

Bibliometric assessment of the National Physical Laboratory's contribution to Quantum Technologies

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Glossary and methods guide

DATASETS

Term	Reader guide
QT dataset	Scopus thematic set built iteratively from NQTP-supported papers using tf-idf and analyst validation. It targets QT applications rather than enabling science.
Standardization	LLM-classified Scopus dataset of publications related to standardization practices for 2001-2025, including a QT subset.
ISO standards	Citation dataset linking ISO standards to referenced Scopus documents using reference lists supplied by ISI Fraunhofer.
Retrieval	Entity publication sets combine address matching, funding acknowledgements, Gateway to Research fuzzy matching, NQTP hub checks, and NPL DOI matching.

METHOD CHOICES

Term	Reader guide
Period of analysis	Covers 2001-2025, reported mainly in five-year periods, with one recent ten-year split, where useful.
Counting method	Full counting is used throughout. Each participating entity receives one full publication count for every paper on which it appears.
Rebasing	For QT, non-QT, standardization datasets and topic clusters, indicators are rebased to the relevant world reference for each year and subject area so that the world level equals 1.00.
Topic clusters	Clusters are higher-level groups of citation-based Scopus topics. They help organize portfolios and support benchmarking analyses.

Selection of comparators: The findings for NPL are compared to the world and UK level and, specifically, to the UKRI, EPSRC, ISCF, and NQTP. These entities are not only active in the same or similar research fields (quantum tech) but also part of the previous evaluation of NPL's QT programme. To ensure consistency, these entities are included again.

Glossary: output and citation impact

OUTPUT

Term	Reader guide
Number of publications	Total publication output attributed to an entity using full counting.
Specialization index (SI)	Shows whether an entity publishes proportionately more or less in a field than the world average. Values above 1 indicate specialization.
Compound annual growth rate (CAGR)	Measures how output changes over time while accounting for compounding. The calculation uses the first and last years in a period.

CITATION IMPACT

Term	Reader guide
Average of relative citations (ARC)	Average field- and year-normalized citation impact across an entity's papers. Values above 1 indicate above-world citation impact.
Citation distribution index (CDI)	Summarises how papers are distributed across citation deciles relative to the world. Zero indicates parity; positive values indicate stronger overall distribution.
Highly cited publications (HCP)	Share of papers in the top 10%, 5% or 1% most cited papers in their field and year, normalized to the world level.
Field-weighted CiteScore (FWCS)	Average field-weighted journal CiteScore of the outlets where an entity publishes. Values above 1 indicate publication in higher-impact journals.

Glossary: translation and interdisciplinarity

INTERDISCIPLINARITY AND READING NOTES

Term	Reader guide
Disciplinary diversity of authors (DDA 10)	Share of papers in the top 10% for diversity of authors' prior disciplinary backgrounds, normalized by subfield and year.
Disciplinary diversity of references (DDR 10)	Share of papers in the top 10% for diversity of cited disciplines, normalized by subfield and year.
World level = 1	Most benchmark indicators in this report are normalized so that 1 represents the world average. Values above 1 are above world level; values below 1 are below world level and, by that, above/below expectation.
Interpretation note	A lower DDR can signal stronger focus rather than weaker performance. Strong private-sector or policy values can highlight downstream relevance even when citation impact is closer to world level.

TRANSLATIONAL REACH

Term	Reader guide
Private-sector citations	Normalized share of publications cited by private-sector research. It reflects uptake of scientific work by companies.
Policy citations	Normalized share of publications cited by policy documents indexed in Overton. It reflects policy-facing influence.

