"Theagenion" Cancer Hospital (TCH)	Greece	Other (e.g. government)
HLT11	University Hospital of Wuerzburg	Germany	Other (e.g. government)
HLT11	Hospital Beaujon	France	Other (e.g. government)
HLT11	ASMN-IRCCS	Italy	Other (e.g. government)
HLT11	Royal Surrey County Hospital	United Kingdom	Other (e.g. government)
HLT11	Physics Department St Lukes Hospital	Ireland	Other (e.g. government)
HLT11	Philips GmbH Innovative Technologies, Research Laboratories	Germany	Industry
HLT11	Eckert and Ziegler Nuclitec	Germany	Industry
HLT11	GE Medical Systems	Israel	Industry
HLT11	Sirtex Technology Pty Ltd	Australia	Industry
HLT11	Radioisotope Service Belfast Health & Social Care Trust	Ireland	Other (e.g. government)
HLT11	Erasmus MC	Netherlands	Other (e.g. government)
HLT11	Erasmus MC	Netherlands	Other (e.g. government)
HLT11	Erasmus MC	Netherlands	Other (e.g. government)
HLT11	National Center for Nuclear Research	Poland	University /public research org

HLT11	IMSERM UMR	France	University /public research org
HLT11	(ICRNA) Institut Regional du Cancer Nantes-Atlantique	France	University /public research org
HLT11	John Hopkins University	United States	University /public research org
HLT11	University of Ulm	Germany	University /public research org
HLT11	University of Potsdam	Germany	University /public research org
HLT11	Department of Physics, Nanoscience Center, University of Jyväskylä	Finland	University /public research org
IND01	Johnson Matthey	United Kingdom	Industry
IND01	Sisecam	Turkey	Industry
IND01	Erdemir	Turkey	Industry
IND01	Vitkovice	Czech Republic	Industry
IND01	Safina	Czech Republic	Industry
IND01	ZPA Nova Paka	Czech Republic	Industry
IND01	Omega	United Kingdom	Industry
IND01	Fraunhofer Institute	Germany	University /public research org
IND02	Emerson & Cuming Microwave Products N.V.	Belgium	Industry
IND02	Powerwave UK Ltd	United Kingdom	Industry
IND02	Rohde & Schwarz GmbH & Co. KG	Germany	Industry
IND02	Schlumberger Cambridge Research Ltd	United Kingdom	Industry
IND02	Infineon Technologies AG	Germany	Industry
IND02	Cyclops Technologies Ltd.	United Kingdom	Industry
IND02	Jožef Stefan Institute	Slovenia	University /public research org
IND02	Instytut Technologii Materia?ow Elektronicznych	Poland	University /public research org
IND02	University of Birmingham	United Kingdom	University /public research org
IND02	Warsaw University of Technology,	Poland	University /public research org
IND02	University of Nottingham	United Kingdom	University /public research org
IND02	University of Nova Gorica, Materials Research Laboratory	Slovenia	University /public research org
IND03	MAXIMATOR GmbH	Germany	Industry
IND03	WIKA Alexander Wiegand SE & Co. KG	Germany	Industry
IND03	PREMATLAK, a.s.	Slovakia	Industry
IND03	Hottinger Baldwin Messtechnik GmbH	Germany	Industry
IND03	PREMATLAK, a.s.	Slovakia	Industry
IND03	MAXIMATOR GmbH	Germany	Industry
IND03	WIKA Alexander Wiegand SE & Co. KG	Germany	Industry
IND03	Uhde High Pressure Technologies GmbH	Germany	Industry
IND03	Uhde High Pressure Technologies GmbH	Germany	Industry
IND03	Hottinger Baldwin Messtechnik GmbH	Germany	Industry
IND03	High Pressure & Force Metrology and Consultancy, Global technologically tubular testing	Netherlands	Other (e.g. government)
IND03	High Pressure & Force Metrology and Consultancy, Global technologically tubular testing	Netherlands	Other (e.g. government)
IND03	Commissariat à l'énergie atomique et aux énergies alternatives	France	University /public research org
IND03	Commissariat à l'énergie atomique et aux énergies alternatives	France	University /public research org
IND04	Acroni d.o.o, Slovenia	Slovenia	Industry
IND04	Arcelor Mittal Galati SA	Romania	Industry
IND04	U.S. Steel Košice - Labortest s.r.o	Slovakia	Industry
IND04	SN Seixal-Siderurgia Nacional, SA,	Portugal	Industry
IND04	Strore Steel d.o.o	Slovenia	Industry

IND04	UNESID (Unión de Empresas Siderúrgicas)	Spain	Other (e.g. government)
IND05	NGFE	United Kingdom	Industry
IND05	Anton Parr	Switzerland	Industry
IND05	SDS Ltd	United Kingdom	Industry
IND06	Polytechnic of Milan	Italy	University /public research org
IND06	Polytechnic of Milan	Italy	University /public research org
IND07	Plasma Quest Limited	United Kingdom	Industry
IND07	Accurion GmbH	Germany	Industry
IND07	Laboratorio "Materials and Devices for Microelectronics"	Italy	University /public research org
IND07	Rochester Institute of Technology	United States	University /public research org
IND08	Sensitec	Germany	Industry
IND08	NXP	Germany	Industry
IND08	Bartington Instruments Limited	United Kingdom	Industry
IND08	Innovent	Germany	University /public research org
IND08	RAL	United Kingdom	University /public research org
IND08	Ghent University	Belgium	University /public research org
IND08	Czech Technical University in Prague	Czech Republic	University /public research org
IND10	Mahr GmbH, Carl Zeiss Promenade 10, 07745 Jena	Germany	Industry
IND10	asphericon GmbH, Stockholmer Str. 9, 07747 Jena	Germany	Industry
IND11	KP Technology	United Kingdom	Industry
IND11	Hardide	United Kingdom	Industry
IND11	Teer Coatings	United Kingdom	Industry
IND11	Wallwork Heat Treatment Ltd	United Kingdom	Industry
IND11	University of Aarhus	Denmark	University /public research org
IND11	ICB UMR5209 - Optique en champ proche (OCP), Université de Bourgogne	France	University /public research org
IND12	Philips Medical Systems GmbH	Germany	Industry
IND12	Visteon-Autopal Services s.r.o.	Czech Republic	Industry
IND12	miCos GmbH	Germany	Industry
IND12	Reuter Technologie GmbH	Germany	Industry
IND12	Cinquepascal	Italy	Industry
IND12	Karlruhe Institute of Technology (KIT)	Germany	University /public research org
IND12	Labor für Vakuumtechnik, Technische Hochschule Mittelhessen	Germany	University /public research org
IND12	Russian Academy of Sciences Dorodnicyn Computing Center	Russian Federation	University /public research org
IND13	Magnicon GmbH	Germany	Industry
IND13	SIOS GmbH	Germany	Industry
IND13	TNO Science and Industry	Netherlands	University /public research org
IND14	EXFO	Canada	Industry
IND14	Diamond SA	Switzerland	Industry
IND14	EADS-SODERN	France	Industry
IND14	Astrium GmbH	Germany	Industry
IND14	Airbus España S. L.	Spain	Industry
IND14	Menlo Systems GmbH	Germany	Industry
IND14	NKT Photonics A/S	Denmark	Industry
IND14	Kayser-Threde GmbH	Germany	Industry
IND14	Oclaro Technology Limited	United Kingdom	Industry

IND14	IDIL Fibres optiques S.A.S.	France	Industry
IND14	FOCUS S.L.	Spain	Industry
IND14	Opticsvalley	France	Other (e.g. government)
IND14	European Space Agency	Netherlands	Other (e.g. government)
IND14	Direction Generale de l'Armement	France	Other (e.g. government)
IND14	Swiss National Committee of IEC and Cenelec	Switzerland	Other (e.g. government)
IND14	BSI British Standards	United Kingdom	Other (e.g. government)
IND15	Mettler-Toledo (Schweiz) GmbH	Switzerland	Industry
IND15	SÜD-CHEMIE AG	Germany	Industry
IND15	Thales Alenia Space SpA	Italy	Industry
IND15	AstraZeneca	United Kingdom	Industry
IND15	W. C. Heraeus GmbH	Germany	Industry
IND15	Bruker Nano	Germany	Industry
IND15	Tascon GmbH	Germany	Industry
IND15	Innopsys	France	Industry
IND15	Cambridge Display Technology	United Kingdom	Industry
IND15	Insplorion AB	Sweden	Industry
IND15	Thermo Fisher Scientific s.p.a.	Italy	Industry
IND15	Catal International	Other	University /public research org
IND15	Competence Center for Catalysis at Chalmers University of Technology KCK	Sweden	University /public research org
IND15	University of Nottingham	United Kingdom	University /public research org
IND16	Anritsu	United States	Industry
IND16	Astrium Satellites	Germany	Industry
IND16	Rohde & Schwarz GmbH & Co. KG	Germany	Industry
IND16	Jan Verspecht b.v.b.a.	Belgium	Industry
IND16	esz AG calibration & Metrology	Germany	Industry
IND16	Cambridge Wireless	United Kingdom	University /public research org
IND16	Institut für Nachrichtentechnik	Germany	University /public research org
IND16	Institut für Hochfrequenztechnik	Germany	University /public research org
IND51	Keysight UK	United Kingdom	Industry
IND51	WiCO	China	Industry
IND51	Quintel	United Kingdom	Industry
IND51	Keysight DK	Denmark	Industry
IND51	U2T Photonics QG	Germany	Industry
IND51	NEC/Mobile VCE/ICT KTN	United Kingdom	Other (e.g. government)
IND51	ESA	Netherlands	University /public research org
IND51	European Telecommunications Standards Institute	France	Other (e.g. government)
IND51	ETH Zürich	Switzerland	University /public research org
IND52	Konica Minolta	Germany	Industry
IND52	Merck KgaA	Germany	Industry
IND52	Escolab nv	Belgium	Industry
IND52	Fogra Forschungsgesellschaft Druck e.V.	Germany	Industry
IND52	Eldim	France	Industry
IND52	TQC	Netherlands	Industry
IND52	Munksjö	France	Industry
IND52	NUBIOLA	Spain	Industry
IND52	St Gobain Recherche	France	Industry

IND52	TechnoTeam Bildverarbeitung GmbH	Germany	Industry
IND52	Rhopoint Instruments Ltd	United Kingdom	Industry
IND52	AUDI AG	Germany	Industry
IND52	Cramer Forschungsinstitut	Germany	Industry
IND52	Lucideon	United Kingdom	Industry
IND52	2C	France	Industry
IND52	Deutsche farbwissenschaftliche Gesellschaft e.V.	Germany	Other (e.g. government)
IND52	PPG IBERICA SA	Spain	Other (e.g. government)
IND53	University of Strathclyde	United Kingdom	University /public research org
IND54	IBM	United States	Industry
IND54	Universite de Picardie Jules Verne	France	University /public research org
IND54	Wisconsin-Madison University	United States	University /public research org
IND55	Selex-ES	Italy	Industry
IND55	Spectratime	Switzerland	Industry
IND56	Sorin Group Italia s.r.l., Italy	Italy	Industry
IND57	IRSN – Institut de Radioprotection et de Sûreté Nucléaire	France	University /public research org
IND57	VÚHŽ a.s.	Czech Republic	University /public research org
IND58	Physik Instrumente (PI) GmbH & Co.	Germany	Industry
IND58	TESCAN Brno, s.r.o	Czech Republic	Industry
IND58	Ferrovac GmbH	Switzerland	Industry
IND58	Mecartex SA	Switzerland	Industry
IND58	Queensgate Instruments	United Kingdom	Industry
IND58	Sios Meßtechnik GmbH	Germany	Industry
IND58	California Nano Systems Institute	United States	University /public research org
IND58	Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF	Germany	University /public research org
IND59	Mitutoyo Research Center Europe	Netherlands	Industry
IND59	ZygoLOT GmbH	Germany	Industry
IND59	Werth Messtechnik GmbH	Germany	Industry
IND59	SARIX SA	Switzerland	Industry
IND59	Alicona Imaging GmbH	Austria	Industry
IND59	TU Ilmenau	Germany	University /public research org
IND59	National Taiwan University	Taiwan	University /public research org
IND59	IMT, TU Braunschweig	Germany	University /public research org
IND61	Rolls Royce	United Kingdom	Industry
IND61	EPRI	United States	Industry
IND61	Tecvac	United Kingdom	Industry
IND61	E.ON New Build & Technology	United Kingdom	Industry
IND61	Alstom Power	United Kingdom	Industry
IND61	Alstom Power	United Kingdom	Industry
IND61	Doosan Babcock	United Kingdom	Industry
IND61	Turbomet	United States	Industry
IND61	Laser Cladding	United Kingdom	Industry
IND61	CNR-ITC, Italy	Italy	Industry
IND61	Monitor Coatings	United Kingdom	Industry
IND61	University Southampton, UK	United Kingdom	University /public research org
IND62	Hexagon Metrology, S.A.	Spain	Industry
IND62	AIRBUS	United Kingdom	Industry

