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A SUMMARY OF SCIENCE METRIX'S BIBLIOMETRIC ASSESSMENT OF THE NATIONAL PHYSICAL LABORATORY'S OUTPUTS ON ADVANCED MANUFACTURING, DATA & DIGITAL, LIFE SCIENCES & HEALTH, AND ENERGY & ENVIRONMENT (2013-2023)

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A Summary of Science Metrix's Bibliometric Assessment of the National Physical Laboratory's Outputs on Advanced Manufacturing, Data & Digital, Life Sciences & Health, and Energy & Environment (2013-2023)

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ABSTRACT

Science-Metrix was commissioned by the National Physical Laboratory (NPL) to conduct a bibliometric study on NPL's publications output over 2013-2023. The analysis evaluated NPL's performance across five research fields: metrology, advanced manufacturing, data & digital, life science & health, and energy & environment, comparing it with 27 other National Metrology Institutions (NMIs). This paper focuses on the findings in advanced manufacturing, data & digital, life science & health, and energy & environment fields - namely "the sectors". NPL ranked amongst the top performing NMIs across all sectors, placing third in research output for life sciences & health and data & digital, second for energy & environment, and fourth for advanced manufacturing. Co-publication indicators demonstrated consistent growth across all sectors, with NPL outperforming the global average, the UK, and other NMIs, with the most notable growth seen in life sciences & health and data & digital. Uptake of NPL's research by the private sector and in policy documents exceeded global and UK levels across all sectors. Collaboration with NPL positively impacted partner institutes across sectors, boosting international collaboration, public-private partnerships, and policy and private sector uptake.

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GLOSSARY/ABBREVIATIONS

With special thanks to:
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EXECUTIVE SUMMARY

The National Measurement System (NMS) serves as a cornerstone of the United Kingdom's (UK) scientific infrastructure, housing cutting-edge laboratories that champion measurement science and technology. These facilities provide the nation with measurement standards that are both accurate and traceable, essential for driving innovation and productivity across various industries. Recognizing the pivotal role of measurement in enhancing the productivity of UK industries, the NMS plays a crucial part in bolstering the nation's prosperity. At the forefront of the NMS, as the UK's leading National Measurement Institute (NMI), stands the National Physical Laboratory (NPL). Established as a government laboratory[1] in 1900, NPL is committed to delivering impactful research, products, and services to the UK. Its research contributions span diverse fields such as emissions monitoring, materials science, quantum, and bioscience, with applications ranging from ship design to global positioning.

Analysts from Science-Metrix conducted a bibliometric study on NPL's publication output in five research fields: metrology, advanced manufacturing, data & digital, life sciences & health, and energy & environment (the last four research fields are "the sectors of NPL[2]"), comparing it with 27 other NMIs[3]. This document offers a simplified digest of the analysis, summarising the key messages from the sectors.

Compared to other four selected NMIs, National Institute of Standards and Technology (NIST), National Metrology Institute of Germany (PTB), and Korea Research Institute for Standard and Science (KRISS), NPL ranked amongst the top performing NMIs across all sectors from 2013 to 2023, placing third in number of publications for life sciences & health and data & digital, second for energy & environment, and fourth for advanced manufacturing. While life sciences & health and data & digital showed strong growth during the first half of the study period, output volume for energy & environment declined by 7.3% annually. Collaboration indicators demonstrated consistent growth across all sectors. NPL outperformed the global average, the UK, and other NMIs, with the most notable growth seen in life sciences & health and data & digital. In energy & environment, NPL ranked second in international collaboration and fourth in public-private collaboration, while in advanced manufacturing, NPL also surpassed the global and UK averages.

However, it is also important to acknowledge that different NMIs operate under different national remits, strategic priorities, and funding environments, which may influence their performance across the key indicators assessed. For instance, some NMIs may receive higher levels of sustained investment or be mandated to prioritize specific sectors due to national policy goals, while others may focus more narrowly on core measurement science. These institutional variations can result in differing capacities for research output, collaboration intensity, or publication impact. As such, while NPL's performance compares favourably across several scientific domains, these rankings should be interpreted with consideration of the broader operational and structural differences between the institutes.

Citation-based indicators varied by sector. NPL achieved strong rankings in citation distribution related indicators for life sciences & health and advanced manufacturing, placing second or third among NMIs. However, in the cases of data & digital and energy & environment, citation scores have declined in recent years. Uptake of NPL's research by the private sector and in policy documents exceeded global and UK levels across all sectors. In life sciences & health, private sector uptake was the highest among NMIs, while data &

[1] Since January 2016, NPL operates as a public corporation as it is a wholly owned company of DSIT.

[2] NPL's scientific groups are labelled across four sectors, namely, Advanced Manufacturing, Data & Digital, Life Sciences & Health, and Energy & Environment.

[3] Please see the list of 27 NMIs in Annex-1.

digital saw the strongest growth in patent uptake. Energy & environment maintained strong policy and private sector uptake despite lagging in patent citations, and in advanced manufacturing; NPL's patent uptake surpassed the global average by 2.4 times.

Collaboration with NPL positively impacted partner institutions across sectors, boosting international collaboration, public-private partnerships, and policy and private sector uptake. While collaborations generally led to increased research impact, sectors like life sciences & health experienced declines in relative citation scores and patent uptake due to NPL's applied research focus. In contrast, partnerships in data & digital, energy & environment, and advanced manufacturing saw consistent improvements in industry and policy engagement.

1 INTRODUCTION

Context:
Science-Metrix was commissioned by NPL to conduct a bibliometric study on NPL's publications output over 2013-2023. The analysis evaluated NPL's performance across five research fields: metrology, advanced manufacturing, data & digital, life science & health, and energy & environment, comparing it with 27 other NMIs. This comparative analysis benchmarks NPL's scientific output against the broader UK landscape and other NMIs. Additionally, the assessment investigates the scientific performance of NPL's key collaborators. This comprehensive evaluation also identifies key and emerging research topics relevant to NPL, providing insights into its research landscape and collaborative efforts within the field of metrology. This paper, specifically, summaries the findings of Science-Metrix's work for "the sectors" while focusing on five NMIs, National Institute of Standards and Technology (NIST), National Metrology Institute of Germany (PTB), Korea Research Institute for Standard and Science (KRISS) and NPL, named as "selected NMIs" afterwards.

Time period:
The data used in this study covers the years 2013 to 2023, while also segmenting the period into two distinct five-year segments, from 2013 to 2017 and 2018 to 2022 to compare the performance of and NMI over two periods. Three-year moving periods are also used to capture trends rather than relying on yearly data, which enhances the reliability of the trend analyses. However, it is important to note that the impact of scientific papers on policy and the private sector has not been computed beyond 2021 due to insufficient citation accumulation. Similarly, the analysis of the impact on patents is limited, with data not evaluated beyond 2018.

Data sources:
The primary data source utilized in this study is the Scopus[4] scientific publication collection, which provides a comprehensive overview of academic research outputs. Additionally, for analysing patent-related citations and assessing the uptake of research in patents, the study employs the European Patent Office's Worldwide Patent Statistical Database (PATSTAT)[5]. To evaluate the influence of research on policy-related literature, Overton[6] is used as a source for tracking citations in policy-relevant documents. This multi-faceted approach allows for a thorough examination of the impact of scientific research across different domains, including patents and policy.

Data sets creation method:
Relevant publications were retrieved using a two-step approach. First, keyword searches were conducted across titles, abstracts, keywords, affiliations, and journals to identify publications pertinent to each targeted area. In the second step, an artificial intelligence (AI) algorithm was employed to discover additional related publications by utilizing embeddings of the publications' titles and abstracts. This combination of traditional search methods and advanced AI techniques ensure a comprehensive and relevant collection of literature for the study.

[4] The main website of Scopus: https://www.elsevier.com/products/scopus

[5] The PATSTAT website: https://data.epo.org/expert-services/index.html

[6] The Overton website: https://www.overton.io/

2 INDICATORS USED IN THE STUDY BY TYPE

Bibliometrics is the application of mathematical and statistical methods to publications with a view at measuring scientific output and technological research through data derived from scientific literature and patents. Bibliometrics has a whole range of specific measurements and indicators (Okubo, 1997), (Pritchard, 1969).

Science Metrix has used fifteen different indicators in its bibliometric study. In this study the results for the ten of those indicators are reported under four different types, namely, growth, collaboration, citation impact and altmetrics.

- **Output indicators:**
  - **Number of Publications:** This is the total count of publications published by a specific entity in the defined period.
  - **Compound Annual Growth Rate (CAGR):** This measures the average annual rate at which a given entity's production changed over a number of years, taking compounding effects into account. CAGR can also be used on any indicator to study trends over several years.
  - **Specialization Index (SI):** This indicator captures the publishing effort of an entity in a research area (expressed as the share of its publications that are in that area) relative to the global effort in that research area; in other words, it consists of the relative activity of an entity in the corresponding area. Scores above 1 indicate stronger emphasis on a given area compared to the global level.
- **Collaboration indicators:**
  - **International Collaboration (ICR) (%):** This measures the percentage of an entity's research that includes author affiliations from at least two countries. This is known to benefit the reach and influence of publications.
  - **Public-Private Collaboration (PPR) (%):** This measures the percentage of an entity's research that is published in collaboration between the public and private sectors. This type of partnership is known to favor the translation of research towards innovation.
- **Citation impact indicators:**
  - **Average Relative Citations (ARC):** This is the average citation rate of all papers published by a given entity normalized by field of science and year of publication to correct for differences in the frequency and timing of citations. It offers a proxy for the average scientific impact of its research. Scores above 1 indicate a performance above global level.
  - **Citation Distribution Index (CDI):** Citations to scholarly outputs are highly skewed, with a minority of publications (e.g., 10%) receiving close to 50% of all citations. At the institutional level, highly cited publications can significantly influence the average of relative citations, pulling it above the median. The CDI was designed to provide a normalized measure of central tendency that is less sensitive to outliers, better reflecting the 'average' scientific impact of an entity. Scores above 0 denote performance above world level.
  - **Highly Cited Publications (HCP) (%):** This indicator is broadly recognized as a proxy for scientific excellence due to the very high concentration of citations received by the most highly cited papers. It shows the percentage of an entity's publications that are among the top 10% of all publications, in terms of citations. Scores above 10% (expectation) indicate performances exceeding the global level. Once divided by 10% (expectation by subfield, document type and year), we obtain a normalized share of HCP.
  - **Field-Weighted Citation Score (FWCS):** The Cite-Score (CS) measures the prestige or influence of scientific journals based on the extent to which their

content was cited and accounting for their size. A journal's score in a given year is then attributed to each of its papers in the corresponding year prior being normalized to obtain a Relative CS. Similar to ARC, an average above 1 indicates performance above world level.

- **Altmetrics:**
  - **Share of publications cited by patents (PCP):** This measures the percentage of an entity's research that is referenced in patent documents normalizing by publication year, subfield, and document type. It offers a proxy for the uptake of research in innovation.
  - **Share of publications cited by the private sector (PCI):** This measures the percentage of an entity's research that is referenced in scientific publications by the private sector normalizing by publication year, subfield, and document type. It offers a proxy for the use of knowledge in applied research.
  - **Share of publications cited in policy-relevant literature (PCPL):** This measures the percentage of an entity's research that is referenced in policy-related documents normalizing by publication year, subfield, and document type. It offers a proxy for the influence of research on policymaking.

3 TOPIC CLUSTERS

SciVal Topic clusters are Scopus-defined aggregations of publications grouped by thematic similarity, to identify key and emerging research niches. These clusters are labeled using three distinctive terms that frequently appear in the associated publications, offering insight into the content of each cluster (e.g., Photonics; Optical Resonator; Nonlinear Optics). The analysis focuses on identifying key and emerging research topics across four sectors, covering both NPL and all NMIs grouped together. Key topics are defined based on the total number of publications in a specific sector, while emerging topics are identified through their recent growth in publication volume.

However, it's important to acknowledge that while these Topics are created through robust algorithmic methods—specifically direct citation analysis—the process carries inherent limitations. The exclusivity rule (a publication belongs to only one Topic and one Cluster) may oversimplify the interdisciplinary nature of modern research. Furthermore, the reliance on citation patterns introduces some experimental variability: citation behaviors differ across fields and timeframes, potentially affecting how Topics form or evolve. Prominence, a metric derived from citation counts, view counts, and average CiteScore, offers insight into a Topic's momentum, not its inherent importance. Although there is a notable correlation between prominence and future funding, this does not equate to a guarantee. In this light, SciVal Topics serve as a valuable, but not infallible, tool for research intelligence—most effective when complemented by expert judgment and contextual understanding (SciVal Topics, 2025).

To support this analysis, a positional chart is used to combine information on scientific impact, specialization, output volume, and growth rate. This enables a clear understanding of both current strengths and areas with potential for future development within NPL and the broader NMI landscape. Annexes 2 to 5 list the topic clusters for four sectors.

4 LIFE SCIENCES & HEALTH

From 2013 to 2023, the world's research output in the field of health & life sciences totaled over 1.5 million publications.

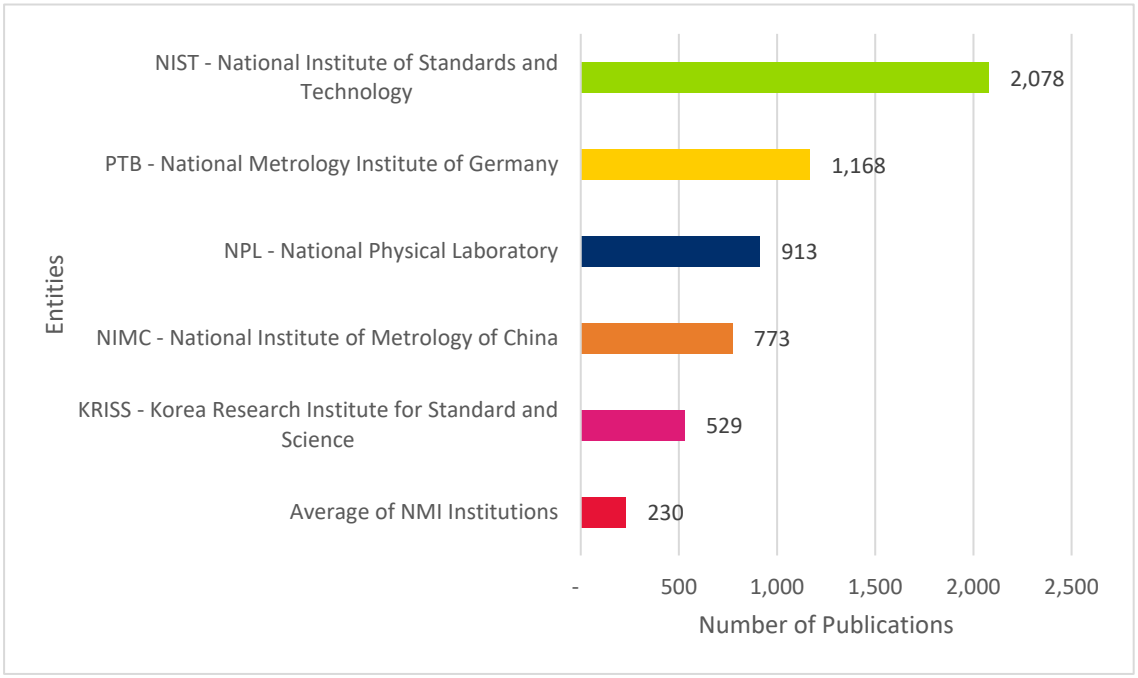

Figure 1. Number of publications in the field of life sciences & health from 2013-2023.

Figure 1 highlights NIST as the leading contributor among the NMIs for the period from 2013 to 2023, with over 2000 publications, followed by PTB with over 1.1 thousand publications. NPL ranks third with 913 publications, surpassing NIMC (773) and KRISS (529). NPL's output surpasses the global NMIs average by nearly four times, Figure 1.

4.1 GROWTH

Table 1. Compound annual growth rate in the field of life science & health for the periods of 2013-2017 and 2018-2022.

Entity	No.	CAGR	
	2013–2023	2013–2017	2018–2022
World	1,547,564	7.0%	15.6%
United Kingdom	106,508	7.6%	8.1%
NPL - National Physical Laboratory	**913**	**12.9%**	**3.5%**
NMI institutes	6,440	7.7%	3.1%
NIST - National Institute of Standards and Technology	2,078	4.7%	-3.4%
PTB - National Metrology Institute of Germany	1,168	5.8%	3.3%
NIMC - National Institute of Metrology of China	773	11.2%	25.1%
KRISS - Korea Research Institute for Standard and Science	529	8.9%	3.3%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

At the world level, the CAGR of life sciences & health output has more than doubled, compared to the first half of the period, from 7% to 15.6%, Table 1. It could be due to the increased demand of global health spending (Deloitte, 2019). Drivers of this growth are predicted to be novel therapies that address key, unmet needs, and increased access to medicines, as a result of new pricing policies around the world. It also may be attributed to heightened research activities spurred by the COVID-19 pandemic (Nature, 2022).

Between 2013 and 2017, NPL exhibited a robust CAGR of 12.9% in its life sciences & health research output, surpassing global, UK, and other NMIs by nearly 6 percentage points. However, from 2018 to 2022, NPL's research output growth decelerated to a CAGR of 3.5%, marking a nearly fourfold decrease from the previous period, while the global output volume CAGR doubled.

Similar to NPL, most NMIs experienced higher output growth during 2013–2017 compared to 2018–2023, Table 1. This slowdown may reflect broader and international pandemic challenges.