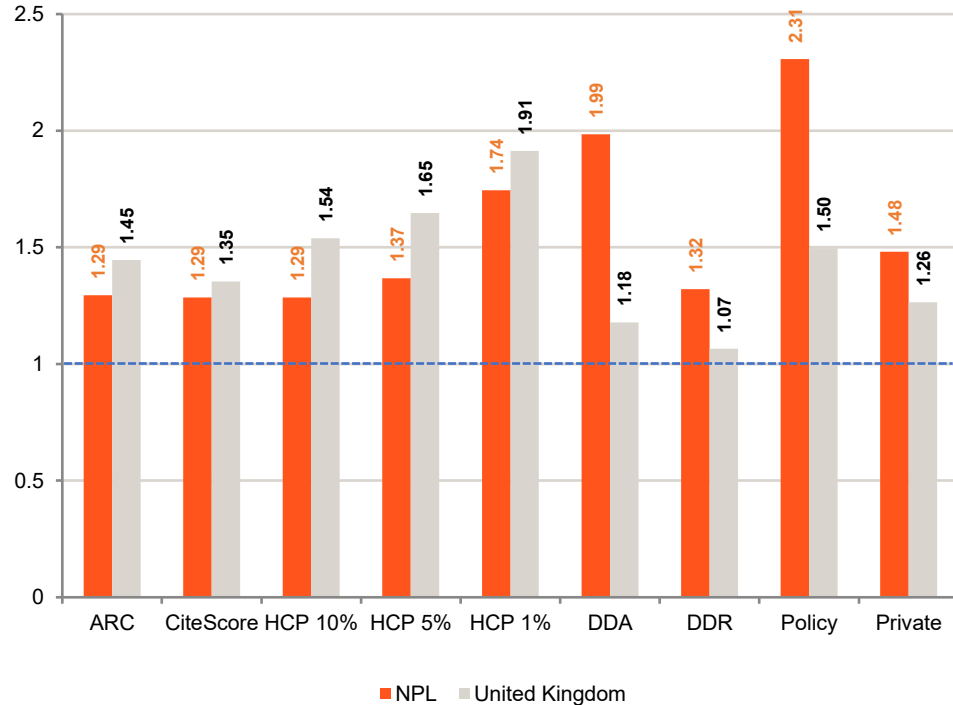
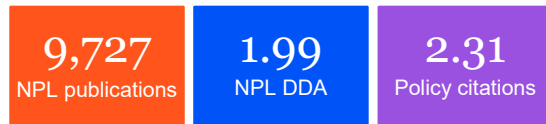


Bibliometric analysis

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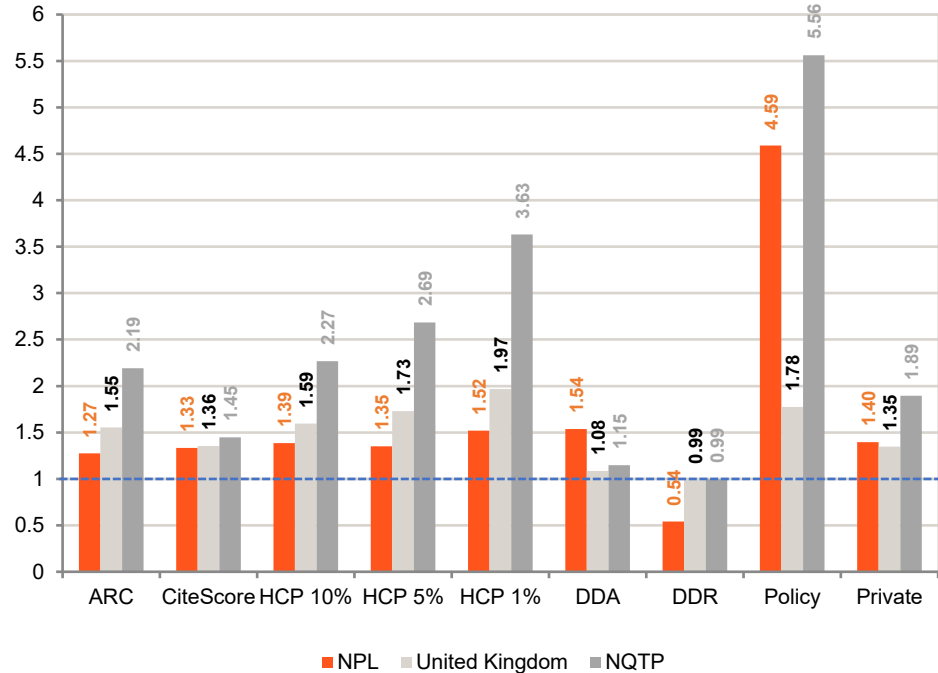
Scientific performance of NPL in all research fields (2001–2025)