IND62	Rolls-Royce	United Kingdom	Industry
IND62	Mitutoyo ?esko, s.r.o.	Czech republic	Industry
IND62	Dassault Aviation	France	Industry
IND62	GEOMNIA	France	Industry
IND62	C.D. Measurement Ltd.	United Kingdom	Industry
IND62	Zkušebna VUOS, s.r.o.	Czech republic	Industry
IND62	TOPMES, m??icí stroje, v.o.s.	Czech republic	Industry
IND62	SolidVision	Czech republic	Industry
IND62	AlwaiD s.r.o.	Czech republic	Industry
IND62	Advance Manufaturing Technologies	Spain	Industry
IND62	Valmet Oyj (former Metso Oyj)	Finland	Industry
IND62	Verein Deutscher Werkzeugmaschinenfabriken	Germany	Other (e.g. government)
IND62	University Research Laboratory in Automated Production (LURPA)	France	University /public research org
IND63	Murata Electronics Oy	Finland	Industry
IND63	VTT	Finland	University /public research org
NEW01	Samsung Electronics Co. Ltd	Korea, Republic of	Industry
NEW01	CNR-IMM	Italy	University /public research org
NEW01	Dipartimento di Scienze dell'Ambiente e della Vita (DISAV)	Italy	University /public research org
NEW02	Gloucester Hospitals NHS Trust	United Kingdom	Other (e.g. government)
NEW02	Renishaw	United Kingdom	Industry
NEW02	WITec GmbH	Germany	Industry
NEW02	Nanotechnology Industries Association (NIA)	Belgium	Other (e.g. government)
NEW04	SCA Hygiene Products AB	Sweden	Industry
NEW04	CEA: Commissariat à l'énergie atomique et aux energies alternatives	France	Other (e.g. government)
NEW04	IMEKO TC21: Mathematical Tools for Measurement	Other	University /public research org
NEW04	NAFEMS: The International Association for the Engineering Analysis Community	Other	University /public research org
NEW04	PUCC: Pontificia Universidad Catolica de Chile	Chile	University /public research org
NEW04	CUNY: Columbia University New York	United States	University /public research org
NEW05	CSM Instruments	Switzerland	Industry
NEW05	SiMetrics GmbH	Germany	Industry
NEW05	Particular GmbH	Germany	Industry
NEW05	Institute for Technical Chemistry, University Essen Duisburg	Germany	Industry
NEW05	Quantum Wise A/S	Denmark	Industry
NEW05	Koc University	Turkey	University /public research org
NEW06	Rolls-Royce	United Kingdom	Industry
NEW06	Airbus UK	United Kingdom	Industry
NEW06	Build IT	Canada	Industry
NEW06	IMEKO TC 21	Hungary	Other (e.g. government)
NEW07	QMC Instruments Ltd.	United Kingdom	Industry
NEW07	"Department of Metrology Standardization and Certification, Siberian State Academy of Geodesy (SSAG)"	Russian Federation	Other (e.g. government)
NEW07	Leibnitz Universität Hannover, Institut für Grundlagen der Elektrotechnik und Messtechnik	Germany	University /public research org
NEW07	"Institut für Elektromagnetische Verträglichkeit (IEMV), Technische Universität Braunschweig)"	Germany	University /public research org
NEW07	University of Würzburg, Department of Toxicology	Germany	University /public research org

NEW07	Institut für Nachrichtentechnik (IfN), Technische Universität Braunschweig	Germany	University /public research org
NEW08	Crystec	Germany	Industry
SIB01	Oxford Instruments	United Kingdom	Industry
SIB01	Aalto	Finland	University /public research org
SIB01	University of Cantabria	Spain	University /public research org
SIB01	University of Delaware	United States	University /public research org
SIB01	Chinese Academy of Sciences	China	University /public research org
SIB02	Institute for Experimental Physics, Heinrich-Heine-Universität	Germany	University /public research org
SIB03	Mettler-Toledo	Switzerland	Industry
SIB03	Bureau International des Poids et Mesures	France	Other (e.g. government)
SIB03	Centre for Nuclear Applications Australian Nuclear Science and Technology Organisation	Australia	University /public research org
SIB03	Centre européen de recherche nucléaire	Switzerland	University /public research org
SIB03	University of Turin	Italy	University /public research org
SIB03	Cagliary University, department of physics	Italy	University /public research org
SIB03	Cagliary University, department of physics	Italy	University /public research org
SIB03	Ecole Polytechnique de Lausanne, Laboratoire de Systèmes Robotiques	Switzerland	University /public research org
SIB04	Institute of Laser Physics, Siberian Branch of the Russian Academy of Sciences	Russian Federation	University /public research org
SIB04	Institute of Geodesy, Leibniz Universität Hannover	Germany	University /public research org
SIB04	York university and University of Ottawa	Canada	University /public research org
SIB05	Troemner Inc	United States	Industry
SIB05	Mettler Toledo	Switzerland	Industry
SIB05	Haefner	Germany	Industry
SIB06	Royal Surrey County Hospital (RSCH)	United Kingdom	Other (e.g. government)
SIB06	Universitätsklinikum Hamburg-Eppendorf (UKE)	Germany	Other (e.g. government)
SIB06	Helmholtz-Zentrum für Gesundheit und Umwelt (HZM)	Germany	University /public research org
SIB06	Loma Linda University Medical Center (LLU)	United States	University /public research org
SIB06	Clatterbridge Centre for Oncology (CCO)	United Kingdom	University /public research org
SIB06	Centre for Medical Radiation Physics (CMRP), University of Wollongong	Australia	University /public research org
SIB06	Centre for Medical Radiation Physics (CMRP), University of Wollongong	Australia	University /public research org
SIB06	University of Ontario Institute of Technology (UOIT)	Canada	University /public research org
SIB06	Deutsches Krebsforschungszentrum (DKFZ)	Germany	University /public research org
SIB06	Klinikum rechts d. Isar, Technical University Munich (TUM)	Germany	University /public research org
SIB06	University of Pavia	Italy	University /public research org
SIB06	Ion Beam Centre (IBC), University of Surrey	United Kingdom	University /public research org
SIB06	Università Degli Studi di Padova (UPD)	Italy	University /public research org
SIB06	Universitá Degli Studi di Palermo (UNIPA)	Italy	University /public research org
SIB06	Heavy Ion Laboratory (HIL) of the University of Warsaw	Poland	University /public research org
SIB06	Nuclear Physics Institute (NPI), Czech Academy of Science	Czech Republic	University /public research org
SIB07	Aalto University	Finland	University /public research org
SIB08	ASML	Netherlands	Industry
SIB08	IBS Precision Engineering B. V.	Netherlands	Industry
SIB08	Queensgate	United Kingdom	Industry
SIB08	Optocraft	Germany	Industry

SIB08	SIOS	Germany	Industry
SIB08	Vrije Universiteit Amsterdam	Netherlands	University /public research org
SIB08	TU Delft	Netherlands	University /public research org
SIB10	Optris GmbH	Germany	Industry
SIB10	Heitronics Infrarot Messtechnik GmbH	Germany	Industry
SIB10	DIAS Infrared GmbH	Germany	Industry
SIB10	Isotech	United Kingdom	Industry
SIB10	Sensortherm GmbH	Germany	Industry
SIB51	Fluke Calibration	United States	Industry
SIB51	TransMIT GmbH	Germany	Industry
SIB51	Magnicon GmbH	Germany	Industry
SIB51	esz AG calibration & metrology	Germany	Industry
SIB51	Aalto ubiversity	Finland	University /public research org
SIB51	Chalmers tekniska hoegskola AB	Sweden	University /public research org
SIB52	Rolls-Royce plc	United Kingdom	Industry
SIB52	Isover Saint-Gobain CRIR	France	Industry
SIB52	FIW	Germany	Other (e.g. government)
SIB53	Analog devices	Spain	Industry
SIB55	TimeTech GmbH	Germany	Industry
SIB55	Observatoire Royal de Belgique	Belgium	University /public research org
SIB55	Laboratoire Souterrain de Modane	France	University /public research org
SIB55	DIATI-POLITO (Politecnico di Torino)	Italy	University /public research org
SIB57	Cogenda	Other	Other (e.g. government)
SIB57	Aalto University	Finland	University /public research org
SIB59	The Universidad de Málaga (ISIS - DTE - UMA)	Spain	University /public research org
SIB60	Onsala Space Observatory (OSO)	Sweden	University /public research org
SIB60	Korea Advanced Institute of Science and Technology (KAIST)	Korea, Republic of	University /public research org
SIB60	Universität der Bundeswehr	Germany	University /public research org
SIB60	Frankfurt University of Science (FRA-UAS)	Germany	University /public research org
SIB61	Polytec GmBh	Germany	Industry
SIB61	STS Nanotechnology	Germany	Industry
SIB61	SiMetrics GmbH	Germany	Industry
SIB61	Omicron Nano Technology GmbH	Germany	Industry
SIB61	NanoWorld Service GmbH	Germany	Industry
SIB61	Sensofar Tech SL	Spain	Industry
SIB61	Physik Instrumente GbmH & Co KG (PI)	Germany	Industry
SIB61	SPECS Surface Nano Analysis GmbH	Germany	Industry
SIB61	Image Metrology A/S	Denmark	Industry
SIB61	MEMC Electronic Materials SpA	Italy	Industry
SIB62	Polar Instruments	United Kingdom	Industry
SIB63	HBM	Germany	Industry
SIB63	GTM	Germany	Industry
SIB63	IBMB	Germany	Other (e.g. government)
SIB64	Valmet Automation Inc.	Finland	Industry
SIB64	Metrohm	Finland	Industry
SIB64	Raute Oyj Mecano Business Unit	Finland	Industry
SIB64	Henkel Slovenija d.o.o.	Slovenia	Industry

SIB64	Seltek Ltd	Turkey	Industry
SIB64	Intertek Pharmaceutical Services Manchester, ITS Testing Services, Ltd	United Kingdom	Industry
SIB64	TBD Biodiscovery	Estonia	Industry
SIB64	Domel d.o.o.	Slovenia	Industry
SIB64	Universidad Politécnica de Cartagena	Spain	University /public research org

7 Annex B: Mobility grants

7.1 Mobility grants

There were 79 mobility grants. 56 Researcher Mobility Grants (RMG) and 23 Early Stage Researcher Mobility Grants (ESRMG).

Figure 38: Mobility grants

Project	Type of grant	Organisation	Country	Organisation type
ENG01	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
ENG04	ESRMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
ENG05	ESRMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
ENG05	ESRMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
ENG07	RMG	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	NMI / DI
ENG08	RMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
ENG08	RMG	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara "Horia Hulubei"	Romania	University / Public research org
ENG09	RMG	Laboratoire national de métrologie et d'essais	France	NMI / DI
ENG09	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG52	ESRMG	General Directorate of Metrology	Albania	NMI / DI
ENG54	RMG	Fundación General de la Universidad de Valladolid	Spain	University / Public research org
ENG55	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG55	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG55	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
ENG55	RMG	Loughborough University	United Kingdom	University / Public research org
ENG55	RMG	JRC - Joint Research Centre - European Commission	European Commission	University / Public research org
ENG55	RMG	Loughborough University	United Kingdom	University / Public research org
ENG56	RMG	Ministarstvo ekonomije	Montenegro	NMI / DI
ENG59	RMG	Instituto Português da Qualidade, I.P.	Portugal	NMI / DI
ENG59	RMG	Instituto Português da Qualidade, I.P.	Portugal	NMI / DI
ENG60	RMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
ENV01	ESRMG	Ministarstvo privrede Direkcija za mere i dragocene metale	Serbia	NMI / DI
ENV01	RMG	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	NMI / DI
ENV07	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
ENV08	RMG	Bulgarian Institute of Metrology	Bulgaria	NMI / DI
ENV53	ESRMG	Aalto-korkeakoulusäätiö sr	Finland	University / Public research org
ENV58	RMG	Sveuciliste U Zagrebu, Fakultet Strojarstva I Brodogradnje	Croatia	University / Public research org
ENV58	RMG	Instytut Niskich Temperatur i Badan Strukturalnych im. Wlodzimierza Trzebiatowskiego Polskiej Akademii Nauk	Poland	University / Public research org
ENV58	RMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
ENV58	RMG	Ministarstvo ekonomije	Montenegro	NMI / DI
EXL02	RMG	Tallinna Tehnikaulikool	Estonia	University / Public research org
EXL04	ESRMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
EXL04	RMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
EXL04	RMG	NPL Management Limited	United Kingdom	NMI / DI