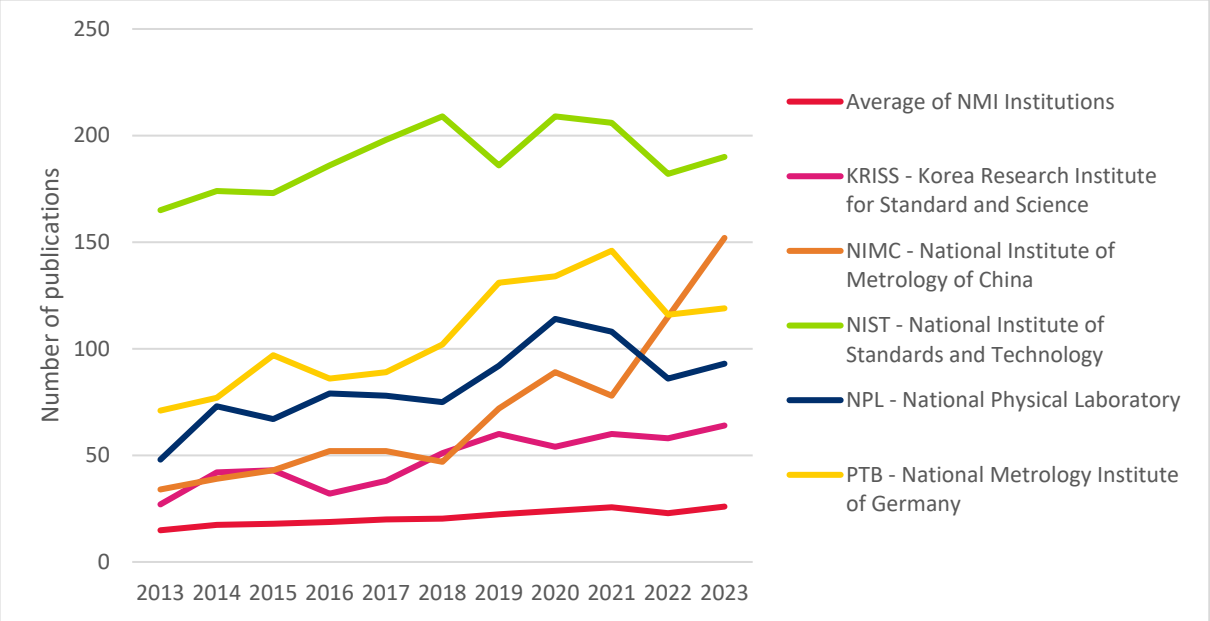

Figure 2. Number of publications by year in the field of health and life sciences over 2013-2023.

The share of some major countries in the Nature Index showed very different trends in the first two years after the outbreak of the Covid-19 crisis (Nature, 2022). Many countries saw their share rise sharply from 2018 to 2020 (Figure 2), which may be related to participation in important, early research related to the pandemic. This growth may have caused some countries to see their share decline in the following year, as the number of studies fell back to a level closer to that of the pre-pandemic period. In addition, while NIST is still taking the lead position of life sciences & health studies, NIMC achieved a CAGR of 25.1% between 2018 and 2022, and its outputs surpassing NPL and PTB in 2022, and is poised to overtake NIST in the near future.

4.2 COLLABORATION PATTERNS

Table 2. International collaboration rate and public–private collaboration rate in the field of health and life sciences over 2013-2023.

Entity	Networking			
	ICR	CAGR†	PPR	CAGR†
World	24.2%	0.7%	8.1%	0.5%
United Kingdom	66.9%	2.9%	15.3%	1.9%
NPL - National Physical Laboratory	**63.8%**	**0.9%**	**25.4%**	**9.0%**
NMI institutes	39.6%	2.2%	17.3%	5.6%
PTB - National Metrology Institute of Germany	62.8%	2.2%	17.0%	6.0%
KRISS - Korea Research Institute for Standard and Science	37.4%	2.1%	14.9%	0.6%
NIST - National Institute of Standards and Technology	35.4%	2.7%	20.6%	5.7%
NIMC - National Institute of Metrology of China	21.5%	3.8%	13.6%	7.5%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

Throughout the study period, NPL's ICR is 2.7 times higher than the global average and approximately 1.6 times higher than the average level of 28 NMIs combined. Moreover, by 2023, NPL's PPR reached 25.4%, which is three times higher than the global average and 1.7 times higher than the UK level, Table 2. NPL's PPR and the CAGR of the PPR exceeded those of the global average, the UK, and average level of all NMIs. These elevated level of international collaboration highlights NPL's active engagement in both global research partnerships and private sector partners, thereby enhancing the practical relevance and application of its research in life sciences & health.

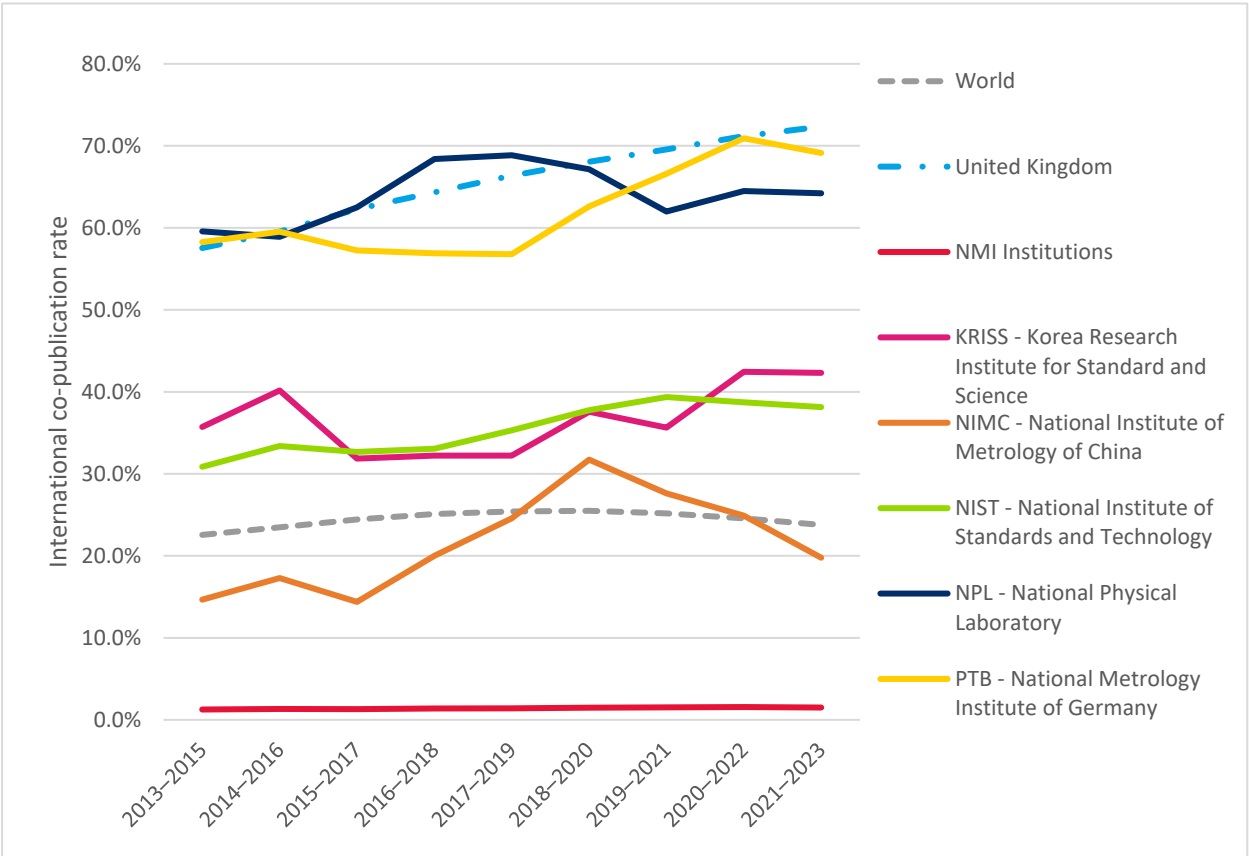

Figure 3. International collaboration rate in the field of life sciences & health by 3-year moving period over 2013-2023.

Between 2013–2015 and 2017–2019, NPL's ICR was on par with the UK's national average. However, from 2018–2020, NPL's ICR fell below the UK average, becoming the second highest among the selected NMIs behind PTB.

The ICRs of NIST and KRISS have been close ICR during the study period, but they both exceed NIMC.

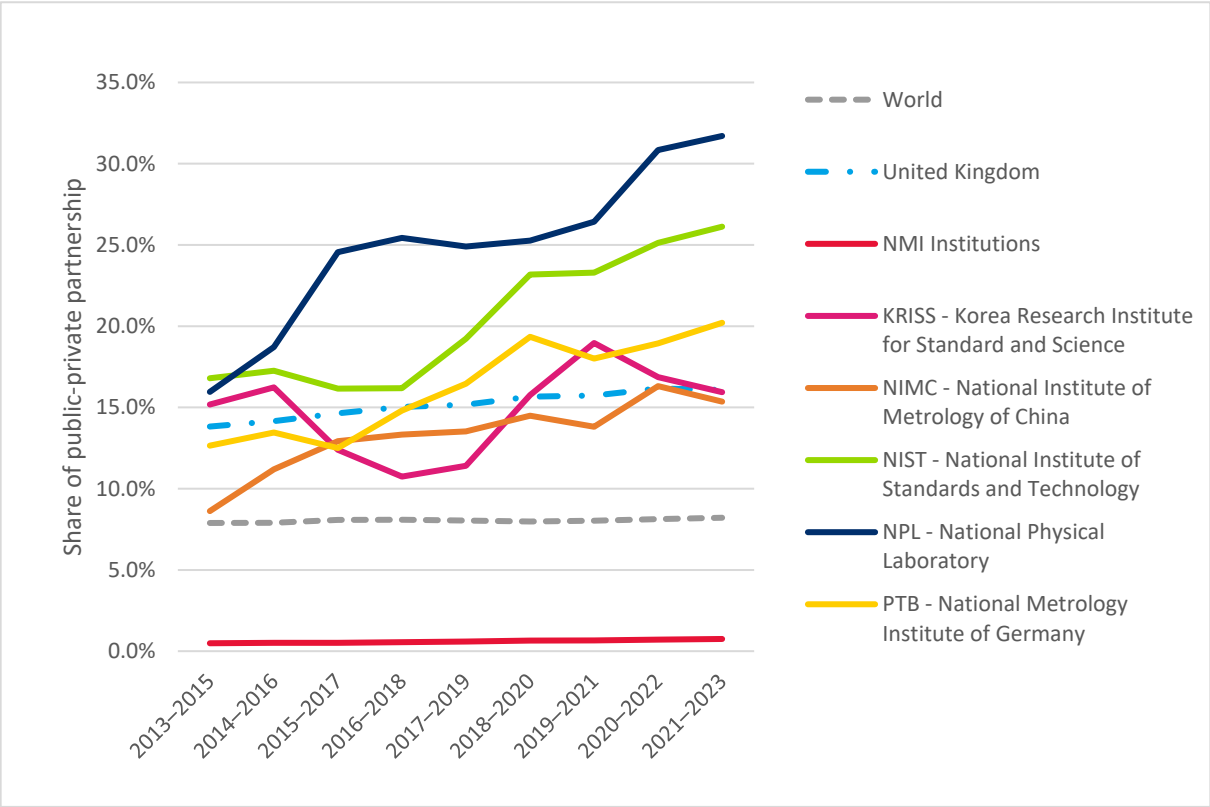

Figure 4. Public–private collaboration rate in the field of life sciences & health by 3-year moving period in 2013-2023.

Over the study period, NPL's PPR rose steadily and had the highest PPR among the selected NMIs from 2013-2015 (Figure 4), peaking at 31.7% for the 2021–2023 period, which was significantly higher than the global average of 8.2% and the UK level of 16.1%. NPL probably stands out because of its focus on applied research and collaboration with commercial enterprises. NPL has established effective channels for knowledge exchange between the public and private sectors. Initiatives such as joint seminars, workshops and secondment programmes have strengthened relationships and increased the results of collaboration.

While NPL's PPR surged from 16% in 2013–2015 to an impressive 31.7% by 2021–2023, other NMIs such as NIST and PTB exhibited slower but consistent growth.

In general, most NMIs have shown an increasing trend in both PPR and ICR from 2013 to 2023.

4.3 CITATION IMPACT

Table 3. Average relative citations and field-weighted citation score in the field of life sciences & health over 2013-2023.

	ARC		FWCS	
Entity	**Score**	**CAGR†**	**Score**	**CAGR†**
World	1.31	-1.0%	1.12	-0.5%
United Kingdom	2.26	-0.8%	1.46	0.2%
NPL - National Physical Laboratory	**1.16**	**-1.6%**	**1.09**	**-0.2%**
NMI institutes	1.10	-1.2%	1.14	-0.4%
NIST - National Institute of Standards and Technology	1.45	-1.8%	1.36	-0.9%
PTB - National Metrology Institute of Germany	1.05	-1.1%	1.16	-0.5%
KRISS - Korea Research Institute for Standard and Science	0.69	7.7%	0.94	-0.5%
NIMC - National Institute of Metrology of China	0.59	9.4%	0.86	5.6%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

During the 2013–2023 period, NPL's ARC stood at 1.16, below the global ARC benchmark of 1.31 and ranked second among all selected NMIs, Table 3. Most selected NMIs had an ARC below the global average, with the exceptions of NIST, showing that NIST publications appeared in high-impact journals during this period.

From 2013 to 2023, the majority of NMIs experienced a negative CAGR for ARC. Notable exceptions include NIMC with a positive CAGR of 9.4% and KRISS at 7.7%. Among all 5 NMIs, NPL's FWCS (1.09) ranked secondly, NIST (US, 1.36) ranked first and slight below the world level in health and life science area, Table 3.

Table 4. Citation distribution index and highly cited publications in the field of life sciences & health over 2013-2023.

		HCP10	
Entity	**CDI**	**Score**	**CAGR†**
World	4.8	13.6%	-0.1%
United Kingdom	14.1	21.7%	0.1%
NPL - National Physical Laboratory	**8.4**	**13.6%**	**-6.0%**
NMI institutes	1.4	11.1%	-2.5%
NIST - National Institute of Standards and Technology	6.9	15.5%	-0.9%
PTB - National Metrology Institute of Germany	4.9	10.7%	0.4%
KRISS - Korea Research Institute for Standard and Science	-12.1	6.1%	7.6%
NIMC - National Institute of Metrology of China	-15.3	3.3%	13.5%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

NPL's CDI and HCP10 scores were always above world level for both indicators. And ranked first for CDI among the selected NMIs. Additionally, CDIs of both PTB and NIST might increase in the coming years considering the CAGR of the CDI. Among selected NMIs, NPL's HCP10 (13.6%) ranked second behind NIST with a HCP10 of 15.5%, Table 4.

Across all scientific impact indicators (ARC, CDI, HCP10, FWCS), NIST holds the highest rank in ARC and FWCS and is tied for the top position in HCP10 among the selected NMIs.

The UK's CDI, ARC, HCP10 and FWCS surpassed those of all other selected NMIs. It may be due to the consistently invested fundings from UK government and organisation to the life sciences sector (LifeArc, 2023), (ARC Group, 2023).

4.4 ALTMETRICS

Table 5. Altmetrics normalised share (diff in p.p.) cited in the field of life science & health over 2013-2023.

Entity	Altmetrics (2013–2023)					
	Norm share (diff in p.p.) cited in					
	Patents (PCP)	Δ	Private sector (PCI)	Δ	Policy lit. (PCPL)	Δ
World	4.5	-1.8	8.2	-1.2	0.2	-0.4
United Kingdom	7.7	-1.8	21.3	0.9	4.9	-1.2
NPL - National Physical Laboratory	**3.7**	0.0	**22.8**	-5.5	**5.0**	-2.3
NMI institutes	4.3	-0.8	13.9	-1.4	3.8	-0.7
NIST - National Institute of Standards and Technology	8.9	-1.9	20.5	1.9	6.7	-1.5
KRISS - Korea Research Institute for Standard and Science	1.8	-0.3	2.8	1.7	1.6	3.2
PTB - National Metrology Institute of Germany	0.8	0.9	18.4	-5.7	3.5	2.4
NIMC - National Institute of Metrology of China	0.1	-2.6	-4.9	1.4	-0.4	-0.3

Note: Δ computed based on the 3-year moving periods (measures percent growth moving from one period to the next).

Table 6. Altmetrics (complementary[7]), share of paper cited at least once in the field of life sciences & health over 2013-2023.

Entity	Almetrics (complementary)		
	Share of papers cited at least once by		
	Patents	Private sector	Policy lit.
World	12.9%	51.3%	5.5%
United Kingdom	16.4%	64.9%	11.2%
NPL - National Physical Laboratory	**11.7%**	**65.3%**	**8.3%**
NMI institutes	12.0%	56.0%	7.3%
NIST - National Institute of Standards and Technology	17.1%	64.8%	11.0%
KRISS - Korea Research Institute for Standard and Science	10.3%	47.2%	4.3%
PTB - National Metrology Institute of Germany	7.5%	55.5%	7.0%
NIMC - National Institute of Metrology of China	7.5%	37.2%	1.7%

NIST leads among NMIs in PCP, with 8.9 p.p of its papers receiving at least one patent citation. This score surpasses both the global and UK averages and is 2.4 times higher than that of the NPL, which ranks second.