- NPL records 9,727 publications in all fields, versus 4,530,339 publications for all UK institutions.
- For NPL, the strongest normalized indicators are DDA and DDR, the measures of interdisciplinarity, and Policy Citations (2.31).
- Citation-linked indicators remain above world level for NPL, with ARC (1.29), CiteScore (1.29) and HCP 1% (1.74).
- All measures are computed relative to the world average, normalized to 1, depicted by the blue dashed line.



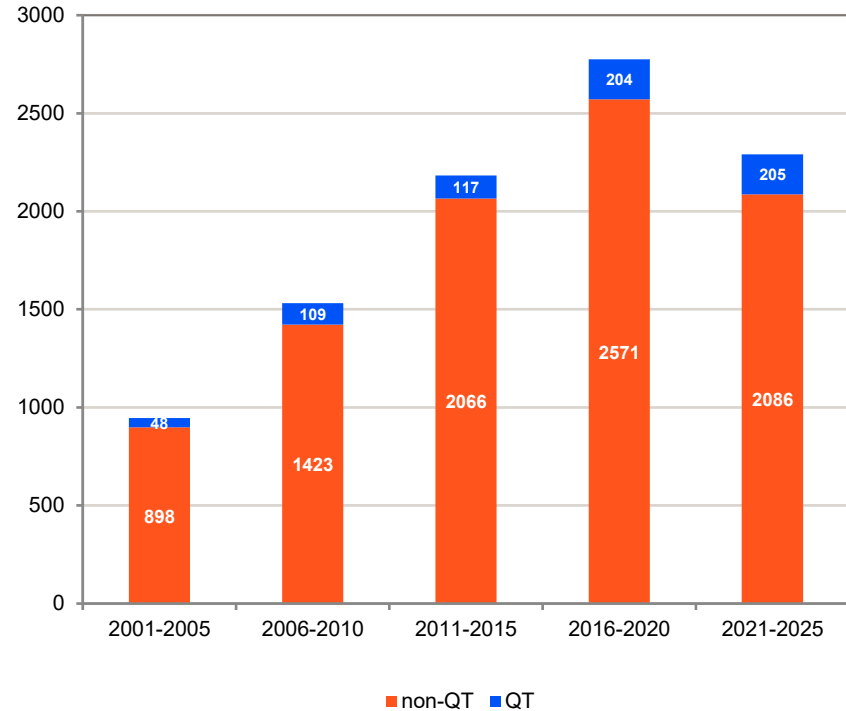
Scientific performance of NPL in quantum tech research (2001–2025), compared to the overall UK and the NQTP output

- In Quantum Tech, we record an overall number of 27,016 publication for the whole UK, among that 683 from NPL and 1,779 from NQTP for the full time-span 2001-2025. Because NQTP was initiated in 2014, most of the related publications were published in the last 10 years.
- NPL exceeds the UK values for the diversity of authors (DDA) and policy citations
- Except for DDR, where NPL-QT publications trails the world average in terms of diversity of referenced material, therefore, below the world average of 1, NPL-QT publications exceed the world level for every measure.
- NQTP was chosen as an additional comparator for Quantum Tech and demonstrates a strong position in this field.