EXL04	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
HLT02	RMG	Helsingin Yliopisto	Finland	University / Public research org
HLT06	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
IND01	ESRMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
IND01	ESRMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
IND04	ESRMG	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara "Horia Hulubei"	Romania	University / Public research org
IND04	ESRMG	Centro de investigaciones energeticas, medioambientales y tecnologicas	Spain	University / Public research org
IND04	ESRMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
IND07	RMG	Institut za fiziku	Croatia	University / Public research org
IND08	ESRMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
IND15	ESRMG	Bundesanstalt fuer Materialforschung und -pruefung	Germany	University / Public research org
IND57	ESRMG	Physikalisch-Technischer Pruefdienst des Bundesamt fuer Eich- und Vermessungswesen	Austria	NMI / DI
NEW01	RMG	Interuniversitair Micro-Electronicacentrum IMEC VZW	Belgium	University / Public research org
NEW02	RMG	Istituto Nazionale di Ricerca Metrologica	Italy	NMI / DI
NEW03	RMG	Research Centre for Natural Sciences, Hungarian Academy of Sciences	Hungary	University / Public research org
NEW06	ESRMG	Central Office of Measures	Poland	NMI / DI
NEW07	RMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
NEW07	RMG	Philipps-Universität Marburg	Germany	University / Public research org
NEW07	RMG	Philipps-Universität Marburg	Germany	University / Public research org
SIB01	ESRMG	Centro Español de Metrología	Spain	NMI / DI
SIB02	ESRMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
SIB04	RMG	Institute of Solid State Physics Bulgarian Academy of Sciences	Bulgaria	University / Public research org
SIB05	RMG	Ministrstvo za gospodarski razvoj in tehnologijo	Slovenia	NMI / DI
SIB05	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
SIB05	RMG	Instituto Português da Qualidade, I.P.	Portugal	NMI / DI
SIB06	ESRMG	Studiecentrum voor Kernenergie, Centre d'Etude de l'Energie Nucléaire, Fondation d'Utilité Publique	Belgium	University / Public research org
SIB06	ESRMG	Narodowe Centrum Badań Jądrowych	Poland	Other (e.g. government)
SIB10	ESRMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI
SIB10	ESRMG	Central Office of Measures	Poland	NMI / DI
SIB10	RMG	Central Office of Measures	Poland	NMI / DI
SIB10	RMG	Slovenský Metrologický Ústav	Slovakia	NMI / DI
SIB10	RMG	Instytut Niskich Temperatur i Badan Strukturalnych im. Wlodzimierza Trzebiatowskiego Polskiej Akademii Nauk	Poland	University / Public research org
SIB10	RMG	Central Office of Measures	Poland	NMI / DI
SIB10	RMG	Ministarstvo privrede Direkcija za mere i dragocene metale	Serbia	NMI / DI
SIB10	RMG	Ministarstvo privrede Direkcija za mere i dragocene metale	Serbia	NMI / DI
SIB10	RMG	Ministarstvo ekonomije	Montenegro	NMI / DI
SIB10	RMG	Biroul Roman de Metrologie Legala	Romania	NMI / DI
SIB10	RMG	Instytut Niskich Temperatur i Badan Strukturalnych im. Wlodzimierza Trzebiatowskiego Polskiej Akademii Nauk	Poland	University / Public research org

SIB55	RMG	Cesky Metrologicky Institut	Czech Republic	NMI / DI
SIB56	RMG	Physikalisch-Technische Bundesanstalt	Germany	NMI / DI
SIB57	ESRMG	Agencia Estatal Consejo Superior de Investigaciones Cientificas	Spain	University / Public research org
SIB57	RMG	Tallinna Tehnikaulikool	Estonia	University / Public research org
SIB59	RMG	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Turkey	NMI / DI
SIB60	RMG	Ústav přístrojové techniky AV ČR, v.v.i.	Czech Republic	University / Public research org
SIB60	RMG	Institut za mjeriteljstvo Bosne i Hercegovine	Bosnia and Herzegovina	NMI / DI

8 Annex C: Impact case studies

Summaries of the impact case studies (for the Energy, Environment, Industry and Health themes) are presented below. The longer version of each case study can be found at:

Energy

https://www.euramet.org/energy-case-studies

Environment

https://www.euramet.org/environment-case-studies

Industry

https://www.euramet.org/industry-case-studies

Health

https://www.euramet.org/health-case-studies-diagnosis

https://www.euramet.org/health-case-studies-therapies

ENERGY THEME CASE STUDIES

Supporting innovation in measurement technology

Future-proofing Europe's gas networks

Michell Instruments, a leading supplier of humidity instrumentation, has developed a novel optical device to measure water content specifically for the gas industry. Working with the EMRP project *Characterisation of energy gases*, Michell Instruments used a new humidity facility developed as part of the project to evaluate the instrument's performance at the highest levels of accuracy relevant to their target market. This not only gave Michell confidence in the product's performance but also provided robust evidence to support their marketing and sales activities.

The product was launched in 2014 and has been installed in a number of locations worldwide. The improved performance of Michell's instrument offers network operators improved confidence in the quality of gas they buy and sell while avoiding unnecessary and costly drying processes before the gas is injected into the network. Besides improving efficiency and confidence across Europe's existing gas networks, the new instrument paves the way for a range of gas mixtures, readying the network for a more renewable, secure gas future.

Paving the way for next-generation nuclear energy

The EMRP project *Metrology for new generation nuclear power plants* developed, tested and patented a new temperature sensor, capable of operating at temperatures up to 1300 °C. Unlike previous instruments, these sensors can be used to ensure the safety and reliability of upcoming Generation IV nuclear reactors, which operate at higher temperatures to offer increased electricity production with reduced waste reprocessing requirements. The Idaho National Laboratory in the US recently held a comparative laboratory test campaign between several conventional thermocouples and a new one developed in the project by the University of Cambridge to select viable temperature sensors for its upcoming Very High Temperature Reactor fuel test validation. Following the lab test campaign Dr Michele Scervini from the University of Cambridge was awarded the opportunity to test the new sensor in Idaho's prototype reactor, one of only a few facilities of its sort in the world.

Testing will assess the new sensor's performance in the high radioactivity and temperature environment of Generation IV reactors. This will provide the validation needed to encourage the sensor's adoption by the conservative nuclear industry, paving the way to next generation nuclear power plants and stable, low carbon energy for Europe.

New in-line flow calibration supports significant energy savings

KROHNE, a leading manufacturer of industrial process instrumentation, has developed a new improved ultrasonic flow meter to monitor power plant processes. Through participation in the EMRP project *Metrology for improved power plant efficiency*, KROHNE used a newly-developed meter design together with a calibration device developed within the EMRP project. This calibration device simulates typical plant operating conditions to demonstrate the meter's accuracy. The validation of the technology using the new calibration device provided KROHNE with the impetus and confidence to start production of the ultrasonic flow meter.

E.ON, another project collaborator, has purchased and installed KROHNE's device in a nuclear power plant in Sweden for evaluation, in part due to the promising results of the project. Preliminary indications are that efficiencies in plant operation resulting from the device's use would be equivalent to around 60 MW, approximately the amount of electricity required to power thousands of extra homes. This is a significant improvement in plant efficiency, and given Europe's dependence on large-scale power plants for the foreseeable future, an important contribution to the efforts to reduce Europe's carbon footprint.

Better measurement for smarter grids

The EMRP project *Metrology for smart electrical grids* developed calibration equipment, software and processes that enable phasor measurement units (PMUs) – the 'life support monitors' of smart grids – to be validated against traceable measurement standards for the first time in Europe. Best practice guidelines for PMU use resulting from the project have also been incorporated into a revised IEEE standard.

Fluke Corporation, a manufacturer of industrial testing equipment, has introduced a unique PMU calibration service based on the methods developed in the project. The service enables operators to demonstrate compliance with the revised IEEE standard, and confidently compare PMU measurements across the grid, safe in the knowledge that all devices produce consistent and robust measurements. Arbiter Systems, a manufacturer of precision timing and power measurement devices, is introducing an improved and cheaper combined PMU and power quality measurement instrument for smart grids following involvement in the project. Grid operators can use Arbiter's new device to demonstrate compliance with the revised IEEE standard, and make reliable grid stability measurements at a price they can afford.

Increased access to cost-effective calibration services and devices, such as these, will help operators ensure the stability of smart grids and accelerate their adoption in Europe, supporting widespread renewable energy generation and a more stable, low-carbon energy future for Europe.

New instrument supports energy harvesting for greener transport

German manufacturer, Netzsch, has developed a precision instrument for measuring electrical conductivity and the Seebeck coefficient – a material property which strongly influences the efficiency and power output of a thermoelectric generator. Netzsch is marketing the instrument with a new reference material developed in the EMRP project *Metrology for energy harvesting*. Together, these products enable automotive manufacturers to reliably assess the performance of thermoelectric materials developed for use in energy harvesting devices.

The reference material will give Netzsch's customers confidence that the thermal efficiency measurements they make agree with national standards in place to ensure accuracy and consistency, enabling potential customers to better compare products. Netzsch's product provides the measurement capability needed to accelerate development and uptake of improved thermoelectric generators within the automotive industry. By making Europe's vehicles more efficient, energy harvesting technology has the potential to reduce one of the most significant contributions to Europe's greenhouse gas emissions.

Supporting smart renewable energy

With support from South Dublin City Council, the International Energy Research Centre (IERV - National Tyndall Institute), Siemens, Intel and Microsoft, the Micro Electricity Generation Association (MEGA) is piloting a 'smart energy cluster' in the outskirts of Dublin, which links small-scale renewable energy generators with local consumers through a smart grid. MEGA's smart cluster distributes locally-generated wind and biogas power using a power stabiliser incorporating a PMU, which links the cluster to the main grid system and allows inflow of power when renewable generation cannot meet local demand.

Through engagement with the EMRP project *Metrology for smart electrical grids*, MEGA received help evaluating the smart cluster's PMU and best practice guidance to enable accurate grid stability monitoring. Support from the project will help to ensure a reliable power supply to users of MEGA's smart cluster and the success of the pilot project. MEGA hopes to eventually interconnect local small-scale smart grids into a citywide system for Dublin. This will be an important step towards widespread renewable energy generation in Ireland and a more stable, low-carbon energy future for Europe.

Supporting standardisation to promote sustainable energy

New regulations support stable energy future for Europe

The EMRP project *Metrology for Liquefied Natural Gas (LNG)* developed a new primary flow standard. This will be used to provide traceability to the mid-scale LNG calibration facility, enabling flow meters used in the transfer

and sale of LNG to be calibrated with top-class accuracy under typical operating conditions. Guidance documents issued by the International Organization of Legal Metrology (OIML) are currently undergoing revision to include a new section on LNG transfer flow metering developed within the project. Project interactions with ISO standard committees is enabling the inclusion of LNG measurements and flow metering systems into the documentary standards that underpin the International Group of Liquefied Natural Gas Importers Handbook used throughout the LNG industry.

This infrastructure will help to ensure fair and open trade of LNG, reducing financial risks and resulting in more stable energy prices. Increased adoption of LNG, which is more economical to transport over large distances and facilitates the supply of natural gas from new sources, could play a major role in diversifying Europe's energy supply.

New standard for safer, greener roads

The Italian standards organisation (UNI) has incorporated research performed within the EMRP project *Metrology for solid-state lighting* into a new standard for the illumination of road tunnels, optimizing the lighting requirements in the tunnel internal zone and at night.

The new UNI standard enables the safe introduction of LED lighting into Italian road tunnels and has enabled a significant reduction in the consumption of electrical power for tunnel lighting. LEDs operating at the new safe lighting levels identified within the project have contributed a further 33 % saving in electricity consumption. With LED lighting already introduced into approximately 95 % of Italy's 1,500 km of highway road tunnel network, this standard will lead to safer roads with significantly reduced power consumption and associated CO2 emissions.

New standard supports development of biofuel-ready vehicles

The EMRP project *Metrology for biofuels* developed a reference method for determining the pH value of the most commonly used biofuel, bioethanol (pHe). This serves as a best practice example for measuring pHe, which can be used as a quick and simple indicator of bioethanol's corrosiveness - a property of crucial concern for engine manufacturers. These practices have since been incorporated into a new ISO standard, enabling users to make pHe measurements of the highest accuracy and reliably compare them across the world.

This will enable researchers to confidently assess the corrosive effects of bioethanol on materials being developed for use in next-generation engines, built to withstand biofuel blends. Accelerating the development of biofuel-ready engines, and encouraging consumer confidence, is an important step towards widespread adoption of biofuels and meeting the obligations of the Renewable Energy Directive, which requires 10 % of the transport fuel of every EU country to come from renewable sources such as biofuels.

Lighting the way to a greener Europe

The EMRP project *Metrology for solid-state lighting* has developed improved measurement practices and quality metrics to support reliable, accurate performance testing of LED lighting - the most energy-efficient lighting technology available - which meets the needs of end-users. The methods developed have contributed to an International Commission on Illumination standard and equivalent European Committee for Standardization (CEN) standard, which have recently been revised to include the testing of LED lighting.

This will enable manufacturers to make confident claims about product performance and demonstrate the quality of their products, both of which are critical to encouraging consumer acceptance. By accelerating adoption of energy saving lighting across Europe in accordance with the aims of the Ecodesign Directive, this will make a significant contribution to reducing CO2 emissions and the use of mercury within the lighting industry, helping Europe meet crucial climate and energy targets.

Standards for biogas

The EMRP project *Characterisation of energy gases* is working with the instrumentation and standards communities to ensure the project's developments in the accurate measurement of siloxanes are adopted in practice and incorporated in forthcoming European standards.

Biogas, biomethane and landfill gas are often contaminated with siloxanes – the silicon-based materials found in everyday products such as detergents, medical products, cosmetics, paper coatings and textiles. Upon combustion, siloxanes form silica (sand) that builds up in gas networks and engines, eventually causing reduced efficiency, increased operating costs and equipment failure. Accurate measurement techniques for siloxanes are needed to demonstrate compliance with the levels specified in forthcoming CEN standards, and ensure cost-effective siloxane removal and avoid unnecessary operational costs.