Between 2013 and 2023, NPL achieved the highest PCI uptake among the selected NMI in the field of life sciences and health research. NPL is the only entity ranked higher than the UK and ranks first among all NMIs. NPL's research priorities are closely aligned with the practical needs of the private sector. This alignment facilitates the adoption of its innovations in private-sector applications. NPL is working to tackle some of the world's biggest health challenges, from reducing attrition rates in drug development to treating cancer and dementia, as well as creating new antibiotics (Bremer, 2017). NPL also has cultivated strong

[7] **Complementary of Altmetrics** refers to the second Altmetric method, which calculates the proportion of scientific publications cited by at least one patent, private sector or policy literature. This is measured as the share of such publications relative to the total number of scientific publications in each sector, offering a complementary perspective to the normalized metric described earlier.

partnerships with private companies, enabling co-development of technologies and solutions that directly benefit the private sector.

In terms of Policy literature, NPL achieved the second highest PCPL score among the selected NMIs, while becoming slightly above the UK level.

4.5 THE IMPACT OF COLLABORATING WITH NPL

Table 7. The impact of collaborating with NPL in the field of life sciences & health for the periods of 2013-2017 and 2018-2022.

Dataset:		Health Life Research					
Period:		2013–2023			2018–2022		
Collaboration with/without NPL		with NPL	without NPL	diff.	with NPL	without NPL	diff.
No. papers (full counting)		652	103,878	-	344	55,519	-
Share		0.6%	99.4%	-	0.6%	99.4%	-
CAGR		10.06%	7.34%	2.72	4.15%	7.86%	**-3.71**
ICR		70.2%	59.7%	**10.5**	69.6%	61.8%	**7.8**
PPP		29.9%	12.3%	**17.6**	31.7%	12.8%	**18.9**
ARC		1.29	2.16	-0.88	1.20	2.09	-0.89
CDI		13.1	14.0	-0.9	10.9	13.8	-2.9
HCP10		15.6%	20.9%	**-5.3**	14.1%	20.6%	**-6.5**
FWCS		1.13	1.48	**-0.34**	1.17	1.48	**-0.31**
Norm share (diff in p.p.) cited	patents (PCP)	2.2	8.1	**-6.0**	0.2	6.4	**-6.3**
	private sector (PCI)	28.5	19.6	**8.9**	23.2	19.3	3.9
	policy (PCPL)	5.7	3.9	**1.7**	4.4	3.7	0.7

Note: This table reports the aggregate scores of all NPL collaborators. The publications from top NPL collaborators are classified as including at least one author from NPL (with NPL) or not including NPL authors (without NPL)

Collaboration with NPL significantly increased its top collaborators' ICR and PPR scores in field of health and life science, Table 7. This increase reflects NPL's key role in connecting research institutes with global networks and with the industry. The growth in PPR is consistent with NPL's mission to facilitate the development and launch of innovative products. By collaborating with NPL, collaborators may benefit from industry-relevant applications, thereby enhancing the translational potential of their research.

NPL's PCI scores further highlights its role as a bridge between academia and industry, as NPL's focus on applied research ensures its collaborations meet the practical needs of industry in the life sciences & health domain. This is consistent with NPL's mission to support innovation and industry impact and strengthens the practical applicability of its research outputs in real-world settings.

Collaboration with NPL also positively influences PCPL scores. Given that NPL maintains UK and international measurement systems, collaboration with government agencies may have a degree of influence on policy orientation. By collaborating with NPL, collaborators may increase the policy relevance of their research, thereby contributing to evidence-based policymaking.

Despite its strengths in applied and translational research, collaboration with NPL was associated with a decline in some indicators of basic research, such as HCP10, FWCS and PCP scores. This trend may stem from NPL's strategic focus on applied research, which prioritises real-world impact over pure theoretical advancement. Basic research in life sciences & health field typically garners higher citation rates but is less aligned with NPL's mission and output profile. As such, while collaborators may score lower in these fields, their collaboration with NPL may broaden the practical and policy-oriented nature of their research.

4.6 KEY & EMERGING TOPIC CLUSTERS

NPL and all NMIs share the same top key topic clusters for life sciences & health research, those are ‘Radia’ which stands for “Radiation Therapy Planning; Computed Tomography; Imaging Phantom” and ‘Gas C’ that is “Gas Chromatography; Tandem Mass Spectrometry; Ultrasonics”, Figure 5.

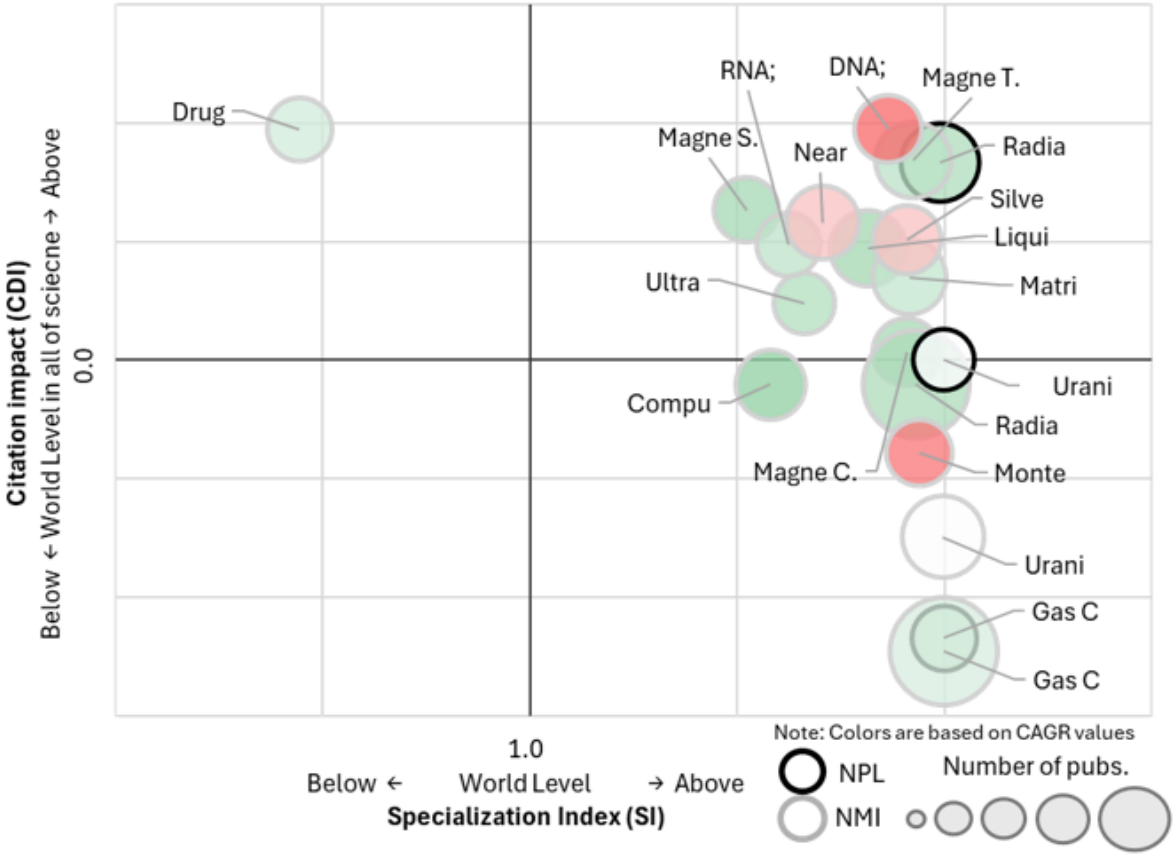

Figure 5. Key and emerging topic-clusters in the field of life sciences & health, NPL vs. NMIs, using aggregated data over 2013-2023.
Note: *‘Red’ points decreasing in CAGR while ‘Green’ means it is increasing in CAGR.*

Figure 5 illustrates that radiation therapy planning, computed tomography and imaging phantom cluster abbreviated as ‘Radia’ has a CDI of almost 0.8 and a SI score of 2 while having considerable level of publications in that cluster. ‘Urani’ is another topic cluster NPL is above the world’s SI score at almost 2 although its number of publications are lower than that other NMI’s average. However, its CDI score is equal to the world average.

5 DATA & DIGITAL

The world produced slightly over 6 million publications in the field of data & digital over 2013-2023. The UK contributed with about 280 thousand publications.

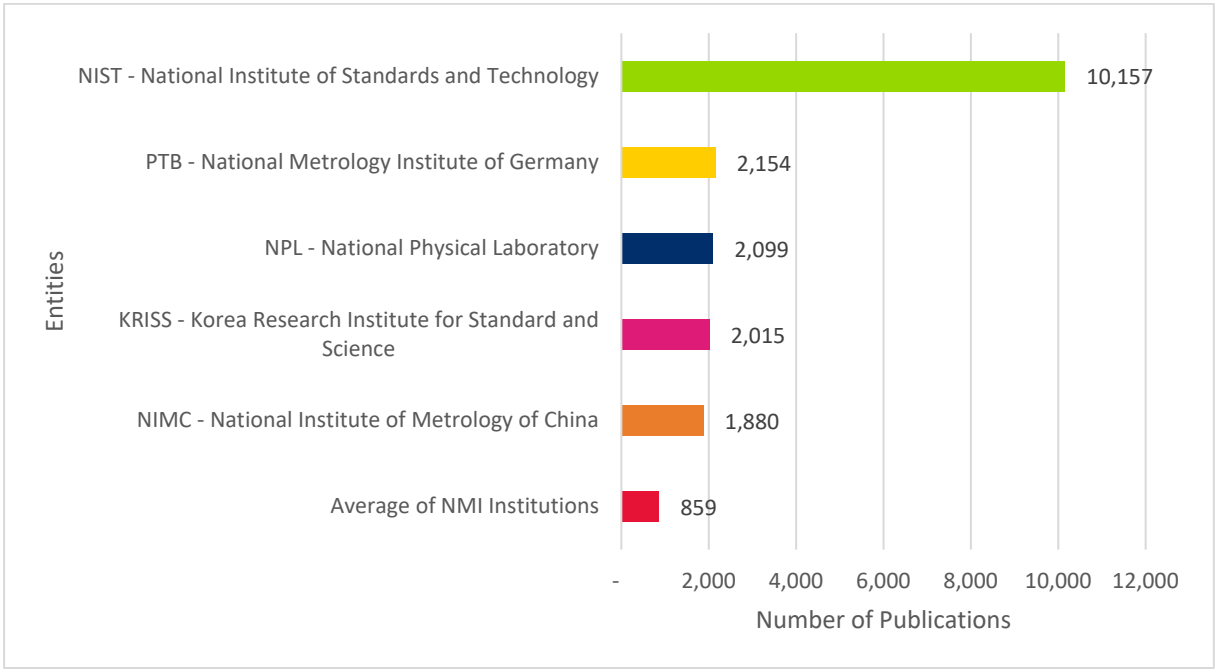

Figure 6. Number of publications in the field of data & digital over 2013-2023.

Among NMIs, NIST leads with over 10,000 publications. Following NIST, PTB accounted for 2,150 publications, narrowly surpassing NPL with 2,099 publications, and KRISS with 2,015 publications. NIMC contributed 1,880 publications, placing it below its peers but still significantly above the average of NMI institutions, which stands at 859 publications.

5.1 GROWTH

Table 8. Compound annual growth rate in the field of data & digital for the periods of 2013-2017 and 2018-2022.

Entity	No.	CAGR	
	2013–2023	2013–2017	2018–2022
World	6,039,575	8.0%	12.2%
United Kingdom	280,766	8.3%	8.0%
NPL - National Physical Laboratory	**2,099**	**6.6%**	**-0.3%**
NMI institutes	24,062	2.4%	0.0%
NIST - National Institute of Standards and Technology	10,157	1.7%	-0.8%
PTB - National Metrology Institute of Germany	2,154	0.7%	-0.9%
KRISS - Korea Research Institute for Standard and Science	2,015	5.1%	2.2%
NIMC - National Institute of Metrology of China	1,880	5.8%	5.2%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

NPL ranked third in output volume among selected 5 NMIs. Between 2013 and 2017, NPL experienced a CAGR of 6.6% in its data & digital research output. However, from 2018 to 2022, this trend reversed, resulting in a slight decline with a negative CAGR of 0.3%, Table 8. This is a significant difference from the development trends compared to the UK and the world.

Compared to NIST, PTB and NPL, KRISS and NIMC still had a positive CAGR in the second half period, specially NIMC have the highest CAGR which could be attributed to the policy initiatives.

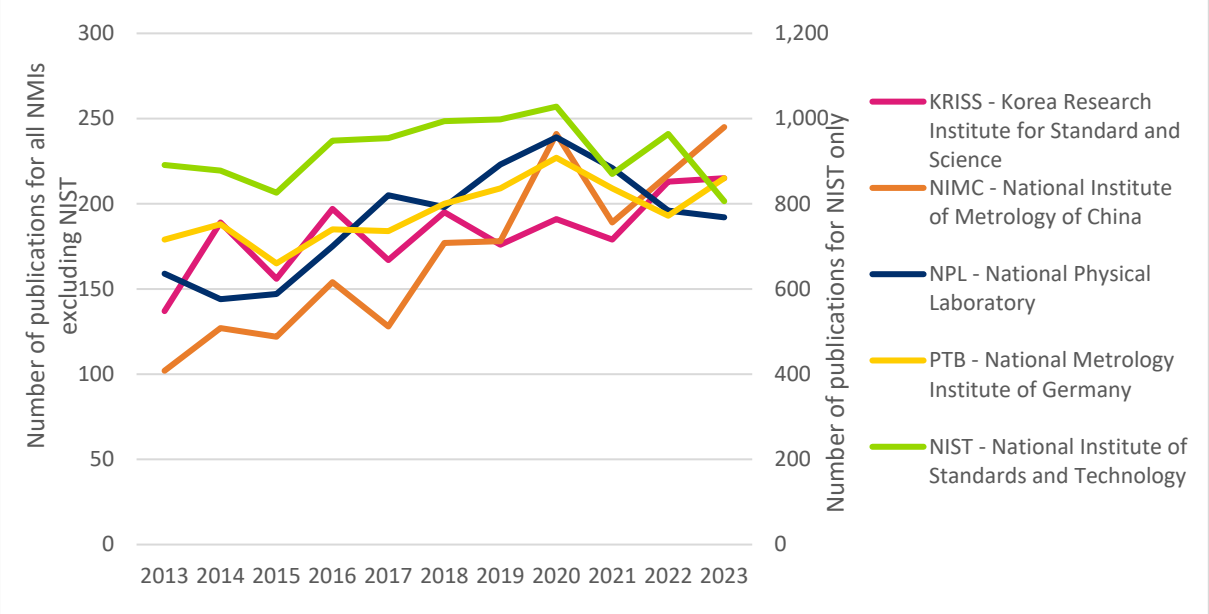

Figure 7. Number of publications by year in the field of data & digital over 2013-2023.

NPL's data and digital research results peaked in 2020, with a total of 239 papers published. Like other selected NMIs, the number of data and digital research papers has decreased after 2020, Figure 7.

5.2 COLLABORATION PATTERNS

Table 9. International collaboration rate and public–private collaboration rate in the field of data and digital over 2013-2023.

Entity	Networking			
	ICR	CAGR†	PPR	CAGR†
World	22.2%	0.6%	8.1%	1.7%
United Kingdom	67.4%	2.7%	12.0%	1.8%
NPL - National Physical Laboratory	**62.6%**	**3.1%**	**19.5%**	**6.2%**
NMI institutes	37.1%	1.4%	12.6%	4.8%
PTB - National Metrology Institute of Germany	53.3%	0.4%	15.7%	-0.7%
NIST - National Institute of Standards and Technology	39.3%	0.6%	11.2%	6.4%
KRISS - Korea Research Institute for Standard and Science	30.3%	-1.6%	8.0%	9.0%
NIMC - National Institute of Metrology of China	11.8%	-1.9%	8.2%	4.3%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

From 2013 to 2023, NPL's ICR and PPR in the field of data & digital increased by 3.1% and 6.2%, respectively. Between 2013 and 2023, NPL achieved an ICR of 62.6% in field of data & digital research, ranking first among selected NMIs, Table 9.

In this study period, NPL's CAGR of ICR in the field of data and digital was five times higher than the global average and about three times higher than the average of NMIs levels. Despite this impressive growth, NPL's ICR score remained slightly below the UK's national reference value throughout the study period.

Between 2013 and 2023, NPL exhibited a CAGR in its PPR that was 3.6 times higher than the global average, 3.4 times higher than the UK average, and 1.4 times higher than that of other NMIs.