Digital standards for the nuclear industry

The EMRP project *Metrology for new generation nuclear power plants* is working with the standards community to develop a compatibility standard for digital data used in the nuclear industry. The increased use of digital data acquisition has led to a range of different digital data formats that hinders interoperability and comparison of important nuclear measurement data between users, across borders and disciplines. These measurements ensure the safe and efficient operation of nuclear power plants, underpin nuclear medicine and provide nuclear security.

The European and international standards communities (CEN and IEC) and the European Thematic Group on the Protection of Critical Infrastructure from Radiological and Nuclear Threats have identified the urgent need for digital data standards and the project team is working with them to develop such an international standard.

ENVIRONMENT THEME CASE STUDIES

Supporting roadside pollution monitoring

Congested areas such as city centres suffer from elevated levels of certain pollutants, including NO2, which is associated with adverse effects on health including reduced life expectancy. As part of the EMRP project *Metrology for chemical pollutants in air*, METAS in Switzerland developed a new traceable mobile NO2 permeation generator, which can be used in the field to directly calibrate instruments monitoring harmful roadside pollution, improving the reliability of their measurements.

The METAS NO_2 generator has already been used by the City of Zurich Health and Environment Department and in other Swiss cities. METAS and LNI Swissgas, a leading manufacturer of environmental gas calibration systems and gas generators, have been awarded funding to commercialise a novel compact NO_2 permeation generator, which incorporates features of the METAS prototype into LNI Swissgas's existing product, resulting in a fully traceable and user-friendly transfer standard.

Portable and compact field calibration instruments, such as LNI Swissgas's, provide crucial support to the expansion of Europe's air monitoring networks, more comprehensive pollution monitoring and effective protection of Europe's citizens.

Innovative roadside pollution monitors

The introduction of new gas micro-sensor technology promises to significantly increase the capacity of NO_2 monitoring networks within our cities. Micro-sensors provide cost-effective real-time measurements, offering the potential to rapidly disseminate pollution warnings to vulnerable city dwellers.

The EMRP project *Metrology for chemical pollutants in air* developed a test protocol for micro-sensors using a specially-designed chamber at JRC Ispra. The facility can be used to evaluate sensor performance at pollutant levels specified in the European Air Quality Directive under typical field conditions. Through participation in the project and use of the new facility at JRC Ispra, Alphasense, a developer and manufacturer of gas sensors, has revised and improved its innovative NO_2 micro-sensors for roadside monitoring measurement platforms. By establishing traceability to national standards, this project has enabled micro-sensors such as Alphasense's to be used in support of the Air Quality Directive, validating their use as a robust yet cost-effective technology for real-time air pollution monitoring.

Improving indoor air quality

Volatile organic compounds (VOCs), commonly found in furniture, carpets and paints, are known to cause respiratory problems, but until recently there was no harmonised labelling scheme or supporting standard test governing VOC emissions from construction materials in the EU.

The EMRP project *Metrology for chemical pollutants in air* developed a new reference material, which reproduces the VOC-emitting behaviour of a typical construction product. Testing laboratories can use the reference material to demonstrate their ability to carry out robust VOC emissions measurements and certification, in compliance with an upcoming CEN standard (prEN 16516:2015).

Testing body eco-INSTITUT used the new reference material along with the proposed CEN test method to demonstrate the capability of its VOC emissions measurement system. Manufacturers can be confident in the accuracy of eco-INSTITUT's system, which has now been benchmarked against the standard, and the emissions certificates issued for their products. This marks the first step towards EU harmonisation of

construction product labelling, which will help remove barriers to international trade and ensure reliable monitoring of indoor environments to protect public health.

Harmonising air quality measurements

The EMRP project *Metrology for chemical pollutants in air* developed and validated accurate reference standards for a range of important outdoor pollutants at the very low concentrations required to comply with the European Ambient Air Quality Directive. A certification protocol was also defined for establishing the purity of the 'zero gas' samples used to set the zero point of gas analysers.

The project team worked closely with the European Network of Air Quality Reference Laboratories (AQUILA) to understand their needs and ensure the transfer of project outputs to key users. As a result, several air quality networks are already using the new reference standards, enabling improved demonstration of compliance with the Directive. The team is also working with the standards community to ensure that the certification protocol for zero gases will gain formal standing via a series of ISO standards.

These improved measurement capabilities will support consistent and robust assessment of air pollutants and help minimise their negative impact on human health and the environment.

High-performance particle counters for emissions testing

To improve public health and the quality of the environment, new passenger cars must meet European emission standards before they can be type approved for sale. Of particular concern are the fine particles emitted by diesel engines – consequently, the latest emission standards include a particle number limit.

The EMRP project *Emerging requirements for measuring pollutants from automotive exhaust emissions* helped to establish the first direct traceability chain for condensation particle counters, one of the key technologies used to measure particle numbers, through contribution to a new ISO standard (ISO 27891:2015) and the development of a new calibration facility.

TSI, a manufacturer of condensation particle counters, was one of the first beneficiaries of the new calibration facility. TSI's internal reference instrument can now be used with the ISO standard to provide traceability to TSI's commercial condensation particle counters, used by engine manufacturers and emissions testing laboratories. This will ensure they can detect the low levels of particulate permitted by the upcoming Euro 6c standard and support robust, comparable emissions testing.

Robust emissions testing under real driving conditions

The low levels of particulate permitted by the European emission standards are now beyond the sensitivity of the technology currently used for periodic engine testing, and from September 2017 the standards will cover emission testing under real driving conditions.

The EMRP project *Emerging requirements for measuring pollutants from automotive exhaust emissions* developed a facility to calibrate and validate automotive particle emission instruments which measure particle number concentration at the low levels required by the regulation.

Testo AG, a world leader in the field of portable measurement technology, used the facility to assess the performance of an innovative exhaust monitoring instrument. Using the results and expertise gained, Testo had confidence that, after further modifications, the new technology would be suitable for launch. Testo has since launched the instrument for new engine tests and a portable version suitable for periodic vehicle testing, including under normal driving conditions, will be available in the near future. This will support implementation of the updated emission standards, which will ensure that vehicles deliver reduced exhaust emissions over their entire life span.

Better UV monitoring to protect public health

Balancing the risks and benefits of solar UV radiation is a challenge for policymakers and health advisors, and improved UV measuring instrumentation is needed to produce reliable measurements on which to identify long-term trends and base decisions. The introduction of newer, faster compact CCD array spectroradiometers will provide a cost-effective alternative to conventional instruments and has the potential to increase the worldwide UV monitoring network.

The EMRP project *Traceability for surface spectral solar ultraviolet radiation* developed best practice guidelines to improve the accuracy and comparability of solar UV measurements, which were disseminated to operators from monitoring stations across the globe during a comparison exercise at the World Meteorological Organisation in Davos, Switzerland. This comparison enabled operators to compare their CCD array

spectroradiometers to the world reference instrument, giving direct traceability for this type of instrument for the first time.

Public Health England (PHE) monitors public exposure to all types of radiation and routinely publishes UV exposure data from its monitoring network for research and trend analysis. PHE took a prototype array spectroradiometer it had developed to the comparison exercise and, following interaction with the project, the instrument, operated with the new best practice procedures, demonstrated improved performance and better agreement with the world reference instrument.

El Arenosillo, an atmospheric research observatory of Spain's space agency, also took part in the comparison exercise and embraced the best practice guidelines derived in the project, improving the comparability and compatibility of both aerial and ground-based measurements performed at the monitoring station.

Advanced optics for atmospheric research

As part of the EMRP project *Traceability for surface spectral solar ultraviolet radiation*, project partner Aalto University, working with industrial partners Kipp & Zonen and CMS Ing Dr Schreder GmbH, has designed a new type of optical component for Brewer spectrophotometers, the sophisticated instruments used to measure stratospheric ozone and solar UV radiation, using novel quartz-based materials.

The new quartz materials can be more easily formed into complex shapes and improve the accuracy of low-angle solar UV measurements. Simulations performed by Aalto University were used to optimise the new design and prototype optics were validated using QASUME, the world's prim0ary spectrophotometer, the performance of which had also been improved using project outputs. Products incorporating the new optics will soon be commercially-available to customers requiring highly-accurate measurements of solar UV for ozone studies.

The incorporation of the quartz optics into new and existing spectrophotometers is giving the UV community greater confidence in the accuracy of the solar UV measurements and helping atmospheric researchers and health protection agencies to reliably assess long-term changes in the Earth's protective ozone layer.

Improving atmospheric data

Spectro-analytical techniques used to identify and quantify concentrations of greenhouse and other gases in the atmosphere are based on the unique spectral 'fingerprints', or spectral lines, generated by molecules interacting with electromagnetic radiation. Accurate spectral line data is required to reduce measurement uncertainties and generate more robust data for climate predictions.

The EMRP project *Spectral reference data for atmospheric monitoring* has enabled the development and commissioning of a new measurement facility capable of generating greenhouse gas spectral line data with improved traceability to the SI. The spectral data generated within the project is due to be included in an upcoming revision of the HITRAN database, one of the most widely-used spectral databases in the world.

The project's contribution will mark a significant increase in the amount of traceable spectral data available to researchers using HITRAN. One of the key users is TCCON, a network of 23 ground-based atmospheric monitoring stations distributed across the globe, which provide performance validation to satellite-borne spectral instruments. The improved data provided by TCCON-validated satellites will make a valuable contribution to reducing the uncertainties involved in climate models and support robust predictions of long-term climate change.

Confidence in climate data

The UK Met Office generates some of the most comprehensive climate projections ever produced, to help decision-makers assess risk exposure to climate change and inform mitigation and adaptation strategies. These projections are guided by climate data from a number of sources, both historic and current.

The Met Office will use a new uncertainty evaluation method developed within the EMRP project *European metrology for Earth observation and climate*, to enable the combination of climate data collected on the most recent European Sentinel satellite missions with its existing datasets. This opens up a significant amount of additional climate data to the Met Office for climate monitoring and modelling purposes, improving the quality and range of measurements available to guide its climate projections.

The method and the research it is based on have also been assembled into a course and textbook for Earth observation scientists, which will be freely-available online in the near future. This is a significant step towards improving measurement uncertainty evaluation in the climate research community and will contribute to improved climate models and projections.

Ensuring accuracy in the upper atmosphere

To assess the impact of tiny variations in atmospheric composition on long-term climate change, the Earth observation community needs highly-accurate measurements of atmospheric composition. However, while carefully calibrated on the ground, instruments on board aircraft and satellites can degrade while in flight.

Within the EMRP project *European metrology for Earth observation and climate*, a new calibration facility was used to provide traceability for airborne spectroradiometers. Two novel, compact black-body radiation sources, developed in collaboration with University of Wuppertal, were calibrated using the new facility prior to use as transfer standards on board a research aircraft.

One of the first instruments to benefit was GLORIA, the first of a new generation of spectroradiometers for Earth observation. GLORIA's novel infrared camera measures trace gases in the atmosphere with an unprecedented combination of vertical and horizontal resolution that relies upon highly-accurate calibration. The new transfer standards enabled the first traceable mid-infrared measurements of thermal emissions – a significant step forward in Earth observation research. This newly traceable technology can now be used on board balloons and satellites, plugging the gap in high-quality data needed for robust climate change assessment.

Helping satellites see ocean colour

Research buoys make local measurements of a range of variables essential to climate models, including ocean colour, which can be used as a measure of phytoplankton concentrations and provide vital information for monitoring the global carbon cycle.

The EMRP project *European metrology for Earth observation and climate* developed a novel easily transportable light source, which can be used to calibrate instruments on buoys in situ. This provides traceability to the buoy's measurements, and those provided by satellites, which are compared to the buoy's and corrected when they pass overhead.

One of the first beneficiaries was BOUSSOLE, an international project supported by organisations including the European Space Agency and French space agency, CNES. Instrumentation on the BOUSSOLE buoy has now been calibrated using the new portable standard and is being used to confirm the response of the European Ocean Land Colour Instrument, recently launched on the Copernicus Sentinel 3 satellite. This is just one example of how the new calibration standard is improving the accuracy of ocean colour measurements, and ultimately supporting more robust carbon cycle trend analysis and climate monitoring.

Understanding our oceans

Oceans are the largest active carbon sinks on Earth, absorbing more than a quarter of anthropogenic carbon emissions. The ocean's interaction with the atmosphere, and its ability to absorb carbon dioxide, is strongly influenced by properties of seawater, such as salinity and acidity. Reliable and comparable measurements of these properties are of crucial importance to climate researchers, enabling them to detect small changes in ocean dynamics over decades and even centuries.

Salinity

The EMRP project *Metrology for ocean salinity and acidity* provided a reference method for ocean salinity, which makes practical salinity measurements traceable to the SI units through density measurements. Ocean Scientific International Ltd (OSIL) is going to incorporate density measurements into the preparation of its standard seawater, which is the only internationally-recognised calibration standard for practical salinity. This will provide traceability to ocean salinity measurements across the globe and allow the oceanography community to reliably identify even small changes.

Temperature

Additionally, probes used to measure the speed of sound in seawater can now be traceably calibrated under typical operating conditions at newly-developed facilities at project partners PTB and INRIM. Measurements at sea have also confirmed the performance of a prototype transfer standard developed at INRIM, bringing easily achievable traceability to ship-based probes. Vessels equipped with such sensors could provide a cost-effective, extensive seawater temperature measurement network to supplement satellite data for climate models.

Acidity

The project also helped to establish a traceability chain for seawater pH by developing primary and reference methods for pH measurements. The team contributed validation methods to a new ISO standard (ISO/CD 18191) for pH and is working with the Scripps Institution of Oceanography - the sole provider of a seawater buffer solution used to calibrate field-based oceanographic instrumentation. The team is also contributing to the two key influential committees that define seawater parameters and methods: the pH subgroup of the Joint

Committee on the Properties of Seawater, which is responsible for maintaining and improving the seawater equation of state, a key tool in ocean science; and a new group of the International Union of Pure and Applied Chemists, which is using project outcomes to ensure greater harmonisation of the measurement methods used by the oceanographic community.

Oxygen levels

EHP-Tekniikka, a provider of environmental monitoring services and equipment, took part in a comparison exercise, organised by the University of Tartu and project partner SYKE, to compare the dissolved oxygen measurements provided by commercially-available sensors to those made using the traceable Winkler titration method for the first time. Using a PONSEL OPTOD oxygen sensor - an optical sensor designed with an internal calibration capability - EHP-Tekniikka was able to directly compare the instrument's response using a procedure developed within the project. The positive results obtained have given confidence in this type of instrument's internal calibration capability and its applicability for high-accuracy measurements of dissolved oxygen concentrations. This validation paves the way to increased use of automated oxygen sensors and will lead to a significant increase in the oceanography community's capacity to produce high-accuracy dissolved oxygen data for robust climate trend analysis.

Building environmental metrology skills

A best practice uncertainty evaluation method, developed by the EMRP project *Metrology for ocean salinity and acidity* provided a key component of a new online course developed by project partner, the University of Tartu in Estonia. The best practice method was developed for use with the Winkler titration method, used to determine the concentration of dissolved oxygen in samples in water quality studies.

The online course, Estimation of measurement uncertainty in chemical analysis, has not only been taken by 700 students so far but is also being used by SP, the Technical Research Institute of Sweden, to train environmental testing laboratories working towards Nordtest accreditation. Nordtest is the Nordic area conformity assessment body whose role is to harmonise compliance with standards and remove barriers to trade across the Nordic countries, which includes the accreditation of measurement and testing and conformity assessment laboratories.

The project's outputs are therefore not only contributing to important climate change research but are supporting the development of skills for practical and effective environmental monitoring.

Taking calibration to the extremes

Accurate assessment of climate change relies on a world-wide network of atmospheric monitoring stations that provide high-quality data, which is comparable regardless of where it's collected.

The EMRP project *Metrology for pressure, temperature, humidity and airspeed in the atmosphere* is taking traceability to remote monitoring locations through a newly-developed portable calibration chamber for temperature, humidity and pressure sensors, known as EDIE.

EDIE was temporarily installed at Ny-Ålesund, a research community in Svalbard, enabling the island's atmospheric monitoring instruments to benefit from traceable calibration without having to be transported to distant calibration laboratories and unavailable for long periods of time. EDIE has, for the first time, enabled on-site calibration of the ground instruments which contribute to the Global Climate Observing System Reference Upper-Air Network, in conditions closer to those encountered during operation in the harsh Arctic environment.

Further developments to EDIE are underway to make a more robust, compact version suitable for long-term installation in Ny-Ålesund - a first step towards a permanent Arctic calibration laboratory that will support multi-national climate observation and research at Svalbard.

Protecting Europe's water resources

The European Water Framework Directive (WFD) aims to protect and improve water quality through legal limits on a wide range of known pollutants.

The EMRP project *Traceable measurements for monitoring critical pollutants under the European Water Framework Directive* developed reference methods, based on different mass spectrometry techniques, for measuring levels of the toxic pollutant TBT in real water samples. This enables testing labs to benchmark their methods, demonstrate compliance with regulation, and perform water monitoring services more accurately, efficiently and economically.

The improved method developed in the project has already been adopted by IPROMA, an organisation contracted for water quality measurements by numerous Spanish Regional Authorities. IPROMA can now offer its clients an improved low-level TBT concentration test, enabling them to demonstrate that TBT levels in the

open water systems used to supply cities and towns meet the requirements of the WFD. The new method is more efficient, requiring less time and labour, and costs 20 % less to implement than its predecessor.

The project team also provided well-characterised reference materials to enable CEN to validate test methods in support of the WFD and provided advice to a working group of the CEN Technical Committee on Water Analysis. This work contributed to three draft standards developed by CEN for the analysis of the pollutants TBT, PBDE and PAH, which were published in 2015. The adoption of the CEN standards and traceable measurements will improve pollutant testing across Europe and help keep priority hazardous substances in waters at a safe level.

Tackling nuclear waste

Research carried out within the EMRP project *Metrology for radioactive waste management* has enabled the construction of the first dedicated transportable nuclear waste assessment facility, which offers a cost-effective solution to the growing problem of nuclear waste disposal.

Developed by ENVINET, a leading provider of products and services for environmental radiation monitoring, the facility takes new measurement methods developed within the project directly to nuclear decommissioning sites. The improved accuracy and speed of the results enable efficient on-site measurements - in particular, correct identification of waste suitable for free release should avoid the significant costs associated with unnecessary long-term storage.

Within the project, ENVINET was able to both validate the transportable facility and also demonstrate to the Czech authorities it had developed the expertise needed to meet stringent criteria governing the free release of nuclear waste. Subsequently, the first consignments of 150 tonnes of accumulated waste at the ÚJV Řež site in the Czech Republic have been accurately and efficiently sorted prior to release for disposal, and the facility will next be used at a decommissioning site in Italy.

INDUSTRY THEME CASE STUDIES

Better heat-treatment process control

ALOtec, a German provider of materials processing services to the manufacturing sector, has improved the performance of its laser-hardening process. Laser hardening is a heat-treatment technique and precise temperature monitoring is required to control the process to ensure high-quality products and minimal waste.

Working with the EMRP project *High temperature metrology for industrial applications (>1000 °C)*, ALOtec tested the portable 'fixed-point' temperature device developed in the project on its laser-hardening system, demonstrating its suitability as an in-situ calibration tool to correct the thermometers that control the process. Testing revealed that the device could correct for large deviations from the ideal processing temperature, where a deviation of 10 °C above or below the required temperature can cause faulty parts. The information gained enabled ALOtec to optimise its laser-hardening process and provide an improved service to its customers in the manufacturing automotive and power generation sectors and mould and tool making industries.

Improving nuclear reactor safety

The Alternative Energies and Atomic Energy Commission (CEA) has become the first user of high temperature cells developed by the EMRP project *High temperature metrology for industrial applications (>1000 ˚C)*. These new temperature cells are helping the CEA research how nuclear reactor containment materials would respond to both the high temperatures and radioactive materials present in the event of a severe accident. This will aid design of safer nuclear facilities, and have wider implications for nuclear reactor safety research, design and energy use.

This EMRP project overcame longstanding problems of measurement uncertainties introduced by non-contact thermometer drift and contamination of measurement observation windows in the harsh environments in industrial furnaces.

Investigating nano-defects

Keysight Technologies Inc, a major manufacturer of test and measurement equipment, can now offer customers accurate, traceably-calibrated Atomic Force Microscopy-based near-field scanning microscopes (NSMMs) for measuring the electromagnetic properties of nano-scale electronic circuits.

Using reference materials and calibration methods developed by the EMRP project *Electromagnetic Characterisation of Materials for Industrial Applications up to Microwave Frequencies*, Keysight has been able to generate a traceable calibration route for its NSMM instruments. Upgrades to Keysight's¬ analysis software are also being implemented to incorporate the project's models and algorithms providing improved accuracy to analytical results.

The calibration techniques developed by the project give NSMM measurements traceability, making NSMM viable for material electromagnetic characterisation measurements offering an improved method for quality control of the next generation of microchips, and supporting the development of new materials for future generations of faster electronics.

High-performance self-heating materials

The Jožef Stefan Institute (IJS) in Slovenia, has implemented a new measurement system for characterising positive temperature coefficient of resistivity (PTCR) ceramics. PTCR ceramics become extremely resistive when heated beyond a threshold temperature, making them ideal for use as PTC thermistors delivering temperature control in electronic devices.

IJS develops prototype PTCR ceramic materials for its customers in the electronics industry and was looking to reduce costs through a reliable, automated measurement system for characterising samples. New measurement test cells for PTCR ceramics were developed within the EMRP project *Electromagnetic characterisation of materials for industrial applications up to microwave frequencies* and automated for use in IJS's materials development facility.

The new system has enabled IJS to reduce the time taken to develop and test novel PTCR ceramics. STELEM, a major European producer of PTC thermistors used in domestic appliances and vehicles, is using the facilities at IJS to provide accurate characterisation of the components in its products, assuring their performance.

Pressure strengthened engines

Measurement instrument supplier, HBM, and high pressure systems supplier, Maximator, have been two early beneficiaries of the new high pressure facility developed by the EMRP project *High pressure metrology for industrial applications*.

HBM used the facility to calibrate one of its high pressure sensors, P3MB Blue Line Top Class transducer©, creating an in-house standard which allows them to calibrate other sensors and provide reliable high pressure measurement services to its customers who develop high pressure technologies.

Maximator used the facility to verify its autofrettage systems, which use high pressure to strengthen materials. This has provided assurance to its automotive customers that its systems meet the pressures required for industrial strengthening processes for new, lower emissions diesel engines. This is helping those customers meet new EU emissions standards and so remain competitive.

Confidence in recycled steel

Two major steel recycling companies, Sidenor Aceros Especiales and Cyclife Sweden AB (formerly part of Studsvik NuclearAB), have adopted new calibration standards developed by the EMRP project *Ionising radiation metrology for the metallurgical industry* to assure the performance of their radioactivity monitoring systems.

Almost half the steel produced in Europe is recycled from scrap materials, some of which may be radioactively contaminated, such as waste from industry, medical facilities and decommissioned nuclear power plants. EU Council Regulation 333/2011 requires scrap metal recycling companies to provide certificates of radioactive content for each consignment produced. However, until recently, there were no calibration standards for steel in the forms commonly encountered in steel recycling.

Sidenor, a leading steel recycler in Europe, is using the standards as part of weekly quality assurance checks of its radioactivity monitoring systems, giving customers confidence in the contamination-free certificates issued.

Cyclife is one of only a few steel producers able to recycle radioactive steel from the nuclear industry. Cyclife used the project's calibration standards to confirm the response of its radioactivity detectors, generating greater confidence in the measurements they routinely make of recycled steel.

Plastic deformation testing

Anton Paar, a specialist in instruments for materials characterisation, has developed a new instrument for plastics and upgraded their existing product range. Through interaction with the EMRP project *Dynamic*

mechanical properties and long term deformation behaviour of viscous materials, Anton Paar gained confidence in their instrument's excellent stability and trialled a prototype specifically for the plastics testing market. They are now marketing a new nano-indentation test instrument for plastics with improved load control and incorporating the project's materials property model into its software. Similar upgrades have also been added across Anton Paar's nano-test instrument range. It has been estimated that over 15 million Euro in increased sales will result from the introduction of these new and upgraded Anton Paar instruments.

The project's testing methodology has contributed to the development of a new ISO standard. This standard will help plastics manufacturers to understand how new feedstocks affect the variability of plastics and predict their behaviour and stability over their service life.

Validating high-performance polymers

Mahr GmbH, a leading manufacturer of measurement equipment, has optimized its profilometers to provide reliable measurements of the polymers used in high-performance products such as electronic coatings and medical implants.

Profilometer measurements of surface features are used for quality assurance processes. However, polymers are relatively soft and can be easily deformed by the measurement process. Mahr used new reference materials developed in the EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials* to assess the performance of its profilometers when measuring polymers.

The knowledge gained through this assessment, along with correction algorithms also developed by the project, helped Mahr to control its profilometers' measuring force at low loads. This significantly reduces surface damage and measurement problems caused by material accumulating on the profilometer probe. Applications of Mahr's improved profilometers include measurements of plastic optics, as well as diamond-turned moulds for optical components.

Modelling material change

The Saxonian Institute, a surface mechanics consultancy, has extended and validated their models used to predict in service performance of material surfaces using highly accurate measurement data generated by the EMRP project *Dynamic mechanical properties and long term deformation behaviour of viscous materials*.

Using this data Saxonian were able to improve their material surface deformation modelling software FilmDoctor©. This relates different surface properties to each other and enables predictions of mechanical properties to be made based on a smaller range of measurements, reducing the need for extensive testing.

The validated Saxonian models are already being used to reduce research and testing time for a wide range of industries, including automotive, engineering and consumer products. For example, one customer of Saxonian, instrument manufacturer Anton Paar has implemented these models into materials nano-testing instruments, improving their ability to provide detailed material property measurements. The FP7 Project, iStress, has also received licences to use a modified Saxonian model as a design aid for predicting properties of novel new reduced wear coatings for engine fuel injector research, reducing the number of variants to be tested by homing in on the required coating properties.

Advancing quantum communications

Toshiba has used the results of an EMRP project in the first public demonstration of a prototype communications system secured using Quantum Key Distribution (QKD). QKD, which shares encryption keys using single photons, offers a level of security beyond that possible with classical communication techniques.