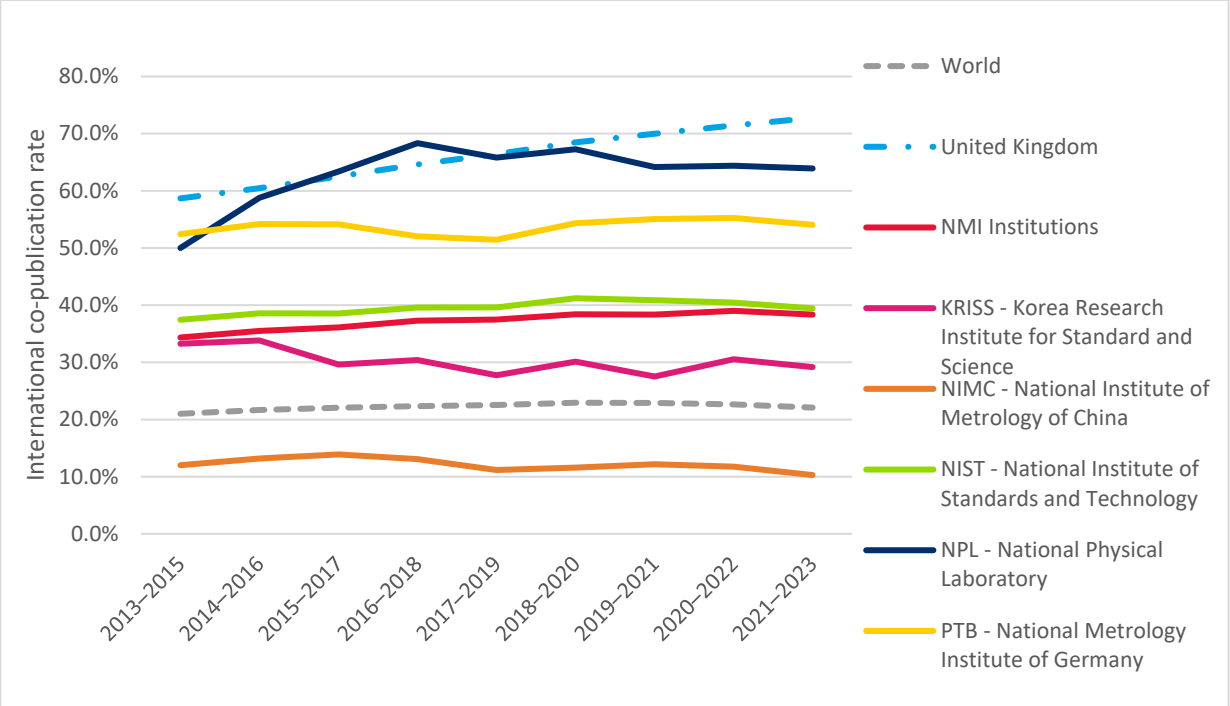

Figure 8. International collaboration rate in the field of data & digital by 3-year moving period over 2013-2023.

NPL's ICR increased rapidly in the first half of this period and stabilized in the latter half while other NMIs exhibited minimal changes over the decade. In addition, the UK's overall ICR in the field of data & digital showed a steady upward trend, Figure 8. This trend may, in part, reflect the UK government's increased focus on the UK's digital sector which deemed as crucial for ensuring economic growth before 2019 (Taylor, 2024). The UK is attracting digital investment by leveraging its infrastructure, skilled workforce, and leading institutions (including some of the world's most renowned universities), as well as the financial strength of London. Moreover, a more direct driver of NPL's performance in this area is likely the substantial government investment in key national programmes such as quantum measurement technologies and national timing centre. From 2020, As part of the UK national quantum technologies programme, NPL has initiated its own quantum programme. In the same year, with the funds from UKRI's strategic priorities fund, the national timing centre programme has also been presented as a clear opportunity for the UK to advance security and resilience of the national time and frequency infrastructure, whilst supporting the development of skills. These initiatives have provided NPL with targeted funding and strategic direction to lead cutting-edge digital innovation and standards development, reinforcing its collaborative and publication outputs in these emerging domains.
Compared to NPL, NIMC keeps the lowest ICR (11.8%) for the past decade, it may be due to the high level of internal citation. From 2020-2022, 62% of citations to China's top 10% of papers came from within the country, and The United States had the second-highest rate of home bias at 24% (Normile, 2024).

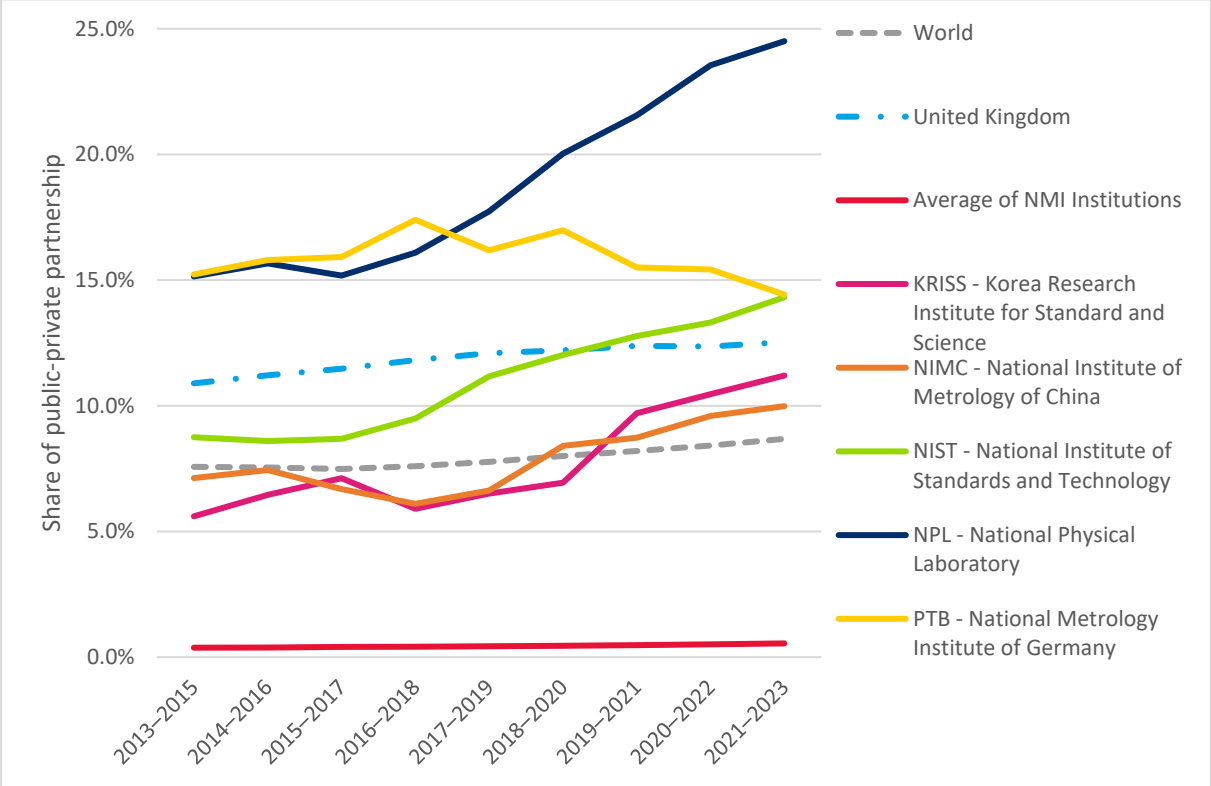

Figure 9. Public–private collaboration rate in the field of data & digital by 3-year moving period over 2013-2023.

NPL's PPR ranked first after 2016-2018, and surpassing both the UK and the world level during the entire study period. By 2021–2023, NPL's PPR reached 24.5%, significantly surpassing all other selected NMIs. Between 2013 and 2023, most NMIs, except for PTB, showed a slow upward trend in both PPR and ICR in the field of data and digital research, Figure 9. NPL's marked increase in PPR can be attributed to a series of targeted collaborations between NPL and UK industry. During the study period, NPL actively pursued

and participated joint work with private sector partners, such as the national timing centre programme and industrial measurement programmes under the UK's industrial strategy challenge fund. From 2020, NPL work more closely with the EPSRC-funded quantum technology hubs and groups of UK research-leading universities on the creation of a comprehensive capability to test and evaluate prototypes and new products based on quantum technologies for the UK (NPL, New NPL quantum programme to support UK economic growth, 2020). The collaboration with partners around the UK is an important aspect of this programme. Moreover, in conjunction with Innovate UK, the national timing centre programme (funded by UKRI's strategic priorities fund) are aimed to support UK companies to develop new products and services to meet these new needs, based on a successful NPL and Innovate UK partnership model (NPL, National Timing Centre programme, 2020). These efforts created more opportunities for co-authored outputs with industry, contributing to the rapidly rise in public–private co-publication rates.

NPL's leading position may also be attributed to the fact that UK government departments and agencies have recognised the value of data and digital Sector in improving service delivery, enhancing decision-making processes, and driving innovation (Christmas, 2023). To address common data challenges, NPL actively engaged and started an integrated approach that combines internal change with private sector supporting mechanisms. The private sector can provide expertise, innovative solutions, and advanced technologies to enable the effective use of data. Public-private collaboration is essential to leverage the strengths of both parties and jointly address common challenges.

5.3 CITATION IMPACT

Table 10. Average relative citations and field-weighted citation score in the field of data & digital over 2013-2023.

	ARC		FWCS	
Entity	**Score**	**CAGR†**	**Score**	**CAGR†**
World	1.28	0.2%	1.11	-0.3%
United Kingdom	2.04	-1.1%	1.45	-0.5%
NPL - National Physical Laboratory	**1.44**	**-3.1%**	**1.35**	**-0.5%**
NMI institutes	1.56	-3.0%	1.44	-1.1%
NIST - National Institute of Standards and Technology	2.15	-2.6%	1.86	-1.0%
PTB - National Metrology Institute of Germany	1.64	-4.9%	1.31	-1.7%
KRISS - Korea Research Institute for Standard and Science	0.95	-3.8%	1.20	-0.5%
NIMC - National Institute of Metrology of China	0.63	4.8%	0.79	2.4%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

Between 2013 and 2023, NPL achieved an ARC of 1.44 in the field of data & digital, surpassing the global ARC of 1.28. And among 5 selected NMIs, NPL's FWCS (1.35) ranked second behind NIST (1.86), Table 10.

Given that the global ARC exceeds one, it suggests that data & digital research is generally more cited than other fields, potentially due to its focus on basic research, which tends to receive higher citation rates (Donner & Schmoch, 2020).

When normalizing NPL's ARC against the global ARC in data & digital research, the rebased score is 1.13, indicating that NPL's publications are 13% more cited than the global average within this research field. Similarly, NPL's FWCS stands at 1.35, higher than the global FWCS of 1.11. The rebased FWCS is 1.22, highlighting that NPL's research is published in more influential journals compared to the global average.

During the whole study period, most NMIs experienced a negative CAGR for ARC, except for NIMC (4.8%). This suggests that NIMC's research impact in the field of data & digital has been increasing over time.

Table 11. Citation distribution index and highly cited publications in the field of data & digital over 2013-2023.

		HCP10	
Entity	**CDI**	**Score**	**CAGR†**
World	5.3	13.8%	1.1%
United Kingdom	15.7	21.5%	0.2%
NPL - National Physical Laboratory	**9.0**	**14.9%**	**-3.3%**
NMI institutes	9.0	16.4%	-3.3%
NIST - National Institute of Standards and Technology	17.0	23.8%	-1.6%
PTB - National Metrology Institute of Germany	9.3	15.7%	-10.1%
KRISS - Korea Research Institute for Standard and Science	-3.1	8.8%	-3.0%
NIMC - National Institute of Metrology of China	-9.8	4.8%	10.2%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

Between 2013 and 2023, the UK led in HCP10 and CDI within data and digital research. The UK has consistently produced a significant proportion of the world's highly cited research outputs, reflecting its strong research impact. For instance, in 2018, the UK accounted for 14% of the world's most highly cited publications and had 2% of its publications among the most highly cited in the world (Department for Business, 2019).

NPL achieved a CDI of 9.0, ranking third among selected NMIs. However, all NMIs exhibited a decreasing trend in CDI over the study period, as indicated by the CAGR. As with CDI score, NPL's HCP10 (14.9%) ranked third and all NMIs showed a decreasing trend in HCP10 throughout the study period, Table 11.

5.4 ALTMETRICS

Table 12. Altmetrics, normalised share (diff in p.p.) cited in the field of data & digital over 2013-2023.

Entity	Altmetrics (2013–2023)					
	Norm share (diff in p.p.) cited in					
	Patents (PCP)	Δ	Private sector (PCI)	Δ	Policy lit. (PCPL)	Δ
World	1.8	-0.4	4.6	1.3	-0.1	0.1
United Kingdom	4.2	-0.1	15.9	2.2	3.2	0.3
NPL - National Physical Laboratory	**3.1**	1.1	**16.6**	0.7	**3.0**	-0.2
NMI institutes	3.7	0.0	10.5	0.6	1.4	0.5
NIST - National Institute of Standards and Technology	7.2	0.5	15.1	2.5	1.9	0.1
PTB - National Metrology Institute of Germany	2.7	2.7	13.2	-1.3	1.7	0.7
KRISS - Korea Research Institute for Standard and Science	0.8	-2.3	0.0	1.4	-0.7	1.2
NIMC - National Institute of Metrology of China	-3.8	-0.2	-5.9	1.1	-0.3	0.0

Note: Δ computed based on the 3-year moving periods (measures percent growth moving from one period to the next).

Table 13. Altmetrics (complementary) share of paper cited at least once in the field of data & digital over 2013-2023.

Entity	Almetrics (complementary)		
	Share of papers cited at least once by		
	Patents	Private sector	Policy lit.
World	7.5%	41.7%	2.3%
United Kingdom	9.9%	53.0%	6.6%
NPL - National Physical Laboratory	**9.6%**	**54.7%**	**4.7%**
NMI institutes	9.8%	45.5%	2.6%
NIST - National Institute of Standards and Technology	13.1%	48.0%	2.9%
PTB - National Metrology Institute of Germany	8.4%	46.4%	2.8%
KRISS - Korea Research Institute for Standard and Science	8.4%	42.5%	0.4%
NIMC - National Institute of Metrology of China	2.6%	29.9%	0.5%

NPL's citation impact scores in non-scientific communities, as measured by citations by PCI and PCPL are above the global averages, and average of NMIs, Table 12. Notably, NPL leads in private sector uptake within the data & digital research domain, Table 13.

The citation impact of NPL in non-scientific communities grew most in PCP compared to other altmetric indicators. The normalised scores of PCP for the UK (4.2) and the selected NMIs were above the world level (1.8) except NIMC (-3.8) and KRISS (0.8), Table 12. The negative result from NIMC may due to the lower volume of increased publication in Data and Digital sector, as China's share of world publications has increased from 5% in 2000 to 26% in 2018, with particularly strong growth in the fields of chemistry, engineering and materials science (Qiu, Steinwender, & Azoulay, 2023) which mainly belongs to other three sectors.

5.5 THE IMPACT OF COLLABORATING WITH NPL

Table 14. The Impact of collaborating with NPL results in the field of data & digital for the periods of 2013-2017 and 2018-2022.

Dataset:		Data Digital Research					
Period:		2013–2023			2018–2022		
Collaboration with/without NPL		with NPL	without NPL	diff.	with NPL	without NPL	diff.
No. papers (full counting)		1,250	357,749	-	685	181,083	-
Share		0.3%	99.7%	-	0.4%	99.6%	-
CAGR		4.50%	4.91%	-0.41	-1.78%	5.28%	**-7.06**
ICR		69.9%	55.5%	**14.5**	69.9%	57.8%	**12.1**
PPP		21.4%	10.8%	**10.5**	23.9%	11.2%	**12.8**
ARC		1.64	1.88	-0.25	1.51	1.80	-0.29
CDI		12.4	14.1	-1.8	10.7	13.3	-2.7
HCP10		16.9%	19.8%	-2.9	16.7%	19.3%	-2.6
FWCS		1.48	1.49	-0.01	1.46	1.48	-0.02
Norm share (diff in p.p.) cited	patents (PCP)	4.1	4.5	-0.4	6.0	3.9	**2.2**
	private sector (PCI)	20.0	13.2	**6.8**	17.1	13.4	**3.7**
	policy (PCPL)	3.3	2.2	**1.2**	4.5	2.3	**2.2**

Note: This table reports the aggregate scores of all NPL collaborators. The publications from top NPL collaborators are classified as including at least one author from NPL (with NPL) or not including NPL authors (without NPL)

Collaborations with NPL have notably enhanced ICR and PPR for the primary partners in data & digital research, Table 14. This aligns with NPL's mission to support the development of new products and maintain both UK and international measurement systems, thereby increasing the relevance of collaborative research with the industry.

NPL's focus on product innovation likely elevates the applicability of its partners' research to industry needs, as evidenced by a higher PCI between 2013 and 2023. However, collaborations with NPL have not shown a significant positive impact on the HCP10, FWCS, or PCP.

5.6 KEY & EMERGING TOPIC CLUSTERS

NPL and the NMIs share the same top key topic clusters in the field of data & digital research. Those are “Photonics; Optical Resonator; Nonlinear Optics” which is abbreviated as ‘Photo O. and “Transition Metal; Molybdenum; Density” labelled as ‘Trans’, Figure 10.

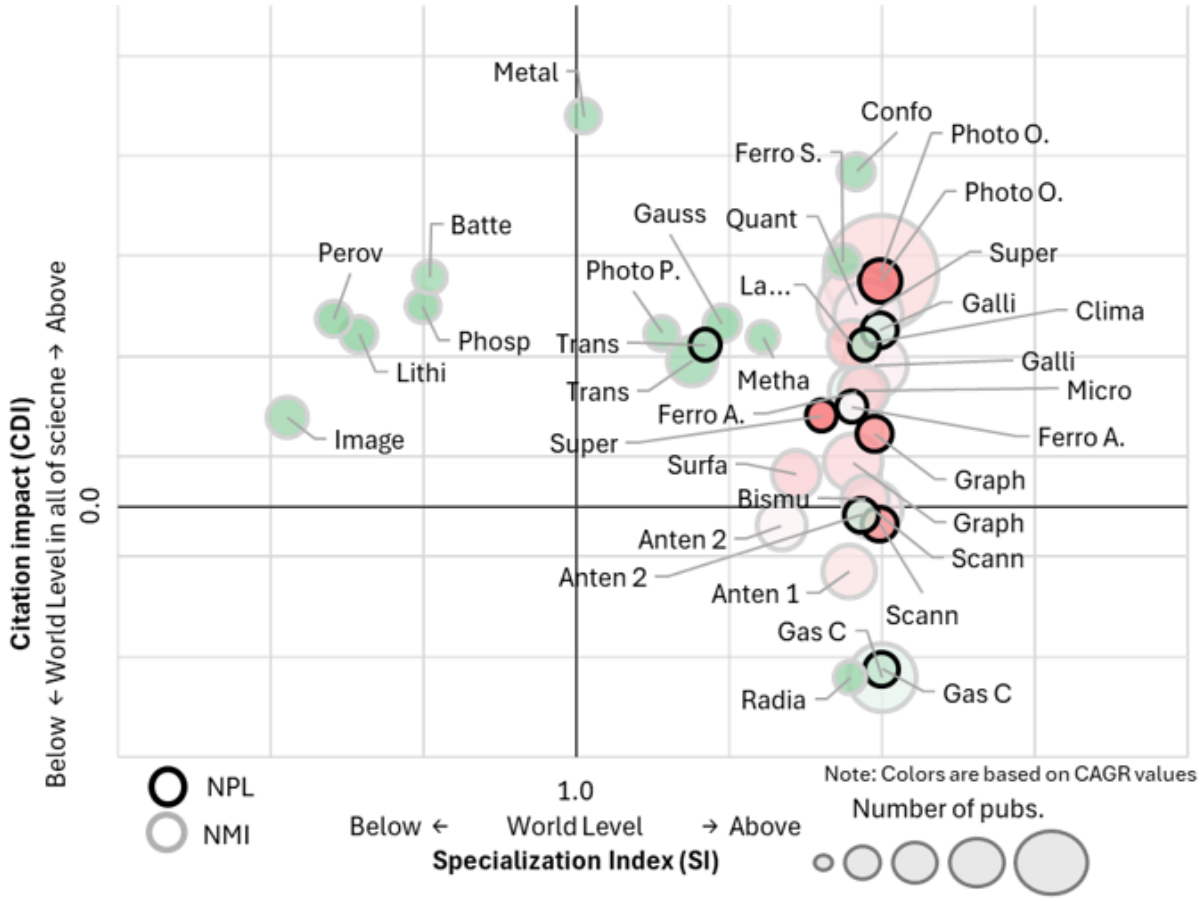

Figure 10. Key & emerging topic-clusters in the field of data & digital Science (NPL, all NMI grouped over 2013–2023).
Note: *‘Red’ points decreasing in CAGR while ‘Green’ means it is increasing in CAGR.*

NPL’s highest CDI score is owned by ‘Photo O’ cluster, which stands for “Photonics; Optical Resonator; Nonlinear Optics”, while its CAGR value is decreasing. For, ‘Trans’ which includes the topics of “Transition Metal; Molybdenum; Density”, NPL both has above the world average scores for CDI and publication count; besides it has an increasing CAGR value. Lastly, for the clusters of ‘Galli’, and ‘Clima’, NPL has similar CDI and number of publication while both of their CAGR score is increasing, Figure 10.

6 ENERGY & ENVIRONMENT

From 2013 to 2023, The world's research output in the field of energy and environment totaled slightly above 432 thousand publications.

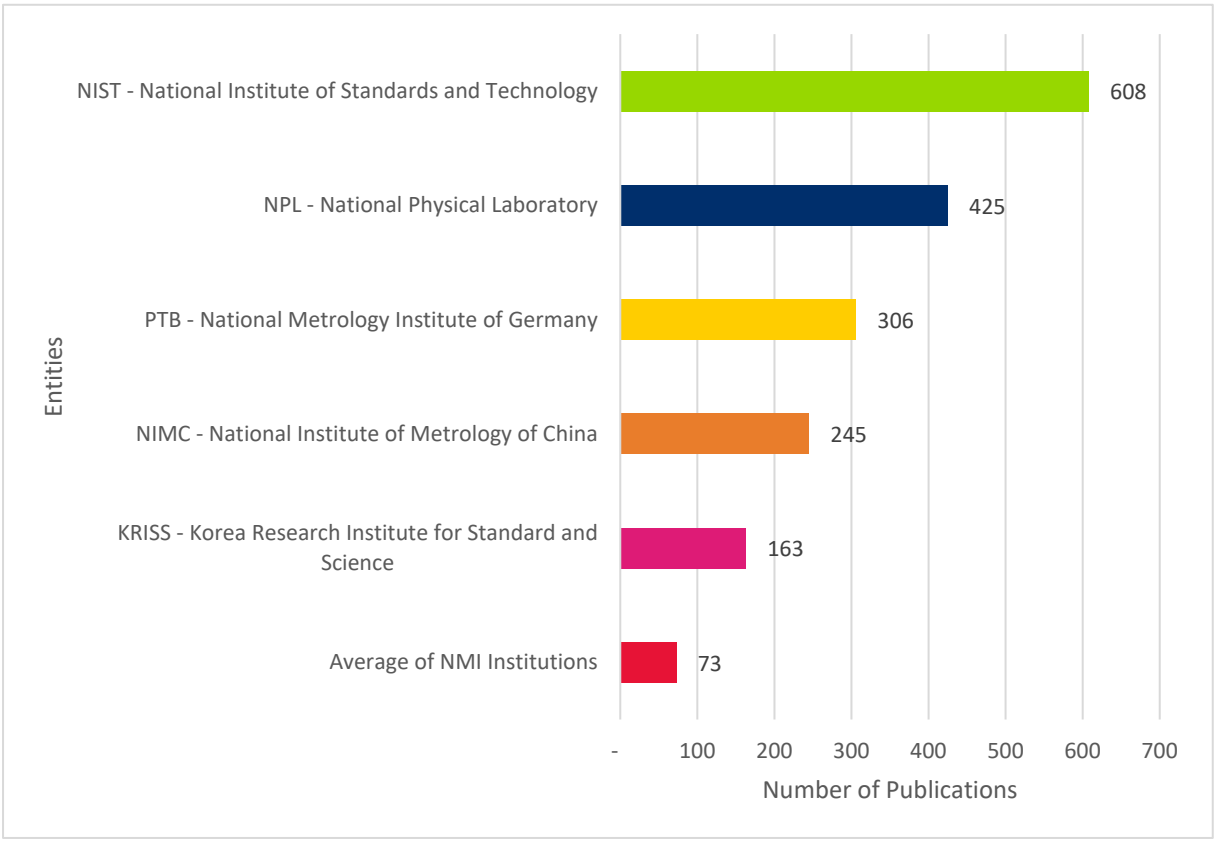

Figure 11. Number of publications in the field of energy & environment over 2013-2023.

Same as other research fields, NIST is the leading contributor among the NMIs for the period from 2013 to 2023, with nearly 608 publications. NPL ranks second with 425 publications, which surpassing the global NMIs average by nearly six times, Figure 11.

NMIs typically produce fewer publications in the energy and environment research compared to fields like advanced manufacturing, data & digital, and life sciences & health.

6.1 GROWTH

Table 15. Compound annual growth rate in the field of energy & environment for the periods 2013-2017 and 2018-2022.

Entity	No.	CAGR	
	2013–2023	2013–2017	2018–2022
World	432,585	9.2%	13.9%
United Kingdom	30,458	5.9%	7.2%
NPL - National Physical Laboratory	**425**	**-3.1%**	**-7.3%**
NMI institutes	2,037	1.3%	-1.6%
NIST - National Institute of Standards and Technology	608	4.6%	-3.4%
PTB - National Metrology Institute of Germany	306	-7.5%	-6.6%
NIMC - National Institute of Metrology of China	245	37.7%	12.6%
KRISS - Korea Research Institute for Standard and Science	163	0.0%	2.4%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

NPL ranked second in output volume among 5 selected NMIs although CAGR was negative in both 5-year moving windows. In the first half of the study period (2013 to 2017), NPL's energy & environment research output decreased at a CAGR of -3.1%. In the second half (2018 to 2022), there was a significant decline in output, with a negative CAGR of -7.3%, Table 15.

From 2018 to 2022, the world and the UK experienced rapid growth in output volume, with CAGRs of 13.9% and 7.2%, respectively. In contrast, average of NMIs have a negative CAGR with -1.6%, while NPL also saw a decline in the CAGR trend.

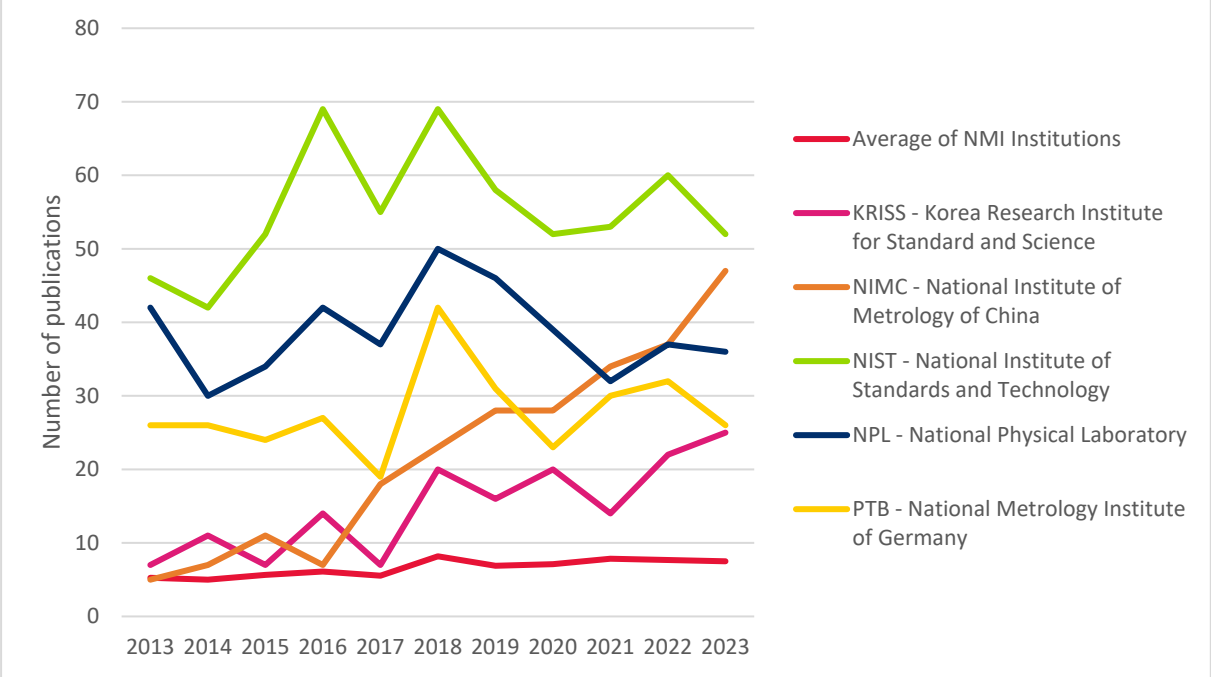

Figure 12. Number of publications by year in the field of energy & environment over 2013-2023.

NPL's output trend decreased from 2018 to 2022 in energy and environment research. NIST and PTB have the similar trend in the study period, Figure 12. Although NIST take the lead position for the entire study period, the rapid growth of NIMC maybe overtake NIST in the coming year.

6.2 COLLABORATION PATTERNS

Table 16. International collaboration rate and public–private collaboration rate in the field of health and life science over 2013-2023.

Entity	Networking			
	ICR	CAGR†	PPR	CAGR†
World	31.9%	-0.6%	7.0%	-0.1%
United Kingdom	78.9%	1.9%	11.4%	0.5%
NPL - National Physical Laboratory	**69.1%**	**2.5%**	**20.7%**	**3.5%**
NMI institutes	41.5%	0.8%	15.4%	3.6%
PTB - National Metrology Institute of Germany	58.5%	4.8%	19.6%	5.1%
KRISS - Korea Research Institute for Standard and Science	52.1%	N/C	10.4%	N/C
NIST - National Institute of Standards and Technology	37.4%	2.4%	14.8%	1.0%
NIMC - National Institute of Metrology of China	22.1%	N/C	11.1%	N/C

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

NPL's ICR and PPR increased from 2013 to 2023 in energy & environment research, with respective CAGRs of 2.5% and 3.5%, Table 16.

Among the selected NMIs in energy & environment research, NPL's ICR (69.1%) ranked first for the whole study period and was 2.2 times higher than the world average and about 1.7 times higher than the average of NMIs.

NPL's ranked first (20.7%) in PPR among the most publishing NMIs for the whole study period. NPL's CAGR for PPR was 7.0 and 1.2 times higher than for the UK and the other NMIs, respectively, Table 16.

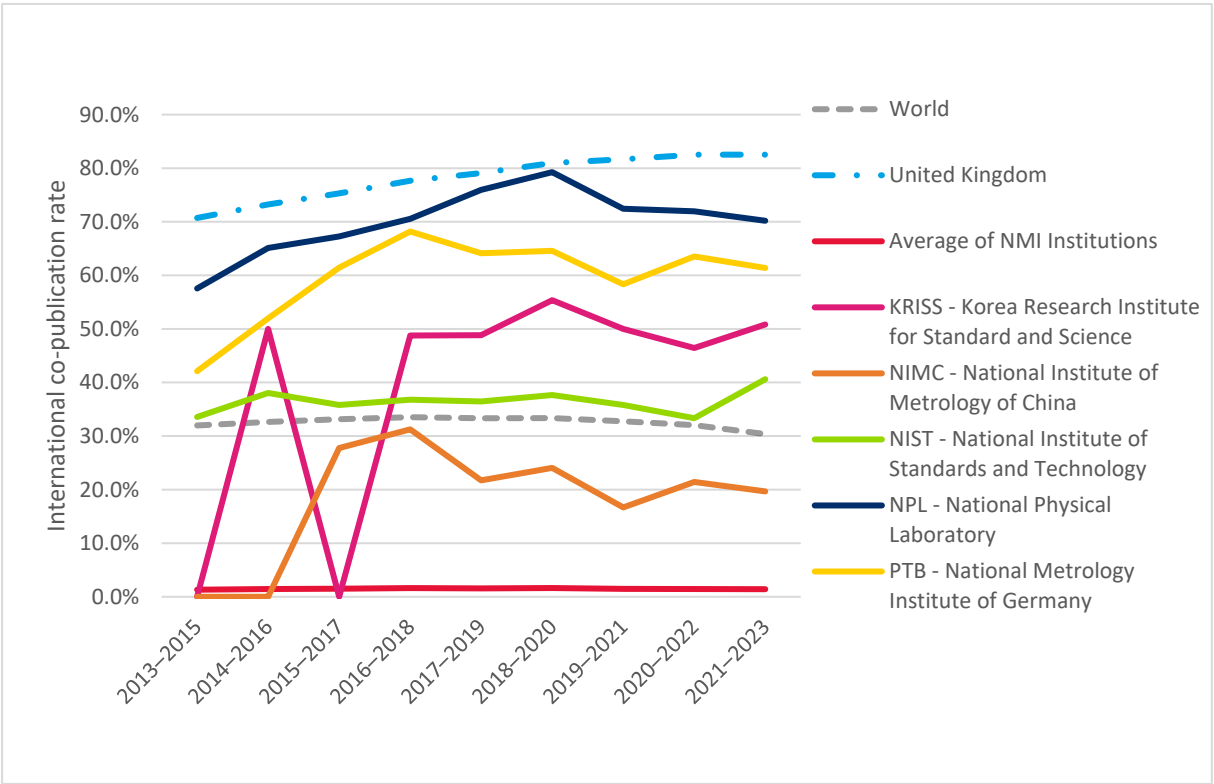

Figure 13. International collaboration rate in the field of energy & environment by 3-year moving period over 2013-2023.

The UK's ICR was above that of NPL, average of NMIs and the world throughout the entire period, Figure 13.

However, due to the small number of outputs, the three-year trend for some NMIs is not fully reflected in all impact indicators. Among the selected NMIs, only NIST, PTB and NPL have at least 30 papers in each three-year period. Among this three NMIs, NPL has the fastest growth in ICR.

NPL's research priorities include global environmental issues such as climate change (NPL, 2024) and international energy and standard projects (net zero energy grid) (Machinery, 2022). This focus has attracted international collaborators with similar goals, which has increased ICR.