The measurement capabilities developed as part of the EMRP project *Metrology for industrial quantum communication technologies* were used to characterise Toshiba's laser system, a crucial element in the prototype communications system. After this performance validation, Toshiba had confidence in the laser's use as a single-photon transmitter, and it was used as part of the first public demonstration of a QKD system using commercially-available components on a standard fibre optic network.

The success of this demonstration, conducted at telecoms company BT, provides validation of this next-generation communications technology and is an important step towards the widespread implementation of QKD networks for secure data transmission.

Building trust in quantum technologies

Micro Photon Devices (MPD), a research establishment of Microgate Srl, a leading producer of professional timing and adaptive optics systems, has improved the accuracy of its single-photon counters' specifications

using the new detector characterisation facility developed within the EMRP project *Metrology for industrial quantum communication technologies*.

Single-photon detectors are the key components underpinning many new and emerging photonic technologies. MPD produces single-photon counters based on these detectors, specifically designed and optimized for applications requiring low-noise and low-power measurements, such as single molecule detection or atmospheric sensing. Precise characterisation at the new facility gives MPD's customers in the research and development sector greater confidence in the performance of its detectors.

Reliable specifications for the components underpinning quantum communications will build end-user confidence and accelerate the introduction of next-generation quantum technologies.

High-performance thin film technologies

Plasma Quest, a developer of thin film materials and deposition technology for customers in the electronics industry, has developed a new, cost-effective production technique for the high-performance barrier layers used to protect advanced thin-film products.

Plasma Quest used a new facility established by the EMRP project *Metrology for the manufacturing of thin films* to test the effect of different production techniques on barrier layer quality. This enabled the company to successfully demonstrate a new technique that enables high-volume production of barrier layers unhampered by dust in the production environment.

The ability to create effective barrier layers without the expense of maintaining clean room conditions will significantly reduce production costs without any reduction in product performance, supporting the development of durable thin film devices, reducing costs and opening new markets. Plasma Quest has already received enquiries from several manufacturers of mobile phone screens looking to implement the new technique.

Advanced magnetic sensing

Bartington Instruments, a UK-based manufacturer of high-performance magnetic fluxgate sensors, validated the performance of its sensors across an extended temperature range using a new magnetic field calibration facility established by the EMRP project *Metrology for advanced industrial magnetics*. Bartington used the results to upgrade its own measurement procedures and validate the performance of in-house test equipment.

RAL Space, at the Rutherford Appleton Laboratory (RAL) in the UK, used Bartington's validated sensors as part of the preparation of navigational instruments for future gravitational astronomy missions like LISA. These missions require spacecraft to be 'magnetically clean' and Bartington's sensors correct for the effects of small magnetic fields induced by spacecraft components.

This is just one early example of the impact created by the new magnetic field calibration facility, which will benefit not only the space industry, but all industries that require magnetic sensor calibration at a greater accuracy and over a more extended temperature range.

Under pressure: sensors for new engines

Kistler Instrumente AG, a leading Swiss manufacturer of dynamic pressure sensors, was one of the first users of a new calibration facility which tested the performance of its pressure sensors under dynamically changing pressure conditions. Kistler supplies sensors, electronics and software to a wide range of industries. They are proposing to use the new facility, validated as part of the EMRP project *Dynamic: Traceable Dynamic Measurement of Mechanical Quantities*, in the development of new prototype sensors. These sensors must perform effectively under extreme conditions, and contribute to engine development aiming to reduce emissions and enhance efficiency and power.

The shock tube facility provides companies with more realistic and traceable measurements, as existing calibration under static conditions differ from those experienced in service and can introduce measurement errors. This method to assure the performance of sensors in dynamically changing pressure extremes has applications in the European automotive, aerospace and defence industries, where improved sensor validation contributes to competitiveness.

Measuring dynamic torque

HBM, an international supplier of measurement instruments, has created a more accurate torque sensor suitable for dynamic measurements in engine performance testing. Using new dynamic torque facilities developed in the EMRP project *Traceable Dynamic Measurement of Mechanical Quantities*, HBM tested its MX410 prototype conditioning amplifier. The results revealed that transducers undergoing dynamic conditions produce signals

over a wider frequency range than anticipated, leading to potential response errors. To rectify this, HBM upgraded its amplifier firmware to improve signal analysis and create a more accurate product suitable for dynamic measurements. This has now been launched as the HBM MX410B conditioning amplifier.

Accurately measuring torque gives insight into how power is transferred from an engine to a spinning part, such as a wheel, drill bit, or turbine blade and is key to understanding inefficiencies across these systems.

Supporting high-quality consumer optics

Mahr GmbH, a leading metrology instrument manufacturer has developed a new Tilted-Wave Interferometer, which is capable of measuring the free-form lenses used in high-quality consumer optics, such as cameras and DVD players, faster and with greater accuracy than previously possible.

Mahr tested a prototype device as part of the EMRP project *Optical and tactile metrology for absolute form characterisation*, and used the knowledge gained to upgrade the instrument's mechanical and electronic components, increasing the accuracy of its measurements. Algorithms used to process the data were also improved within the project, leading to more accurate results.

The ability to offer its customers a faster, cheaper and more accurate way of characterising free-form lenses means the new instrument will give Mahr a commercial edge in an increasingly demanding and rapidly-growing market. Manufacturers purchasing the instrument will benefit from greater control during production processes, increasing confidence in the quality of their products and the capability to develop higher-quality, more innovative products.

Supporting the Belgian diamond industry

SMD-ENS of Belgium's FPS Economy and instrumentation company AC Optomechanix have developed a new scanning contactless measurement head for the Zeiss F25 micro co-ordinate measurement machine to significantly improve the accuracy with which diamonds can be measured.

SMD-ENS and AC Optomechanix used the improved measurement strategies developed in the EMRP project *Optical and tactile metrology for absolute form characterisation* to optimise their measurement head during the design stage. The improved head, which will be operational within the next year, now achieves measurement uncertainties below the level needed by the Belgian diamond industry to guarantee the quality and value of its products.

The results of the project will lead to more accurately calibrated commercial instrumentation, which in turn will enable diamond facets to be measured more accurately, leading to a better distinction between the various diamond grades. By encouraging trade through increased consumer confidence, the infrastructure provided supports the continued success of an industry at the heart of the Belgian economy.

New standards for nano-testing

Friction and wear in industrial processes wastes energy and degrades materials. Durable engineered surfaces that reduce friction and wear, based on nanoscale surface coatings, can be used to develop high-performance products and improve process efficiency in transport, energy generation, manufacturing and mineral extraction.

The EMRP project *Metrology to assess the durability and function of engineered surfaces* developed best measurement practice in testing nano-material coatings, improving the accuracy of low-level friction and wear measurements on engineered surfaces.

The best practice guidance has contributed to a new ISO standard for testing diamond-like carbon films and a new standard being developed by the ISO Technical Committee on Nanotechnologies to support the wider adoption of this technique.

Having these new standardised measurements in place will support the development of improved products, with longer lifetimes and greater efficiency, across many industrial sectors.

Temperature and friction testing

The EMRP project *Metrology to assess the durability and function of engineered surfaces* has developed a new technique to improve the reliability of friction measurements for industrial components. By incorporating a temperature sensitive ruby tip into existing friction probes, it is now possible to measure friction and temperature with a single probe. This overcomes a significant industrial problem, in which high temperatures at the point of contact during testing were compromising the measurements of the material response.

The new probe provides accurate temperature measurements, which can be offset when calculating the effects of friction, leading to a much better understanding of how engineered surfaces respond to friction. The probe is being patented and two manufacturers are now looking to incorporate it into their instruments. The improved measurements will help manufactures in a range of industries - from automotive to mining - develop more durable products.

Driving Nano-precision positioning

TETRA, a developer of systems and components for sensors, robotics and automation, has developed a novel optical sensor for linear drives.

TETRA was commissioned by the EMRP project *Metrology to assess the durability and function of engineered surfaces* to develop a new optical sensor – the critical component in a linear positioning drive. TETRA's sensor meets the project's exacting requirements and is both compact and capable of positioning with nanometre precision.

The new sensor has wider application than the project and TETRA are incorporating this improved optical sensor into their highly precise positioning systems giving them a market-leading capability. Increased precision in operation of linear drives will improve positioning accuracy in many fields, from the precise location of surgical tools used in eye-surgery, to microscope stages, to the positioning of micro-components during manufacture in the aerospace and automotive industries.

3D surface wear imaging

Alicona Imaging GmbH has validated its MeX 3D measurement software, which turns highly accurate 2D images from scanning electron microscopes (SEMs) into 3D visualisations of surface features.

The EMRP project *Metrology to assess the durability and function of engineered surfaces* made extensive measurements of surfaces before and after wear. Simulations of SEM images of typical wear features from a range of angles were then used to develop a highly-accurate model. Alicona was able to use these accurate and validated images to make comparisons with its own MeX 3D visualisation software, confirming the software's accuracy and providing independent validation.

This technology has applications in a wide range of surface engineering industries. One key application is helping manufacturers of machine tools better understand surface wear and so develop more durable products, which will offer substantial time and cost savings to engineering companies.

Faster vacuums for faster production

INFICON, a manufacturer of world-class instruments for gas analysis, used a new vacuum gauge calibration facility to accelerate the development of its new fast-response gauge. The facility, developed by the EMRP project *Vacuum metrology for production environments*, is capable of providing a well-defined rapid change in pressure, from 100 kPa down to 100 Pa in just 23 milliseconds. This enabled INFICON to demonstrate that its new Stripe™ High-speed Capacitance Diaphragm Gauge has a response time twenty times faster than the previous model and validates INFICON's claim that it is the 'fastest gauge in the world'.

Vacuum chambers are an important tool during manufacture of high-tech and high-value products such as semiconductors, photovoltaics and LED lighting. Fast, accurate measurements of vacuum play an important role in process control as product quality, process efficiency, and productivity all depend on how quickly and how consistently a vacuum can be applied. Improved vacuum measurements will assist Europe's precision manufacturing industries to develop more cost effective products and processes.

Ultra-sensitive temperature sensors

Three instrumentation manufacturers have obtained commercial benefits from a new prototype device for ambient temperature measurements developed by the EMRP project *Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures*.

Project collaborator MPro is commercialising the prototype to take better temperature control to a wider range of instrument manufacturers. This will lead to improved accuracy throughout high precision manufacturing, seen as critical by these industries as they develop ever smaller and more complex parts.

SIOS Messtechnik has been able to use the prototype to investigate how its precision dimension measurement instruments are affected by small changes in temperature in industrial environments. This has enabled it to develop calculations to offset these effects, providing greater accuracy to its customers.

An additional industry impact has been that Magnicon, which supplied a low noise amplifier for the prototype, has used the project findings to identify a new line of business in temperature measurements.

Non-destructive surface measurements

Bruker Nano Analytics makes Energy Dispersive X-Ray Spectroscopy (EDS) instruments for non-destructive measurement of surface structure. It is one of several manufacturers that have improved instrument accuracy and confidence through involvement in the EMRP project *Traceable Quantitative Surface Chemical Analysis for Industrial Applications*.

The project developed new SI traceable Certified Reference Materials (CRMs) with carefully created and certified surface chemistries. Using the new CRMs, Bruker identified stability improvements for its EDS instruments which led to the development of a new more accurate instrument. Access to CRMs are proving a valuable selling point for new and existing systems, helping Bruker maintain market share. This in turn is delivering higher levels of accuracy to the innovative products and processes produced by Bruker's customers, which include new catalysts for car exhaust cleaning and coatings to make faster and more durable microelectronics.

Measuring organic layers

Kratos Analytical Ltd, which makes state-of-the-art spectrometers for material research, has proved the viability of a new measurement technique for layered organic surfaces using reference standards developed in the EMRP project *Traceable quantitative surface chemical analysis for industrial applications*. This technique is now helping sectors such as electronics and pharmaceuticals produce new, innovative products.

The project developed organic reference materials which validate and improve the accuracy of X-ray photoelectron spectroscopy (XPS), a technique being used by Kratos's customers to measure layered organic surfaces by removing and measuring one layer at a time. With accurate calibration, Kratos can now be confident in the use of XPS for surface chemistry research and product quality assurance. As a result, this technique is now being used to improve the surface chemistry of innovative multi-layer organic products used for solar cells, touchscreens and slow-release drug administration.

Surface analysis for Alzheimer's

SP Technical Research Institute of Sweden has used traceable time-of-flight secondary ion mass spectrometry

SP Technical Research Institute of Sweden has used traceable time-of-flight secondary ion mass spectrometry (ToF-SIMS) to help investigate the causes of Alzheimer's disease.

SP used a new technique, developed by the EMRP project *Traceable quantitative surface chemical analysis for industrial applications*, to identify plaques and tangles typical in the brains of patients with Alzheimer's disease. The new technique is the first to enable traceable quantitative analysis with ToF-SIMS, allowing researchers to study the characteristic features of Alzheimer's disease with greater confidence. This new technique will ultimately support further research into the causes of Alzheimer's and other diseases.

Semiconductor measurements

Advanced Mask Technology Center (AMTC), a joint venture of GLOBALFOUNDRIES and Toppan Photomask, is developing photomasks used in the production of semiconductor devices. They are using calibration methods developed in the EMRP project Scatterometry: *Metrology of small structures for the manufacturing of electronic and optical devices* to help measure the very small features on next generation photomasks.