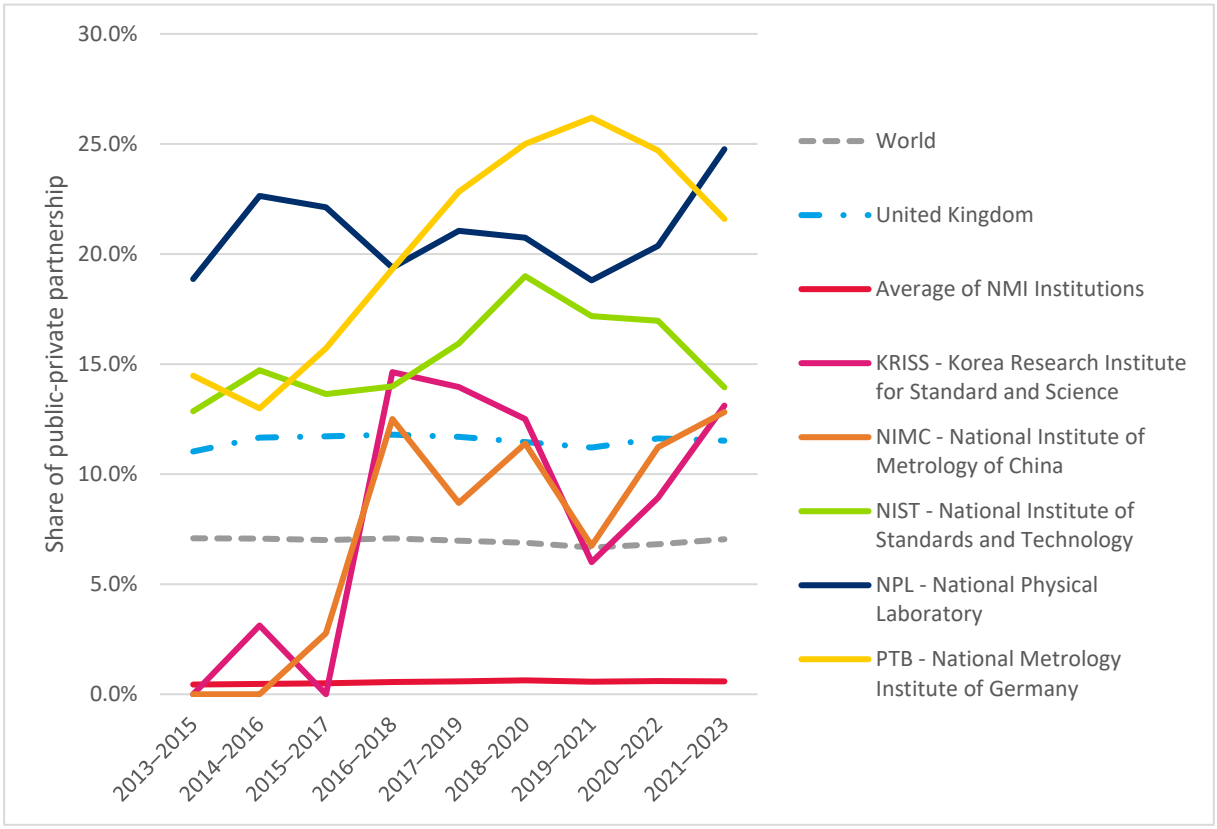

Figure 14. Public–private collaboration rate in the field of energy & environment by 3-year moving period over 2013-2023.

NPL maintained a higher PPR compared to PTB and NIST from 2013–2015 to 2016–2018. From 2014–2016, PTB experienced a rapid increase in PPR and overtook NPL from 2016–2018 until 2020–2022. Since 2019–2021, NPL's PPR has increased and surpassed PTB's.

The PPR of NPL, and its CAGR, were higher than for the world, the UK, and the average of NMIs over the entire period.

6.3 CITATION IMPACT

Table 17. Average relative citations and field-weighted citation score in the field of energy & environment over 2013-2023.

	ARC		FWCS	
Entity	**Score**	**CAGR†**	**Score**	**CAGR†**
World	1.30	-0.5%	1.08	-0.5%
United Kingdom	2.25	0.7%	1.48	0.1%
NPL - National Physical Laboratory	**1.30**	**-7.3%**	**1.13**	**-1.3%**
NMI institutes	1.34	-4.6%	1.07	-1.9%
NIST - National Institute of Standards and Technology	2.12	-4.7%	1.33	-2.2%
PTB - National Metrology Institute of Germany	1.01	-3.1%	1.01	-1.7%
KRISS - Korea Research Institute for Standard and Science	0.52	N/C	0.91	N/C
NIMC - National Institute of Metrology of China	0.46	N/C	0.73	N/C

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

For the 2013–2023 period, NPL's ARC was at 1.30 that was equalled the world's ARC and ranked second behind NIST (2.12) among selected NMIs in energy & environment research, Table 17.

Because ARC is subfield-normalised, the world's score being greater than one indicates that energy & environment research is, on average, 30% more cited than the average paper in the corresponding subfield at world level.

NPL's ARC can be rebased against the world's ARC in energy & environment research to have score 1, indicating that NPL's energy & environment publications were, on average, cited at the average world paper level in the same research field. Similarly, NPL's FWCS (1.13) was higher than the world's FWCS (1.08), with a rebased score of 1.05.

From 2013 to 2023, most NMIs experienced a negative CAGR for ARC and FWCS in Energy and Environment.

Table 18. Citation distribution index and highly cited publications in the field of energy & environment over 2013-2023.

		HCP10	
Entity	**CDI**	**Score**	**CAGR†**
World	6.5	14.3%	-0.4%
United Kingdom	18.9	25.4%	0.5%
NPL - National Physical Laboratory	**4.1**	**14.0%**	**-9.3%**
NMI institutes	0.7	11.5%	-7.8%
NIST - National Institute of Standards and Technology	9.4	17.3%	-5.2%
PTB - National Metrology Institute of Germany	4.6	11.9%	-12.5%
KRISS - Korea Research Institute for Standard and Science	-10.8	2.8%	N/C
NIMC - National Institute of Metrology of China	-14.8	2.5%	N/C

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next

Similar to the other research fields, the UK had the largest share of HCP10 and CDI. NPL's CDI (4.1) ranked third behind NIST (9.4), and PTB (4.6), Table 18. And NPL's HCP10 (14.0%) ranked second behind NIST (17.3%). All NMIs observed a decreasing trend in HCP10 as indicated by the decreased CAGR of HCP10.

Across all scientific impact indicators (ARC, CDI, HCP10, FWCS), NIST secured the highest rank, indicating its leading position in energy & environment research and its larger impact and influence in the field among the 5 NMIs. However, its impact is slowly decreasing.

6.4 ALTMETRICS

Table 19. Altmetrics, normalised share (diff in p.p.) cited in the field of energy & environment over 2013-2023.

Entity	Altmetrics (2013–2023)					
	Norm share (diff in p.p.) cited in					
	Patents (PCP)	Δ	Private sector (PCI)	Δ	Policy lit. (PCPL)	Δ
World	-0.7	0.1	3.6	-1.2	4.9	-3.1
United Kingdom	-0.1	-0.1	19.4	0.4	21.9	-3.6
NPL - National Physical Laboratory	**-1.1**	0.6	**17.7**	-3.2	**12.4**	6.4
NMI institutes	0.9	-0.2	10.8	-7.2	7.3	3.0
NIST - National Institute of Standards and Technology	4.5	1.3	14.3	0.1	10.3	6.0
PTB - National Metrology Institute of Germany	-1.1	-1.2	21.1	-19.6	6.4	3.5
KRISS - Korea Research Institute for Standard and Science	-1.8	N/C	-5.4	N/C	-2.8	N/C
NIMC - National Institute of Metrology of China	-5.1	N/C	-9.9	N/C	-0.6	N/C

Note: Δ computed based on the 3-year moving periods (measures percent growth moving from one period to the next)

Table 20. Altmetrics (complementary) share of paper cited at least once in the field of energy & environment over 2013-2023.

Entity	Almetrics (complementary)		
	Share of papers cited at least once by		
	Patents	Private sector	Policy lit.
World	1.5%	49.5%	16.0%
United Kingdom	1.8%	67.9%	35.8%
NPL - National Physical Laboratory	**3.0%**	**62.5%**	**20.5%**
NMI institutes	5.5%	51.7%	13.4%
NIST - National Institute of Standards and Technology	9.0%	52.2%	16.5%
PTB - National Metrology Institute of Germany	3.7%	61.7%	11.8%
KRISS - Korea Research Institute for Standard and Science	3.0%	40.5%	5.4%
NIMC - National Institute of Metrology of China	1.4%	29.2%	1.3%

NPL's citation impact scores in non-scientific communities, as measured by citations by the private sector and in policy documents, have always been above those of other NMIs and the world, Table 19. NPL's uptake by the private sector is 5 times the world level score. In uptake by the policy literature, NPL's score is 2.5 times the worlds. The uptake in patents of other NMIs has always been above the world, UK and NPL level.

NIST ranked the first for PCP indicator and is the only NMIs that has higher normalised uptake in patents compared to the world, the UK and other NMIs. Most selected NMIs scored well above the world for their uptake by the private sector, except KRISS and NIMC. The citation of NPL's papers in energy & environment research within policy-relevant literature ranked first among five selected NMIs.

6.5 THE IMPACT OF COLLABORATING WITH NPL

Table 21. The Impact of collaborating with NPL results in the field of energy and environment for the periods of 2013-2017 and 2018-2022.

Dataset:		Energy Environment Research					
Period:		2013–2023			2018–2022		
Collaboration with/without NPL		with NPL	without NPL	diff.	with NPL	without NPL	diff.
No. papers (full counting)		267	47,822	-	135	24,245	-
Share		0.6%	99.4%	-	0.6%	99.4%	-
CAGR		-0.80%	3.90%	-4.70	-12.19%	4.16%	-16.34
ICR		86.5%	64.3%	22.25	88.9%	66.9%	22.00
PPP		21.7%	12.1%	9.58	23.7%	12.3%	11.36
ARC		1.59	1.89	-0.31	1.26	1.86	-0.60
CDI		7.7	15.9	-8.2	7.4	16.0	-8.6
HCP10		17.0%	21.3%	-4.2	15.3%	21.1%	-5.8
FWCS		1.17	1.39	-0.22	1.14	1.39	-0.25
Norm share (diff in p.p.) cited	patents (PCP)	-1.2	-0.2	-1.0	-3.5	0.0	-3.5
	private sector (PCI)	19.9	17.3	2.6	18.1	17.4	0.7
	policy (PCPL)	12.4	16.3	-3.9	17.2	14.8	2.4

Note: This table reports the aggregate scores of all NPL collaborators. The publications from top NPL collaborators are classified as including at least one author from NPL (with NPL) or not including NPL authors (without NPL).

Over the study period from 2013 to 2023, collaborations with NPL have significantly influenced the ICR and PPR for its top collaborators in the field of energy & environment research, Table 21.

Collaboration with NPL may increase the industrial relevance of research conducted by its partners, as NPL's mission is to deliver new products. This could explain the positive impact of normalising NPL's output shares for private sector collaborators in 2013–2023.

And since another of NPL's missions is to maintain UK and international measurement systems, collaborating with NPL may increase the policy relevance of the research conducted by its top collaborators. This could explain the positive impact of NPL's share of standardisation outputs cited in policy-relevant documents by its collaborators in 2013–2023.

6.6 KEY & EMERGING TOPIC CLUSTERS

NPL and all NMIs top key topic clusters are ‘Atmos’ that stands for “Atmospheric Aerosol; Particular Matter 2.5; Emissions” and ‘Gas C’ which is “Gas Chromatography; Tandem Mass Spectrometry; Ultrasonics”. ‘Atmos’ which means “Atmospheric Aerosol; Particular Matter 2.5; Emissions” is NPL’s top emerging topic cluster with a CAGR of 13.3%, Figure 15.

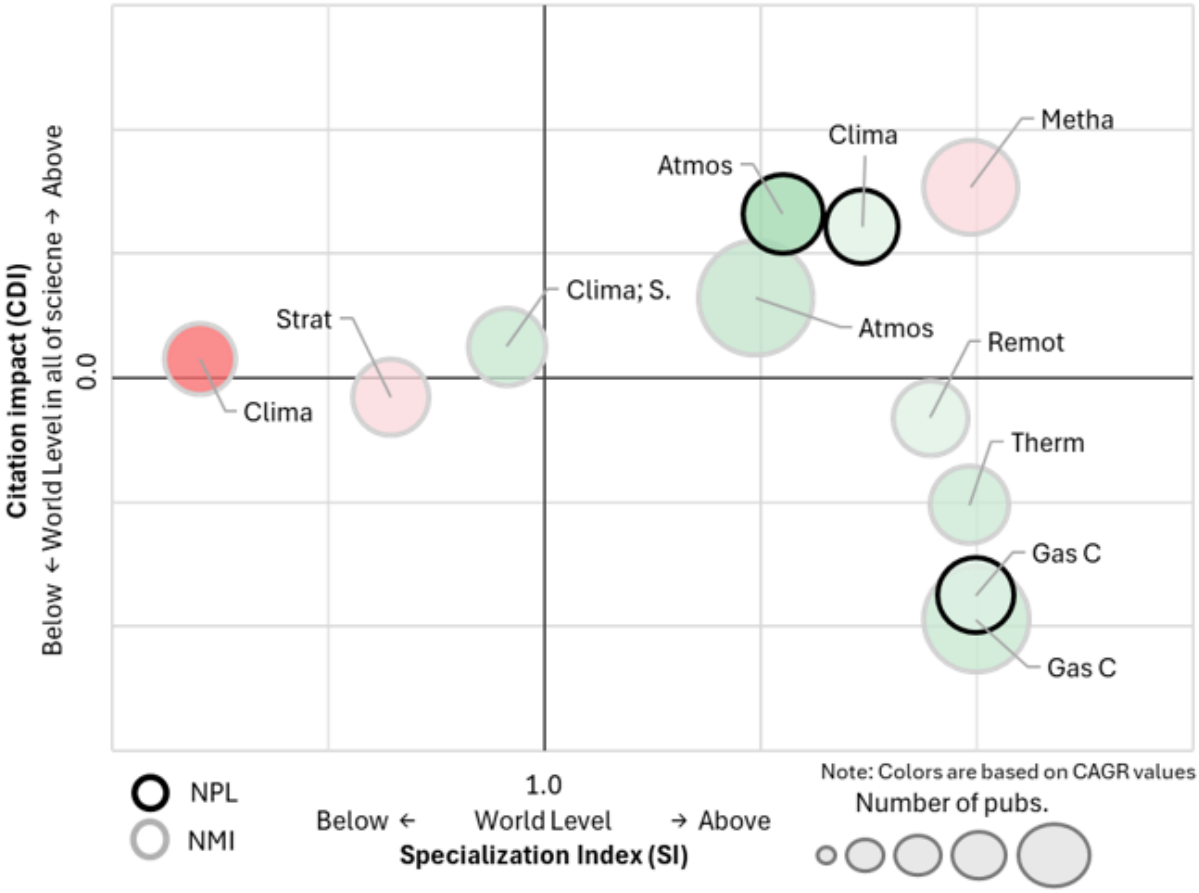

Figure 15. Key & emerging topic-clusters in the field of energy & environment (NPL, all NMI grouped over 2013–2023).
Note: *‘Red’ points decreasing in CAGR while ‘Green’ means it is increasing in CAGR.*

7 ADVANCED MANUFACTURING

From 2013 to 2023, the World's research output in the field of advanced manufacturing totaled 3,3 million publications.

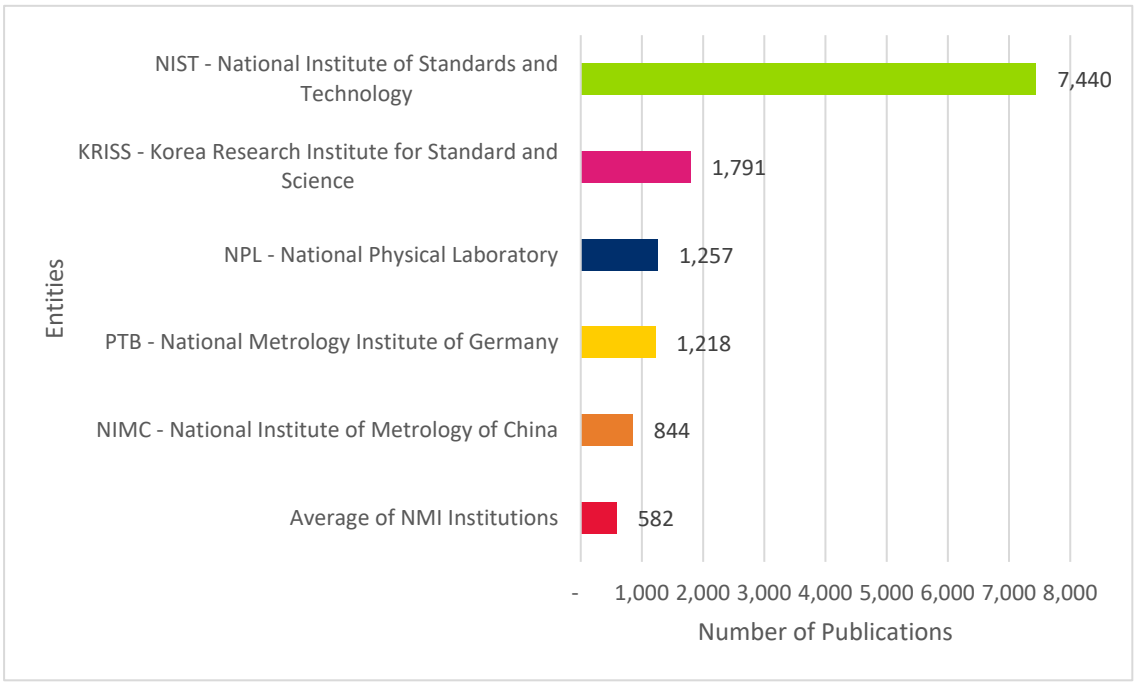

Figure 16. Number of publications in the field of advanced manufacturing over 2013-2023.

During this study period, NPL produced above 1.2 thousand publications in the field of advanced manufacturing, surpassing the average of NMI institutions ranked third among five-selected NMIs, Figure 16.

7.1 GROWTH

Table 22. Compound annual growth rate in the field of advanced manufacturing for the periods of 2013-2017 and 2018-2022.

Entity	No.	CAGR	
	2013–2023	2013–2017	2018–2022
World	3,335,967	6.3%	8.7%
United Kingdom	121,698	6.5%	4.7%
NPL - National Physical Laboratory	**1,257**	**2.1%**	**-1.1%**
NMI institutes	16,296	1.0%	-2.2%
NIST - National Institute of Standards and Technology	7,440	2.4%	-4.9%
KRISS - Korea Research Institute for Standard and Science	1,791	-0.2%	-1.3%
PTB - National Metrology Institute of Germany	1,218	2.7%	-3.9%
NIMC - National Institute of Metrology of China	844	7.3%	10.1%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

Between 2013 and 2023, NPL exhibited a CAGR of 2.1% in advanced manufacturing research during 2013–2017, which declined to -1.1% in 2018–2022. This decrease contrasts with the global CAGR of 6.3% and an increase to 8.7% over the same period, Table 22.

The initial growth phase may reflect NPL's active engagement in advanced manufacturing research, aligning with the UK's industrial strategies. Since 2021, a consortium, led by NPL, has secured £22.6m funding for a 5-year innovation initiative, the first for the advanced machinery & productivity institute (AMPI), which will be based in Rochdale, Greater Manchester. This funding has been provided through UK Research and Innovation's flagship strength in places fund (SIPF) (McHugh, 2021). This project is aimed to develop world leading machinery innovation, advanced materials, automation and production capabilities, vital to the future productivity, security, prosperity of the manufacturing sector in the UK economy. It also stimulates and supports the rapid growth of the UK's machinery manufacturing sector as it transitions to highly integrated digital solutions with sophisticated automated and autonomous robotic systems.

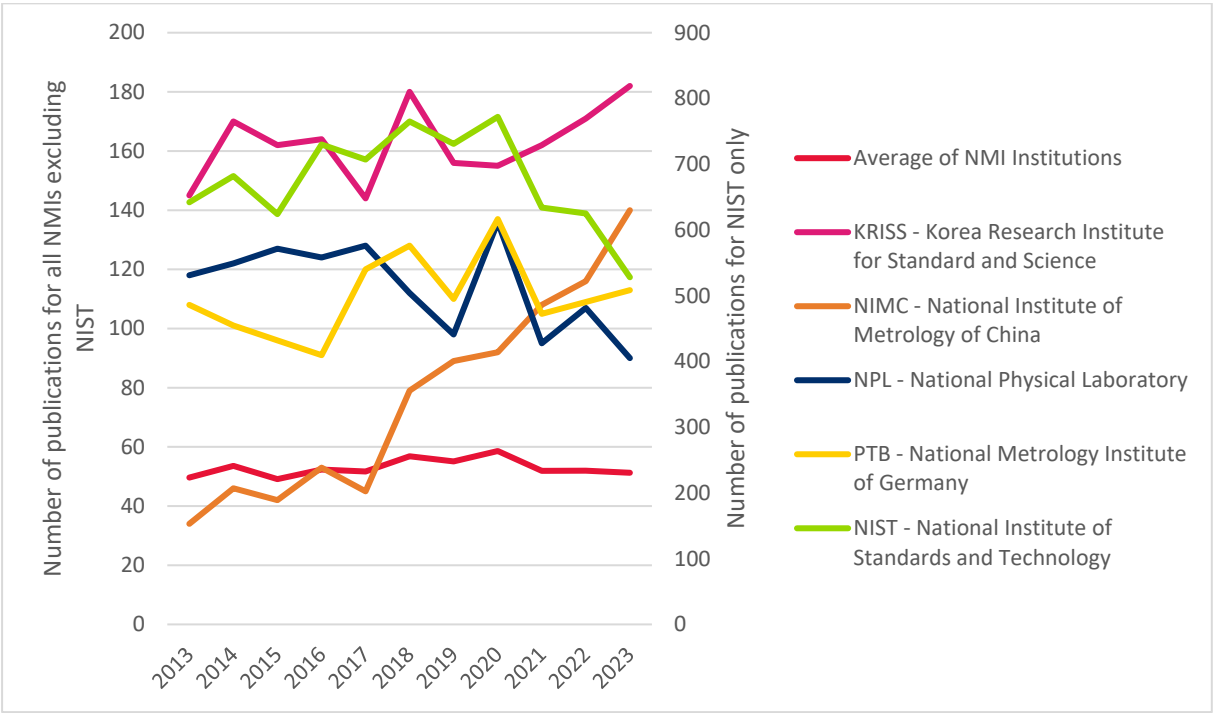

Figure 17. Number of publications by year in the field of advanced manufacturing sector over 2013-2023.

Over the past decade, NIST has significantly decreased its annually output in the advanced manufacturing research, while other NMIs have maintained relatively stable levels of activity except NIMC, Figure 17. The rapidly increased publications of NIMC may be due to the massive research investment by the Chinese government: between 2000 and 2017, the number of Chinese research faculty increased by 69%, and public research funding increased 10-fold, according to the Compilation of Science and Technology Statistics of Higher Education Institutions (CSTS-HEI) produced by the Chinese Ministry of Education. While NIST exhibited the highest output in the field of advanced manufacturing and experienced growth between 2013 and 2017 and reached at the peak time in 2020.

7.2 COLLABORATION PATTERNS

Table 23. International collaboration rate and public–private collaboration rate in the field of advanced manufacturing over 2013-2023.

Entity	Networking			
	ICR	CAGR†	PPR	CAGR†
World	23.0%	0.8%	7.4%	1.4%
United Kingdom	70.6%	2.3%	11.6%	-0.5%
NPL - National Physical Laboratory	**60.9%**	**3.0%**	**18.2%**	**6.9%**
NMI institutes	40.5%	1.3%	13.2%	1.7%
PTB - National Metrology Institute of Germany	55.1%	1.2%	19.7%	2.6%
NIST - National Institute of Standards and Technology	41.9%	1.8%	11.0%	2.4%
KRISS - Korea Research Institute for Standard and Science	32.1%	-0.3%	9.2%	0.5%
NIMC - National Institute of Metrology of China	15.5%	-0.2%	9.7%	10.1%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

Among the selected NMIs in the advanced manufacturing research, NPL's ICR (60.9%) ranked first and PPR (18.2%) ranked second for the whole study period, surpassing both the UK and the world level, Table 23.

NPL's ICR increased with a CAGR of 3.0% during this period. This growth rate is 3.8 times higher than the global average and approximately 2.7 times higher than that of other NMIs, indicating NPL's expanding international collaboration network. NPL's ICR growth closely mirrors the UK's national CAGR, with NPL's ICR remaining slightly below the UK average throughout the study period.

NPL's PPR experienced a CAGR of 6.9%, surpassing the growth rates of the world, the UK, and other NMIs, Table 23. The CAGR for NPL's PPR is approximately 5 times higher than the global rate and six-times higher than that of other NMIs, highlighting NPL's strong engagement with the industry.

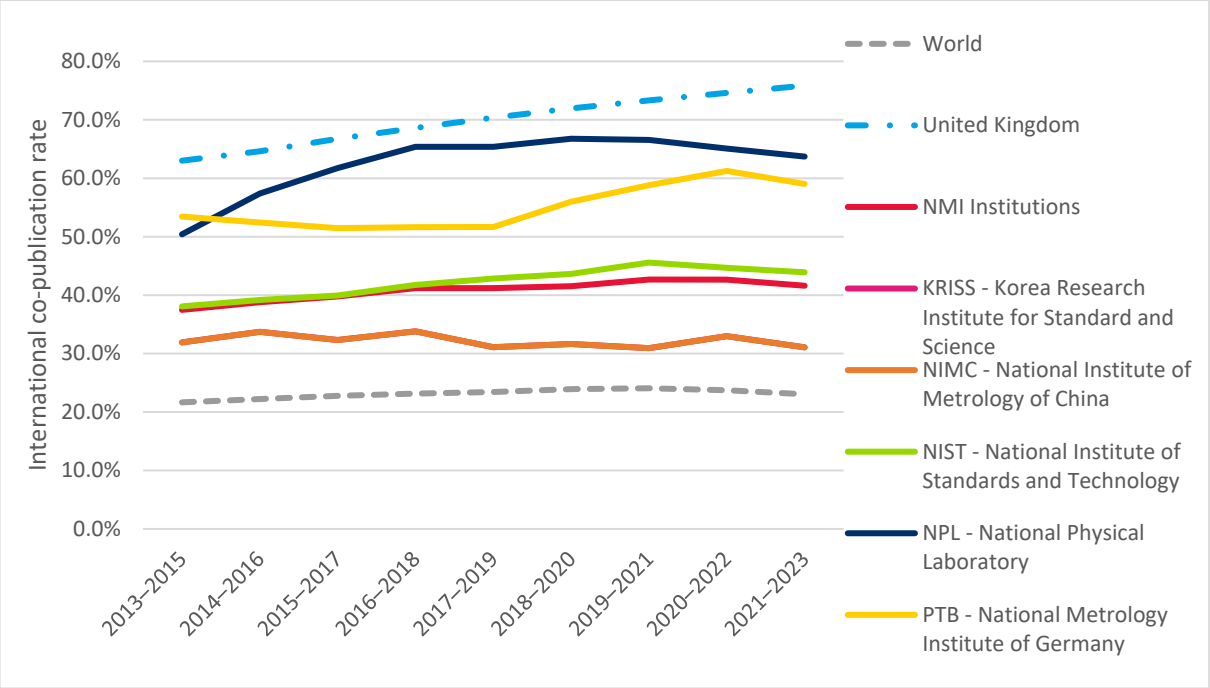

Figure 18. International collaboration rate in the field of advanced manufacturing by 3-year moving period over 2013-2023.

The ICRs of the five selected NMIs are all higher than the world level in terms of research output in advanced manufacturing. In addition to the NIMC being lower than the average of NMIs, the remaining four NMIs are higher than the average of NMIs.

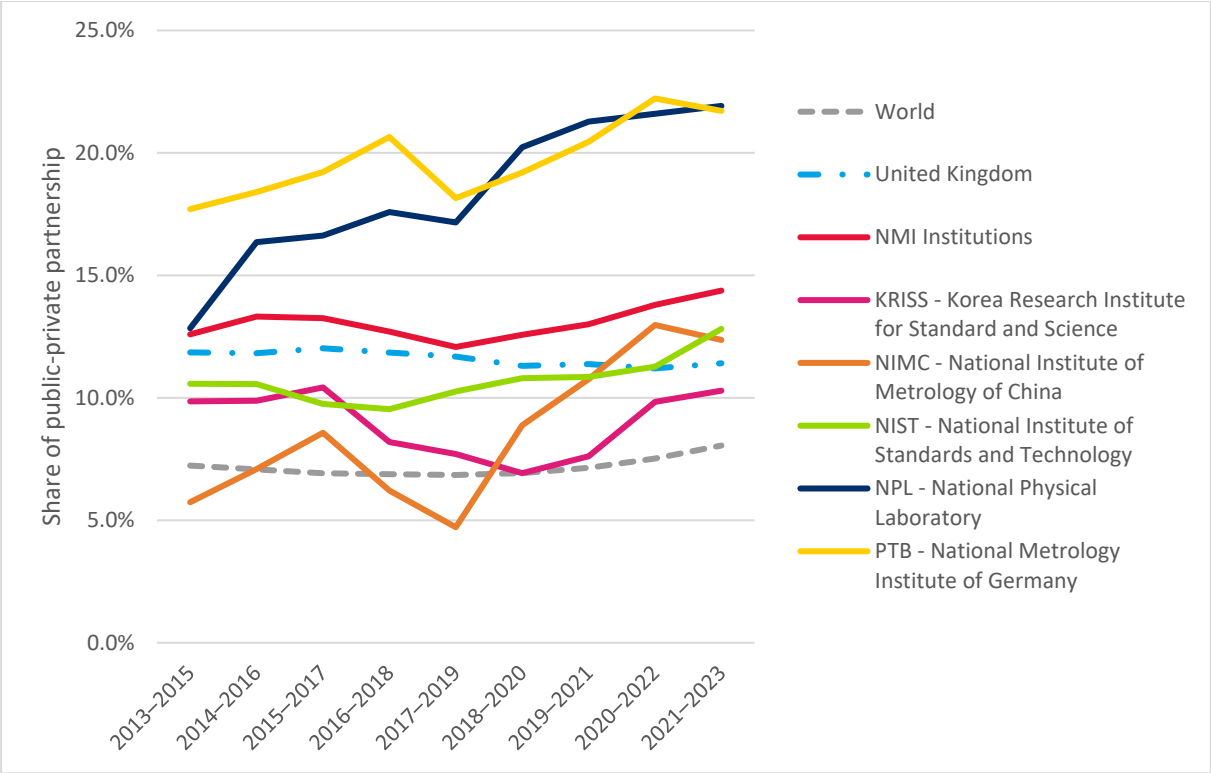

Figure 19. Public–private collaboration rate in the field of advanced manufacturing by 3-year moving period over 2013-2023.

All selected NMIs experienced an increase in ICR and PPR throughout the period. As with performance in other sectors, NPL has been performing in leading position on PPR. And due to the rapidly growth PPR of NPL, NPL may be able to surpass PTB in the future, Figure 19.

7.3 CITATION IMPACT

Table 24. Average relative citations and field-weighted citation score in the field of advanced manufacturing over 2013-2023.

	ARC		FWCS	
Entity	**Score**	**CAGR†**	**Score**	**CAGR†**
World	1.25	-0.2%	1.13	-0.1%
United Kingdom	1.65	-2.6%	1.44	-0.9%
NPL - National Physical Laboratory	**1.27**	**-1.5%**	**1.35**	**1.0%**
NMI institutes	1.44	-3.0%	1.41	-1.3%
NIST - National Institute of Standards and Technology	1.91	-3.8%	1.73	-1.8%
PTB - National Metrology Institute of Germany	1.24	0.5%	1.18	-3.0%
KRISS - Korea Research Institute for Standard and Science	0.93	-4.2%	1.24	-0.4%
NIMC - National Institute of Metrology of China	0.74	4.9%	0.88	1.9%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

For the whole study period, NPL's ARC (1.27) ranked second behind NIST (1.91) among the five NMIs. Besides, most NMIs experienced a negative CAGR for ARC, with the exceptions of PTB (0.5%) and NIMC (4.9%), Table 24.

Same as ARC, NPL's FWCS (1.35) ranked second behind NIST's (1.73), and all selected NMIs are experienced a positive FWCS, Table 24.

For the 2013–2023 period, NPL's ARC (1.27) exceeded the world's ARC of 1.25. Because ARC is subfield-normalised, the world's score being greater than one indicates that advanced manufacturing research is, on average, 25% more cited than the average paper in the corresponding subfield at world level. As such, if NPL's ARC was rebased against the world's ARC in advanced manufacturing, its score would be 1.0, indicating that NPL's output was cited equally as often as the average world paper outputs in advanced manufacturing.

Similarly, NPL's FWCS (1.35) is higher than the world's FWCS (1.13), with a rebased score of 1.19, highlighting that NPL's advanced manufacturing research was published in more influential/prestigious journals.

The ARC of NPL, the UK and other NMIs remained stable throughout the whole period. The FWCS scores of the UK and other NMIs are on par, while NPL's FWCS was slightly lower and closer to the world level.

Table 25. Citation distribution index and highly cited publications in the field of advanced manufacturing over 2013-2023.

		HCP10	
Entity	**CDI**	**Score**	**CAGR†**
World	6.3	13.6%	0.4%
United Kingdom	14.1	18.6%	-1.8%
NPL - National Physical Laboratory	**7.4**	**13.4%**	**0.9%**
NMI institutes	7.8	14.9%	-3.1%
NIST - National Institute of Standards and Technology	13.4	20.5%	-2.8%
PTB - National Metrology Institute of Germany	6.0	11.3%	-7.6%
KRISS - Korea Research Institute for Standard and Science	-2.8	8.2%	-4.6%
NIMC - National Institute of Metrology of China	-6.0	7.0%	4.5%

Note: †CAGR computed on the 3-year moving periods (measures percent growth moving from one period to the next).

NPL's CDI (7.4) ranked second behind that of NIST (13.4) and NPL's HCP10 (13.4%) ranked second behind that of NIST (20.5%), Table 25. As with ARC and FWCS, the UK had both the highest HCP10 and CDI scores. The UK was followed by other NMIs on both indicators as in other national challenge areas.

7.4 ALTMETRICS

Table 26. Altmetrics, normalised share (diff in p.p.) cited in the field of advanced manufacturing over 2013-2023.

Entity	Altmetrics (2013–2023)					
	Norm share (diff in p.p.) cited in					
	Patents (PCP)	Δ	Private sector (PCI)	Δ	Policy lit. (PCPL)	Δ
World	1.2	-0.7	3.9	0.3	-0.6	0.1
United Kingdom	3.9	-0.6	13.1	-2.2	0.0	0.0
NPL - National Physical Laboratory	**2.9**	-1.0	**18.3**	0.1	**1.2**	-0.2
NMI institutes	4.0	-1.1	11.5	-3.1	0.7	-0.1
NIST - National Institute of Standards and Technology	6.2	-1.3	13.8	-3.1	0.9	-0.3
PTB - National Metrology Institute of Germany	2.4	0.0	16.7	0.3	1.2	1.3
KRISS - Korea Research Institute for Standard and Science	0.9	-1.8	1.7	-2.4	-0.5	0.6
NIMC - National Institute of Metrology of China	-4.4	1.1	-5.3	2.5	-0.6	-0.9

Note: Δ computed based on the 3-year moving periods (measures percent growth moving from one period to the next).