AMTC can now make traceable measurements with its scatterometry instruments. This has helped it to verify advanced photomasks with smaller features, below 80 nm, which will be used by AMTC's parent company GLOBALFOUNDRIES to develop 14 nm and 7 nm technology.

The project results allow companies like AMTC to calibrate metrology tools based on scatterometry to improve production processes and develop more precise technologies. This supports the semiconductor industry in its mission to create ever smaller and faster products, fostering greater innovation and international competitiveness.

Modelling small surface features

JCMwave, which produces finite element analysis (FEA) software for nano-optic design, has validated a new application of its software, for analysing the dimensions of small electronic features measured using scatterometry.

Through the EMRP project *Metrology of small structures for the manufacturing of electronic and optical devices*, FEA was investigated and demonstrated to be a viable technique for processing scatterometric data to provide accurate, rapid measurements of surface feature dimensions. This removes a barrier to the uptake of scatterometry, and provides the electronics industry with fast, accurate, surface dimension measurements in a production environment, speeding the development of smaller electronics.

HEALTH THEME CASE STUDIES

Improving radiotherapy success

Elekta and Philips, two leading companies in radiotherapy and MRI imaging, are jointly developing an innovative combined MRI-linac for use in cancer treatment. A new calibration method developed by the EMRP project *Metrology for next-generation safety standards and equipment in MRI* is an essential part of the calibration of the new MRI-linac combination. Elekta and Philips are now working towards the introduction of the MRI-linac combination in to clinical practice in 2017. This will support improved treatment of tumour cells, while minimising exposure of surrounding healthy tissue. MRI-guided radiotherapy, delivered by MRI-linacs, is set to further improve the success of radiotherapy by providing more detailed images of patients during treatment, enabling clinicians to better target tumours. The robust and easy-to-perform calibration method developed by the project provides essential support to the safe, effective introduction of this innovative, high-value medical technology and the benefits it brings to Europe's economy and quality of life for citizens.

MRI standards spur innovation

The magnetic fields of powerful MRI machines can cause medical staff to suffer "motion-induced" effects such as sensations of nausea, vertigo and disturbed vision. This may have serious patient safety implications as new MRI-guided surgical procedures are introduced. National health authorities and regulators rely on reference documents from International safety standardization organizations when setting legal limits for medical clinician and patient safety. One such reference is the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2014 publication on specific exposure levels for staff performing tasks near operating MRI machines. These are used in the EU Directive 2013/35/EU which governs medical clinician safety near magnetic fields. The EMRP project *Metrology for next-generation safety standards and equipment in MRI's* assessment procedure provides hospitals with a strategy for evaluating the safety of staff actions when planning new surgical procedures. This enables hospitals and staff to have greater confidence when identifying critical situations which may exceed safety limits and permits the early introduction of strategies to reduce debilitating "motion-induced" sensations an important step towards the safe performance of new MRI guided surgical procedures.

High resolution brain scans

Before high resolution 7 Teslar (T) MRI scanners are introduced into clinics for diagnosing diseases like Alzheimer's, Parkinson's and Multiple Sclerosis, they need to demonstrate that they do not generate potentially harmful temperature rises in the body. Research performed in the EMRP project *Metrology for next-generation safety standards and equipment in MRI* has helped to establish a safe design for this high-end technology, paving the way for its adoption into routine clinical use. The project developed numerical procedures to compute radio-frequency fields and hence temperature rises throughout the patient's body, and measurement tools to check and validate these simulations. Novel measurement tools and protocols are now available to more accurately calculate exposure levels and to demonstrate 7T MRI scanners are safe to use. Project findings will be adopted in a new international IEC standard, enabling safety verification and certification of 7T MRI scanners. Demonstrating the safety of these new machines clears the path to clinical adoption, opening up markets for manufacturers of these machines. This will provide hospitals with access to technology allowing the earlier diagnosis, and consequently earlier intervention in degenerative brain diseases such as Alzheimer's, Parkinson's and Multiple Sclerosis.

Safer MRI for metal implant wearers

Philips, a global electronics and medical technology company, has upgraded its MRI scanners so that they can be used safely for imaging patients with metal implants such as hip replacements or wires in pace makers. Using measurement methods and simulations developed by the EMRP project, *Metrology for next-generation safety standards and equipment in MRI*, Philips validated a new innovative feature that uses the measurement of the MRI's radiofrequency fields and dynamic magnetic field strength to determine potential tissue heating. Operators

can then make adjustments to MRI settings to ensure patient safety. Philips believe that this new innovative method for determining tissue heating caused by MRI scanning in real-time will give the company a market leading capability. An improved understanding of the heating effects of MRI magnetic fields on metal implants will open up safer MRI scanning to an increased number of patients.

Targeting tumours accurately

PTW, a market leader in dosimetry equipment for radiation therapy, has commercialised the prototype diamond detector developed during a previous Euramet project. The PTW microDiamond detector has now been tested in photon, electron, proton and carbon ion therapy beams during the EMRP project *Metrology for radiotherapy using complex radiation fields*. This demonstrated its capability to be used with all types of radiotherapy and not degrade in the radiation as other detectors do. A set of new correction factors for the microDiamond were established in this EMRP project that opens up the potential for this novel radiation proof instrument to be used to make the highest quality calibration for radiotherapy machines. Greater accuracy in measuring multi-beam radiotherapy delivery will give clinicians increased confidence in being able to match planned dose to that delivered, opening up further the potential for individually designed patient therapies.

Accurate ultrasound cancer therapies

High Intensity Focused Ultrasound, HIFU, a promising new cancer treatment which uses multiple extremely focused ultrasound beams to destroy tumours, has taken a major step towards widespread clinical use. The EMRP project, *Dosimetry for Ultrasound Therapy*, has provided traceable calibration routes for HIFU beams by validating a new ultrasound calibration instrument, which is being commercialised by ultrasound measurement specialist GAMPT mbH. GAMPT and PTB developed a hydrophone – an underwater microphone – which was tested using a new calibration and testing facility for HIFU. By calibrating the new hydrophone a traceability chain is created for clinical HIFU instruments, ensuring confidence in measurements of beam strength, and so allowing clinics to accurately calculate individual treatment regime's for patients. GAMPT has now commercialised the world's first Hydrophone capable of measuring HIFU beams at clinical power providing a vital calibration tool for manufacturers and users of HIFU instruments. Whilst still in its early days, HIFU is already being used to treat prostate cancer and neural brain conditions, and is undergoing trials in many other areas. The HIFU calibration capability, the GAMPT hydrophone and best practice have contributed to IEC standards – providing the infrastructure to make HIFU a reality for cancer treatment.

Accurate dose means effective therapy

MRT can target cancer cells while minimising harm to healthy tissue, however there are no standardised methods to measure the actual dose delivered at the cancer tumour site or to critical normal tissues such as the kidneys or bone marrow. This European project was the first to develop standardised methods for the measurement of absorbed dose in individual patients undergoing MRT. Using the project's methods clinicians will be able to plan the treatments of individual patients and demonstrate that the MRT doses have been delivered safely. The International Atomic Energy Agency (IAEA) is producing a new Health Series publication on Dosimetry for Radiopharmaceutical Therapy to assist so clinicians can accurately deliver Molecular radiotherapy (MRT). New processes and methodologies developed during the EMRP project *Metrology for molecular radiotherapy* will be incorporated into this publication which forms a best practice and reference document for the MRT community. This will help to increase the effective use of this cancer treatment.

Targeting cancer

Sirtex, an international company producing novel palliative cancer treatments, was one of the first to benefit from greater calibration accuracy for their yittrium-90 microspheres. The project *Metrology for molecular radiotherapy* examined the radioactivity of the microspheres before use and at the tumour site. The project determined all the factors that contribute to calibration of the drug's activity before it is given to a patient, from the importance of a uniform container to understanding the hospital activity meter's response to the yittrium-90. As a result of the project, Sirtex now have a better understanding of what can affect activity measurements and are implementing changes to improve traceability and accuracy of measurement. This, coupled with research linking microsphere activity to quantitative imaging will support the wider adoption of yittrium-90 microspheres as a safe and effective palliative cancer treatment. These novel MRT treatments have future potential for use as front line cancer treatments once a robust link between activity and therapeutic dose, and thus treatment response, is established.

Traceability boost for cancer therapy

A portable counting system based on counting flashes of light generated as radioactive decay occurs in a scintillant, has now been tested for use with the high-activity, high-energy, radioactive drugs used in nuclear medicine clinics, such as yittrium-90. The instrument is self-calibrating, and can be used to directly calibrate activity meters in nuclear medicine clinics. Test calibrations were performed at the Italian cancer centres based at the Regina Elena National Cancer Institute and Ospedale Pediatrico Bambino Gesù, as part of the EMRP project *Metrology for molecular radiotherapy*. Sirtex, a company that markets yittrium-90 microsphere technology for molecular radiotherapy (MRT) is keen to have institutions use this direct radioactivity calibration system to ensure traceability and confirm the activity of therapy given to patients. Use of the new system will lead to greater accuracy in the radioactive measurements which are used in calculations of radiation dose to both cancer tissue and to the surrounding healthy tissue. This enables the generation of very accurate therapy delivery data for specific patients and enables better treatment adjustments to individual patient's needs.

Better infant hearing tests

Acoustic Metrology Ltd (AML) a UKAS accredited calibration laboratory, evaluated a new prototype ear simulator for babies and small children. The prototype was developed specifically for calibrating the small head phones used in infant hearing assessments by the EMRP project *Metrology for a universal ear simulator and the perception of non-audible sound*. AML demonstrated that current equipment and methods could be easily adapted to make use of the new calibration ear simulator - an important consideration in the ease of adoption of any new calibration device in hospitals. A new IEC working group has been set up to review the current standard and will be incorporating the use of infant sized ear simulators developed in this project, as well as other improvements to child hearing assessment testing. Access to these infant ear simulators, backed by international standards, will lead to greater accuracy in national hearing assessment tests, and new improved instruments for measuring child hearing. This in turn will lead to more accurate diagnoses and early intervention strategies, helping to promote language development in affected infants.

Faster TB diagnosis

Modern pathological laboratories increasingly use a technique called polymerase chain reaction (PCR) to specifically detect bacterial DNA, if present in patient samples, in a matter of hours for analysis and disease diagnosis. Great Ormond Street Hospital, an important TB pathology laboratory in the UK, participated in a recent performance exercise that confirmed their in-house PCR techniques were very accurate in correctly detecting TB bacteria types. The exercise used a high accuracy digital PCR (dPCR) method, which rapidly amplifies and counts individual bacterial DNA targets, to assign copy number values to reference materials to enable greater measurement traceability than previously possible. Traceabilty, via the dPCR technique was established in the EMRP project *Metrology for monitoring infectious diseases, antimicrobial resistance, and harmful micro-organisms*. To take the calibration to pathology laboratories the project developed a well characterised TB reference material based on bacterial samples supplied by the UCL centre for Clinical Microbiology based at the Royal Free Hospital. Pathology laboratories using PCR methods to rapidly amplify TB bacterial DNA can now have confidence in the accurate diagnosis of the type and severity of TB infection in days rather than weeks. This is important as it enables a more rapid and rigorous TB diagnosis and will reduce initial standard TB treatment with long established antibiotic regimens to which TB is becoming increasingly resistant.

Better flow measurement, safer patients

The Hospital Garcia de Orta in Portugal was one of the first to use a new low flow calibration service for its drug infusion systems. As a result of validated facilities developed in the EMRP project *Metrology for Drug Delivery*, calibrations can now be performed in Europe at the very low flow rates important for infusion drug delivery. The project also investigated how varying the supplier of disposable infusion line components affects the rate of drug delivery. The team discovered that for reliable infusion line operation it is best to use only consumables from the infusion pump manufacturer. Performing calibrations using the system as it will be assembled for use is essential to ensure effective and safe infusion drug delivery. The Hospital Garcia de Orta now has greater confidence in its QA system and ensures that only infusion line consumables from a single manufacturer are used in the hospital as a result of using the new calibration system. By calibrating its infusion lines from the pump to the patient using its precisely calibrated 'master' meter it can confirm flow rates in its clinical units. This ensures that vulnerable patients will receive vital drugs at the prescribed infusion.

Increasing access to anaemia testing

A new diagnostic test for anaemia, which is less toxic and cheaper than the current test, has taken its first steps towards international recognition as a reference method. Timely treatment of anaemia effectively restores health and can raise national productivity levels by as much as 20 % in developing countries. However, the current standard diagnostic test measures blood haemoglobin levels using potassium cyanide, a toxic compound which is difficult to procure and discard. The EMRP project *Metrology for metalloproteins* developed a standardised test method and reference materials, which link haemoglobin measurements to the SI units for the first time. The German standards organisation DIN is incorporating this method into its existing standard on blood sample analysis and has proposed that CEN undertake a new work item on reference methods for determining blood haemoglobin levels. This is an important first step towards the new method's inclusion in an international standard and eventual replacement of the current method, which will reduce the cost of anaemia diagnosis and management.