Table 27. Altmetrics (complementary) share of paper cited at least once in the field of advanced manufacturing over 2013-2023.

Entity	Almetrics (complementary)		
	Share of papers cited at least once by		
	Patents	Private sector	Policy lit.
World	7.8%	48.4%	0.8%
United Kingdom	10.9%	58.0%	1.5%
NPL - National Physical Laboratory	**10.3%**	**62.9%**	**2.7%**
NMI institutes	10.8%	53.1%	1.9%
NIST - National Institute of Standards and Technology	13.0%	53.9%	1.9%
PTB - National Metrology Institute of Germany	8.7%	53.5%	1.9%
KRISS - Korea Research Institute for Standard and Science	9.1%	48.1%	0.4%
NIMC - National Institute of Metrology of China	2.0%	35.7%	0.4%

NPL ranked second behind NIST (6.2) in PCP. NPL had the highest PCI and PCPL in the field of advanced manufacturing, Table 26. NPL's citation impact scores in non-scientific communities, as measured by citations by the private sector and in policy documents, have always been above those of the world average, the UK and other NMIs.

Over the entire period, the NPL's patent uptake score was 2.9 (p.p.), exceeding the world average by 2.4 times. NPL's advanced manufacturing research is cited by the industry at a level 4.7 times that of the world benchmark and are three times than the world average level of policy literature.

7.5 THE IMPACT OF COLLABORATING WITH NPL

Table 28. The impact of collaborating with NPL results in the field of advanced manufacturing for the periods of 2013-2017 and 2018-2022.

Dataset:		Advanced Materials Research					
Period:		2013–2023			2018–2022		
Collaboration with/without NPL		with NPL	without NPL	diff.	with NPL	without NPL	diff.
No. papers (full counting)		777	266,356	-	365	128,855	-
Share		0.3%	99.7%	-	0.3%	99.7%	-
CAGR		0.32%	1.64%	-1.33	0.35%	1.48%	-1.14
ICR		69.8%	57.7%	**12.1**	71.2%	60.3%	**10.9**
PPP		17.6%	10.4%	**7.3**	19.7%	10.1%	**9.6**
ARC		1.41	1.59	-0.18	1.32	1.47	-0.15
CDI		10.0	12.5	-2.5	9.0	11.1	-2.1
HCP10		15.3%	17.2%	-1.9	16.6%	16.0%	0.6
FWCS		1.46	1.48	-0.02	1.48	1.46	0.02
Norm share (diff in p.p.) cited	patents (PCP)	4.2	4.4	-0.2	6.1	3.3	**2.7**
	private sector (PCI)	20.3	11.4	**8.9**	18.8	10.0	**8.8**
	policy (PCPL)	1.5	0.4	**1.1**	2.6	0.3	**2.3**

Note: This table reports the aggregate scores of all NPL collaborators. The publications from top NPL collaborators are classified as including at least one author from NPL (with NPL) or not including NPL authors (without NPL)

Same with all four research fields, collaborations with NPL have significantly enhanced both the ICR and PPR for its primary partners in the field of advanced manufacturing, Table 28. This aligns with NPL's mission to support the launch of new products and maintain both UK and international measurement systems, thereby increasing the relevance of collaborative research to the private sector and policymaking.

NPL's focus on product innovation likely elevates the applicability of its partners' research to industry needs, as evidenced by a higher PCI score between 2013 and 2023. NPL's role in upholding measurement standards enhances the policy significance of its collaborators' research, reflected in an increased normalized share of outputs cited in policy-related documents during the same period.

7.6 KEY & EMERGING TOPIC CLUSTERS

NPL's and all NMI's top key topic cluster in the field of advanced manufacturing is "Graphene; Chemical Vapor Deposition; Scanning Tunneling Microscopy" which is abbreviated as 'Graph'. On the other hand, 'Trans' which stands for "Transition Metal; Molybdenum; Density" and 'Ferrom' that is "Ferromagnetism; Anisotropy; Magnetoresistance" are NPL's top emerging topic clusters with a CAGR of 14.9%, Figure 20.

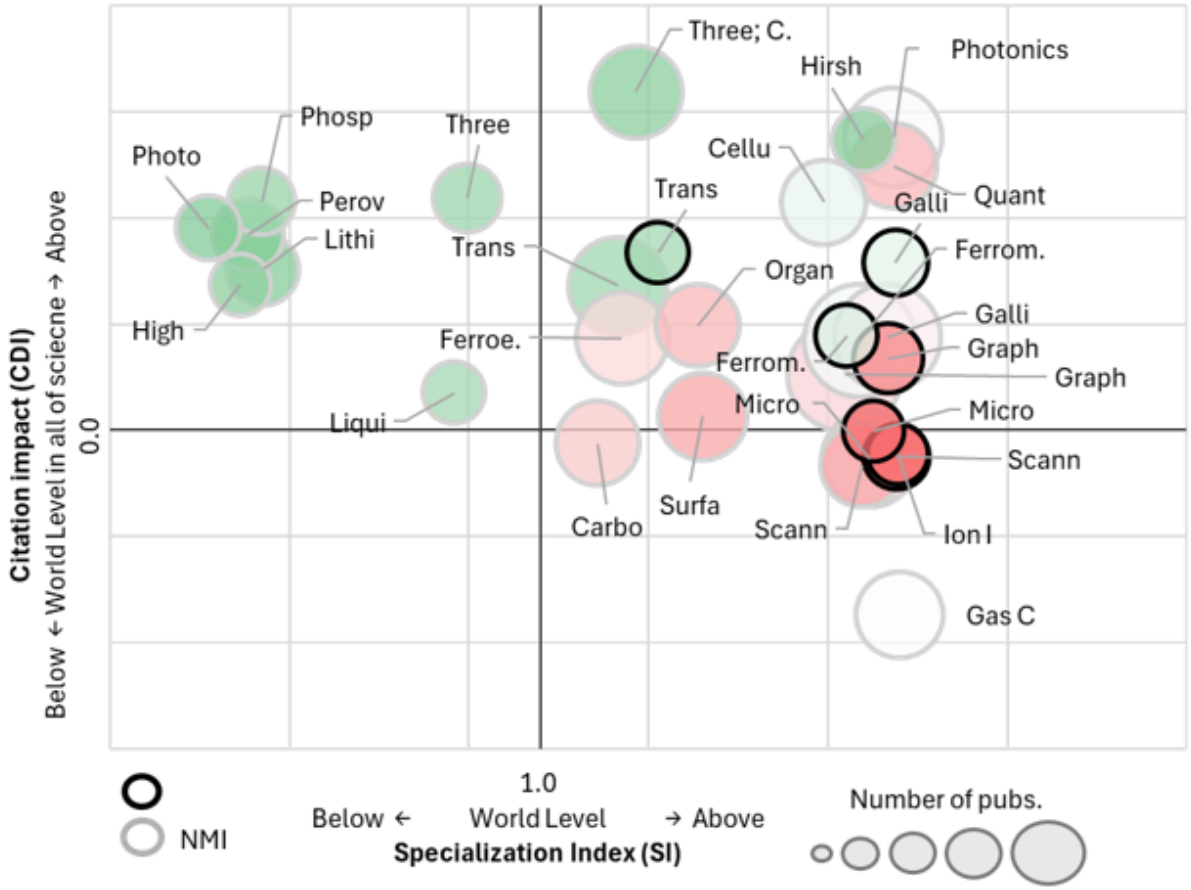

Figure 20 Key & emerging topic-clusters in the field of advanced manufacturing (NPL, all NMI grouped over 2013–2023).
Note: *'Red' points decreasing in CAGR while 'Green' means it is increasing in CAGR.*

In 'Ferrom' cluster NPL is performing both above world's CDI and publication count averages, although its CAGR is losing momentum (light green coloured). Similar to 'Ferrom' cluster, NPL also perform above the world average in 'Galli' cluster while it scores higher than 'Ferrom'.

8 CONCLUSION

NPL ranks among the top three NMIs in terms of research output in all four research fields. Notably, the growth rate of research output between 2013 and 2017 was consistently higher than that between 2018 and 2022.

In terms of the rate of publications resulting from public-private collaborations, NPL has consistently outperformed the global, UK and NMI averages. In addition, NPL's rate of publications resulting from international collaborations has also risen steadily over the analysis period. NPL ranks highest among NMIs in the ICR for research in advanced materials and data and digital, while also being among the top three NMIs in ICR and PPR for all other research areas.

In addition to the impact of investment and changes in output in specific research directions due to the redistribution of internal resources, some aspects of basic output research may have a lower score, considering the emphasis placed by NPL on applied research. Additionally, because NPL attaches great importance to commercialisation and strong connection with public and private sectors, NPL's PPR has scored higher in all research fields.

In the field of data and digital research, the number of NPL patents has steadily increased throughout the period. Consistent with NPL's mission to support new product releases, the share of NPL publications cited in the private sector remains highest compared to policy literature and patents. Notably, the private sector adoption rate of NPL in the field of health and life research is the highest among the selected NMIs.

Overall, the selected NMIs show their respective strengths and trends in terms of data performance. NIST excels in the number of research outputs in most fields, especially in advanced manufacturing and data and digital research, which could be attributed to its strong funding and diverse research priorities. In contrast, NPL excels in citation impact metrics such as ARC and FWCS, particularly in the fields of energy and environment and data and digital research. This success may be attributed to NPL's emphasis on accurate measurement, international standardisation, collaboration with the private sector and policymakers, and the publication of strategic papers in high-impact journals.

The best performing key & emerging topic clusters for NPL are 'Radia' (in life sciences & health), 'Galli' (in data & digital), Atmos', 'Clima' (in energy & environment) and 'Trans' (in advanced manufacturing') with both above world average scores for CDI and publication count while having a positive CAGR values.

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ANNEX-1: NATIONAL METROLOGY INSTITUTES

Acronym	Entity
BEV	Federal Office of Metrology and Surveying of Austria
CEM	Spanish Metrology Centre
CMI	Czech Metrology Institute
DFM	Danish National Metrology Institute
GUM	Central Office of Measures
IMBiH	Institute of Metrology of Bosnia and Herzegovina
INM	Romanian National Institute of Metrology
INRIM	National Institute of Metrological Research of Italy
IPQ	Portuguese Quality Institute
Justervesenet	Norwegian Metrology Service
KRISS	Korea Research Institute for Standard and Science
LNE	National Metrology and Testing Laboratory of France
METAS	Swiss Federal Institute of Metrology
Metrosert	Metrosert AS
MIKES	Centre for Metrology and Accreditation of Finland
MIRS	Metrology Institute of the Republic of Slovenia
NIMC	National Institute of Metrology of China
NMIJ	National Metrology Institute of Japan
NIST	National Institute of Standards and Technology
NPL	National Physical Laboratory
OMH	National Metrology Institute of Hungary
PTB	National Metrology Institute of Germany
RISE	Research Institutes of Sweden
SMD	FPS Economy, SMEs, Middle Classes, and Energy
SMU	Slovak Institute of Metrology
SP	Technical Research Institute of Sweden
TUBITAK UME	Turkish National Institute of Metrology
VSL	Dutch Metrology Institute

ANNEX-2: LIFE SCIENCES & HEALTH TOPIC CLUSTERS DEFINITIONS

Compu	Computed Tomography; Image Processing; Signal-to-Noise Ratio
DNA;	DNA; Genetics; Fossil
Drug	Drug Delivery System; Chemotherapy; Biocompatibility
Gas C	Gas Chromatography; Tandem Mass Spectrometry; Ultrasonics
Liqui	Liquid Chromatography; Tandem Mass Spectrometry; Molecular Biology
Magne T.	Magnetic Resonance Imaging; Transmission Electron Microscopy; Iron Oxide
Magne C.	Magnetic Resonance Imaging; Chemical Exchange Saturation Transfer; Contrast Medium
Magne S.	Magnetic Resonance Imaging; Signal-to-Noise Ratio; Image Processing
Matri	Matrix-Assisted Laser Desorption-Ionization; Desorption; Imaging Mass Spectrometry
Monte	Monte Carlo Simulation; Small-Angle X-Ray Scattering; Neutron Irradiation
Near	Near Infrared Spectroscopy; Optical Imaging; Coherence
Radia	Radiation Therapy Planning; Computed Tomography; Imaging Phantom
RNA;	RNA; Gene Expression Profiling; Cell Proliferation
Silve	Silver Nanoparticle; Transmission Electron Microscopy; Nanomaterials
Ultra	Ultrasonics; Medical Ultrasound; Signal-to-Noise Ratio
Urani	Uranium; Radon; Gamma Spectroscopy

ANNEX-3: DATA & DIGITAL TOPIC CLUSTERS DEFINITIONS

Anten 1	Antenna; Electromagnetic Compatibility; Power Transformer
Anten 2	Antenna; Electronic Circuit; Ultra-Wideband
Batte	Battery (Electrochemical Energy Engineering); Energy Engineering; Hybrid-Electric Vehicle
Bismu	Bismuth; Magnetoresistance; Antenna
Clima	Climate Change; Soil Moisture; Vegetation
Confo	Conformal Field Theory; Quantum Gravity; Superstring
Ferro A.	Ferromagnetism; Anisotropy; Magnetoresistance
Ferro S.	Ferromagnetism; Spin System; Perovskite
Galli	Gallium Arsenide; Quantum Dot; Indium
Gas C	Gas Chromatography; Tandem Mass Spectrometry; Ultrasonics
Gauss	Gaussian Distribution; Signal-to-Noise Ratio; Photonics
Graph	Graphene; Chemical Vapor Deposition; Scanning Tunneling Microscopy
Image	Image Segmentation; Deep Neural Network; Object Detection
Laser	Laser Pulse; Molecular Dynamics; Nonlinear Optics
Lithi	Lithium Ion Battery; Battery (Electrochemical Energy Engineering); Anode
Metal	Metal-Organic Framework; Coordination Polymer; Carbon Dioxide
Metha	Methane; Hydrogen Production; Large Eddy Simulation
Micro	Microelectromechanical System; Atomic Force Microscopy; Piezoelectricity
Perov	Perovskite; Dye-Sensitized Solar Cell; Titanium Dioxide
Phosp	Phosphor; Luminescence; Emission Spectroscopy
Photo O.	Photonics; Optical Resonator; Nonlinear Optics
Photo P.	Photonics; Passive Optical Network; Indium
Quant	Quantum Optics; Quantum Key Distribution; Photonics
Radia	Radiation Therapy Planning; Computed Tomography; Imaging Phantom
Scann	Scanning Tunneling Microscopy; Ferromagnetism; Quantum Optics
Super	Superfluid; Bose-Einstein Condensate; Metamaterial
Surfa	Surface Plasmon; Refractive Index; Antenna
Trans	Transition Metal; Molybdenum; Density

ANNEX-4: ENERGY & ENVIRONMENT TOPIC CLUSTERS DEFINITIONS

Atmos	Atmospheric Aerosol; Particular Matter 2.5; Emissions
Clima; S.	Climate Change; Soil Moisture; Vegetation
Clima	Climate Change; Extreme Event; Global Warming
Gas C	Gas Chromatography; Tandem Mass Spectrometry; Ultrasonics
Metha	Methane; Carbon Dioxide; Nucleation
Photo	Photonics; Optical Resonator; Nonlinear Optics
Remot	Remote Sensing; Coastal Water; Black Sea
Strat	Stratosphere; Troposphere; Planetary Atmosphere
Therm	Thermal Radiation; Heat Conduction; Polarimetry

ANNEX-5: ADVANCED MANUFACTURING TOPIC CLUSTERS DEFINITIONS

Carbo	Carbon Nanotube; Graphene; Scanning Electron Microscopy
Cellu	Cellulose; Scanning Electron Microscopy; Fourier Transform Infrared Spectroscopy
Ferroe.	Ferroelectricity; Perovskite; Barium
Ferrom.	Ferromagnetism; Anisotropy; Magnetoresistance
Galli	Gallium Arsenide; Quantum Dot; Indium
Gas C	Gas Chromatography; Tandem Mass Spectrometry; Ultrasonics
Graph	Graphene; Chemical Vapor Deposition; Scanning Tunneling Microscopy
High	High Entropy Alloys; Titanium; Chromium Alloys
Hirsh	Hirshfeld Surface; Machine Learning; Hydrogen Bonding
Ion I	Ion Implantation; Silicon; Transmission Electron Microscopy
Liqui	Liquid Crystal; Differential Scanning Calorimetry; Ferroelectricity
Lithi	Lithium Ion Battery; Battery (Electrochemical Energy Engineering); Anode
Micro	Microelectromechanical System; Atomic Force Microscopy; Piezoelectricity
Organ	Organic Solar Cells; Conjugated Polymer; Heterojunction
Perov	Perovskite; Dye-Sensitized Solar Cell; Titanium Dioxide
Phosp	Phosphor; Luminescence; Emission Spectroscopy
Photonics	Photonics; Optical Resonator; Nonlinear Optics
Photo	Photocatalysis; Carbon Dioxide; Bismuth
Quant	Quantum Optics; Quantum Key Distribution; Photonics
Scann	Scanning Tunneling Microscopy; Ferromagnetism; Quantum Optics
Surfa	Surface Plasmon; Refractive Index; Antenna
Three;C.	Three Dimensional Printing; Corrosion; Magnesium
Three	Three Dimensional Printing; Fused Filament Fabrication; Ultimate Tensile Strength
Trans	Transition Metal; Molybdenum; Density