Counting bio-particles to spot cancer

Extracellular vesicles (microvesicles) are small particles shed into the bloodstream which have potential for use in point-of-care diagnostic devices to detect cancers, diabetes and heart disease. The International Society on Thrombosis and Haemostasis (ISTH) has demonstrated to the extracellular vesicles research community the importance of harmonised measurement results using a new reference material developed in the EMRP project *Metrological characterisation of microvesicles from body fluids as non-invasive diagnostic biomarkers*. Samples containing this reference material, were used in an ISTH funded comparison to 33 research labs. Differences in results across the labs highlighted the need for greater standardisation in the flow cytometry measurements commonly used to count extracellular vesicles. ISTH, with two other influential organisations – the International for Extracellular Vesicles, and the International Society for Advancement of Cytometry – have now formed a new working group to develop guidance on extracellular vesicles measurement practice as a first step towards an IEC standard. This guidance will promote the use of the projects reference materials and changes to instrument operating methods to enable flow cytometers to be better tuned for measuring the small small extracellular vesicle particles present in blood samples.

Spotting inter-cell communications

Izon Science, a manufacturer of bio-particle analysis instruments, has developed and commercialised a simple kit for preparing blood samples for an exciting new area of disease study – extracellular vesicles (EV). The method and kit rely on optimised procedures for collection, preparation using size exclusion chromatography (SEC) and storage of EV developed in the EMRP project *Metrological characterisation of microvesicles* from body fluids as non-invasive diagnostic biomarkers. Two hundred and fifty labs worldwide are now using the iZon kits to filter tiny extracellular vesicles (EV) particles or microvesicles from blood using the project's SEC technique. EV are key in inter-cell communications, and play an important role in the spread of cancer and other diseases. They are generating considerable excitement amongst medical researchers who believe they hold promise for new methods of early diagnosis, drug efficacy studies, and drug delivery mechanisms. This standardised preparation method will encourage the widespread uptake of EV measurements, which it is hoped will lead to major advances in diagnosis and treatment of a wide range of serious diseases.

Simpler disease diagnostics

Chalmers University of Technology in Sweden, has perfected and demonstrated a new cell for detecting biomarkers – molecules in body fluid samples that are indicators of cancers and other diseases. Within the EMRP project Metrology for the characterisation of biomolecular interfaces for diagnostic devices, the measurement cell was used to successfully detect Alzheimer's proteins. It is now being patented prior to commercialisation. Using this simple cell and an easy-to-use optical microscope, important molecular information is now readily available where complex sample preparation by trained staff using specialised equipment was previously needed. Early adopters of this innovative measurement cell are medical researchers and a major drug company, investigating the interaction of biological particles and potential uses of proteins in drug delivery mechanisms. The measurement cell has the potential to be further developed into a simple diagnostic tool for a range of diseases including cancer and infections such as HIV and Hepatitis.

New bio-sample cell for vacuum analysis

A new method for robustly sealing 'wet' biological and organic samples in a measurement cell for vacuum analysis techniques has been rigorously tested. The cell was successfully used for x-ray spectroscopy analyses

during measurements of proteins attached to the cells x-ray transparent window in the EMRP project *Metrology for the characterisation of biomolecular interfaces for diagnostic devices*. Until now the most accurate measurements of bio-samples required 'wet' samples to be freeze-dried so they can be placed in a vacuum, a process which changes their chemistry and has potential to introduce errors. This new measurement cell allows samples to be measured without the need for freeze drying, making measurements more meaningful since the original chemical structure is unchanged. It is expected this will lead to more reliable techniques for spotting early stage diseases and for distinguishing between strains, supporting new drug research and paving the way for the development of new diagnostic methods.

Speeding up drug discovery

A new drug development template developed by the EMRP project *Metrology for biomolecular origin of disease* has enabled Oxford University and Malvern Cosmeceutics to cost effectively identify new drugs for application through skin using an advanced skin penetration system (Lipodisc®). This research team were one of the first to use the project's template based computer model that can identify potential compounds for use as new antimicrobial drugs. The EMRP project *Metrology for biomolecular origin of disease* successfully showed how and where an antibiotic attaches to a microbe's cell membrane using high resolution spectroscopy and used this information to synthesise a single generic computer-based template that enables the prediction of antimicrobial action and resistance. The Oxford and Malvern Cosmeceutics research team is currently seeking funding for a clinical trial to test their novel skin-based drug-delivery technology as an alternative to drug delivery via the digestive system or the use of injections just under the skin. Reducing drug development costs is crucial to encouraging increased research into the new drugs urgently needed to fight an ever rising microbial resistance to our current drug armoury. The EMRP project's new template offers an example of how 'big data' computer modelling can assist pharmaceutical research.

9 Annex D: Bibliographic indicators

Bibliometric indicators

The bibliometric analysis was conducted by Science-Metrix. Below are their definitions of the indicators used.

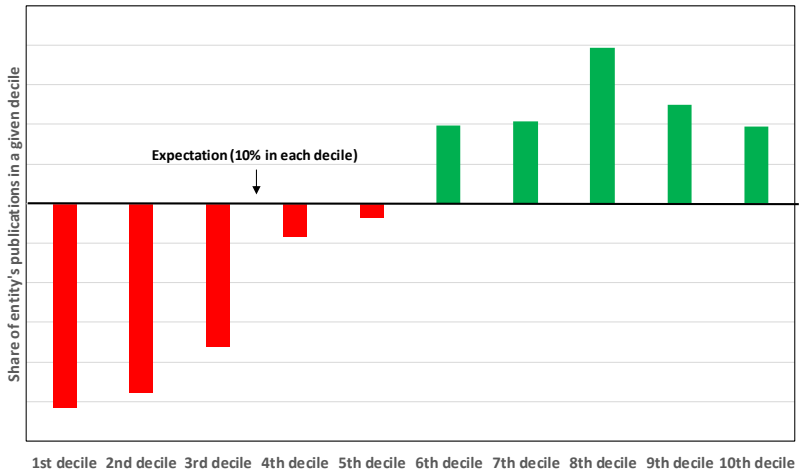
Average of relative citations (ARC)

The average of relative citations (ARC) is an indicator of the average scientific impact of papers produced by a given entity (e.g., a country, an institution) relative to the world average (i.e., the expected number of citations). The number of citations received by each publication is counted for the year in which it was published and all subsequent years (i.e., citation windows of variable length).[14] To account for different citation patterns across scientific subfields and document types (e.g., there are more citations in biomedical research than in mathematics, and reviews include more references and are more cited than articles), as well as to account for differences in the age of publications (i.e., older papers have accumulated citations over a longer period), each publication's citation count is divided by the average citation count of all publications (in Scopus) of the corresponding document type that were published the same year in the same subfield. In this way, one arrives at a relative citation count (RC). The ARC of a given entity is the average of the RCs of the papers belonging to it. An ARC value above 1 means that a given entity is cited more frequently than the world average, while a value below 1 means that its publications receive, on average, fewer citations than the world average.

Citations distribution chart (CDC) and citation distribution index (CDI)

The citation distribution chart (CDC) is a tool that facilitates a simple but nuanced visual inspection of an entity's research impact relative to worldwide performance. To prepare these charts, Science-Metrix divides all publications in a given research area into 10 groups of equal size, or "deciles", based on their RC scores.15 The 1st decile contains the 10 % of publications with the lowest RC scores; the 10th decile contains the 10 % of publications with the highest RC scores.

For a given research entity, it is expected that the RC scores of its publications will follow the global distribution, with an equal number of publications falling in each of the deciles. The CDC for a given entity compares that entity's scientific impact to the global level by showing how its performance compares to the world level in each of the deciles.



Sample of citation distribution chart (CDC)
Source: Prepared by Science-Metrix

[14] For all citation-based measures, a certain amount of time must be allowed for the published work to have an impact on subsequent research, and for articles to be cited. Accordingly, impact measures for the present study can be computed for articles published in 2013 or earlier. Papers published in 2014 or later have not had sufficient time for citations to accrue.

[15] Two adjustments are made in order to ensure high-quality results, and these pertain to (a) cases where a number of publications are tied in their scores, and (b) cases where the total number of publications is not divisible by 10. For the first case (a), papers tied at the margin of two deciles will be grouped together and then divided proportionately to ensure that each decile contains the right number of papers. In the case of the total number of papers not being divisible by 10 (b), papers will be fractioned to ensure that the deciles are always of exactly equal size.

The CDC shows 10 colour-coded bars for a hypothetical entity; each bar represents the relative presence of this entity's papers in each corresponding decile. The world level, in contrast, is represented by the horizontal black line, with no bars, as it represents the uniform distribution of all the publications across the 10 deciles. Thus, the bar's colour shows whether the specific entity has more or fewer publications in that decile than expected (i.e., the horizontal line). Green bars denote production exceeding expectation in that decile, red denotes production below expectation in that decile, and the length of the bar shows how far above/below expectation the entity is in that decile. Consequently, the longer the red bar, the fewer number of articles are found in that decile relative to expectation. Conversely, the longer the green bar, the more publications are to be found in that decile, again relative to expectation. Cases where a decile has no bar associated with it show that the entity's performance is exactly in line with the expectation based on global performance. Accordingly, a CDC with no visible bars shows that the entity in question has 10 % of its papers in the 1st global decile, 10 % of its papers in the 2nd global decile, and so on, which, as previously noted, corresponds to the world distribution of papers based on their RC scores.

Ideally, one would hope to over-perform in the highest deciles, where the most impactful publications are found; similarly, one would hope to underperform in the lowest deciles, where the least impactful publications are found. Thus, strong research performance is shown by long red bars on the left of the CDC and long green bars on the right of the graph. In contrast, weaker research performance is depicted with long green bars on the left side (indicating more publications than expected in the less impactful deciles) and long red bars on the right side (indicating fewer publications than expected in the more impactful deciles). The chart below presents distributions related to best-case, good, bad and worst-case scenarios.

Various scenarios of citation distribution charts (CDC) and their citation distribution index

	Citation Distribution Chart	CDI
Best case scenario		50
Typical best case scenario		25
World level		0
Typical worst case scenario		-25
Worst case scenario		-50

Source: Prepared by Science-Metrix

The content of the CDC can also be summarised numerically using the citation distribution index (CDI). For each decile, the performance of a given research organisation is compared to the global average, and this ratio is then multiplied by the weight corresponding to that decile. Once a score has been produced in this fashion for each decile, they are summed to calculate the CDI for the research organisation. Thus, having a higher-than-expected number of publications in the 1st decile (i.e., the lowest-impact decile) will reduce the CDI more than having a higher-than-expected number of publications in the 2nd decile. The CDI ranges from -50 (worst case scenario) to 50 (best case scenario) with 0 representing parity with the world level.

Highly cited papers top 10 % (HCP_{10})

Highly cited papers (HCP) are publications that received the highest relative citation score (RC) in their respective field. This indicator is frequently used as a proxy to examine research "excellence" because of the high concentration of citations in this elite group of publications. For this study, the top 10 % most cited publications were selected, and data for the institutions were then produced based on these highly cited papers. The 10 % most cited publications in the database were identified using the relative citation (RC) scores of publications. The fraction of an entity's papers falling among these highly cited publications was then computed, which gives the HCP score of that entity. The $HCP_{10\%}$ is also the proportion of publications found in the 10th decile presented in the CDC.

Average of relative impact factors (ARIF)

The ARIF is a *proxy* often used to measure the scientific quality or prestige of the journals in which an entity's papers are published. It is thus based on the average citation rate of the publication venue (measured by the impact factor of journals) instead of the actual publications.

Thomson Reuters calculates an annual impact factor (IF) for each journal based on the number of citations it received in the previous two years, relative to the number of publications it published in the previous two years. Thus, each journal's IF will vary from year to year. For example, the IF of a journal in 2007 is equal to the number of citations to articles published in 2006 (8) and 2005 (15) divided by the number of articles published in 2006 (15) and 2005 (23) (i.e., IF = numerator [23] / denominator [38] = 0.605). However, as pointed out by Archambault

and Larivière, this indicator carries the weight of history and of many choices that were made a long time ago when their effect had not been studied thoroughly.

For example, Moed and colleagues have described the effect of the observed asymmetry between the numerator and denominator of the Thomson Reuters' IF as follows:

> *ISI classifies documents into types. In calculating the nominator of the IF, ISI counts citations to all types of documents, while as citable documents in the denominator ISI includes as a standard only normal articles, notes and reviews. However, editorials, letters and several other types are cited rather frequently in a number of journals. When they are cited, these types do contribute to the citation counts in the IF's numerator, but are not included in the denominator. In a sense, the citations to these documents are "for free*."

In this study, Science-Metrix therefore computes and uses a symmetric IF based on the document types that are used throughout this entire project for producing bibliometric data using a five-year citation window. The IF of publications is calculated by ascribing to them the IF of the journal in which they are published, for the year in which they are published. Subsequently, to account for different citation patterns across subfields of science (e.g., there are more citations in biomedical research than mathematics), each publication's IF is divided by the average IF of all papers that were published the same year in the same subfield to obtain a relative impact factor (RIF). The ARIF of a given entity is the average of its RIFs (i.e., if an institution has 20 publications, the ARIF is the average of 20 RIFs, one per publication). When the ARIF is above 1, it means that an entity scores better than the world average; when it is below 1, it means that on average, an entity publishes in journals that are not cited as often as the world level.

Compared to the other citation impact metrics to be used in this study, the ARIF can be computed up to the most recent year available (i.e., up to 2015).