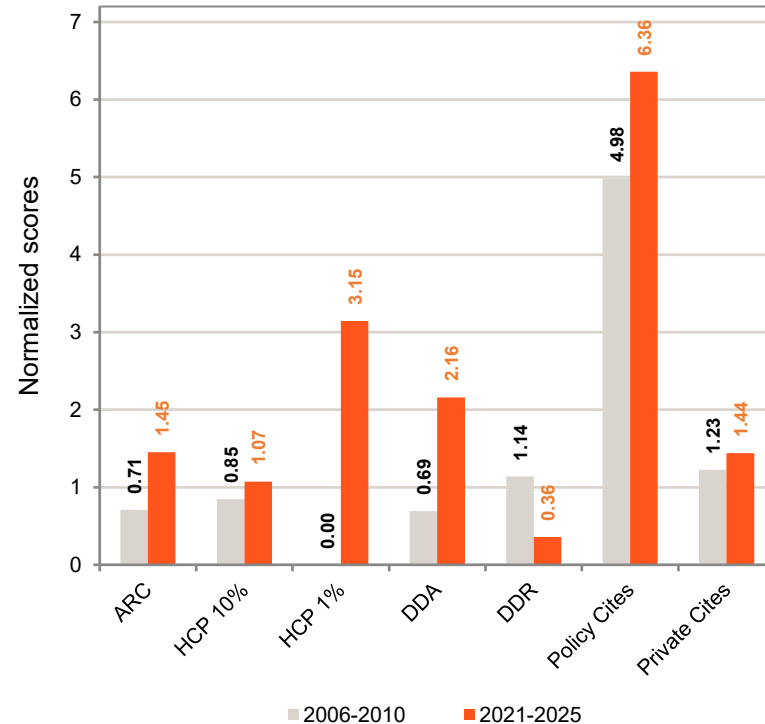
Number of NPL publications, QT and non-QT (2001–2025)

- NPL non-QT output rises from 898 in 2001–2005 to 2,571 in 2016–2020, before easing to 2,086 in 2021–2025.
- NPL QT output grows from 48 to 205 over the same period (factor 4.3), reaching the highest level in 2021–2025.
- QT represents 5.1% of NPL output in 2001–2005 and 8.9% in 2021–2025.



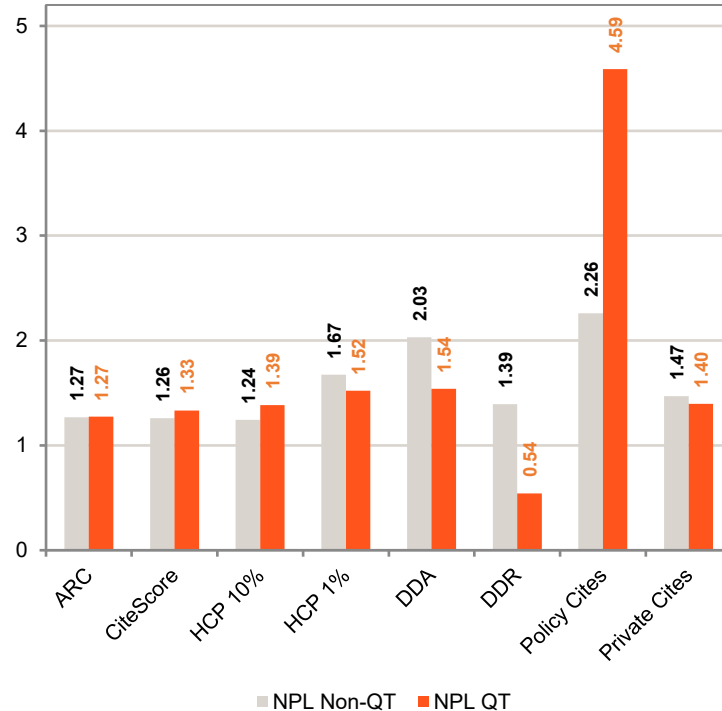
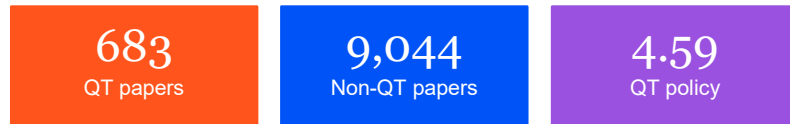
Scientific performance of NPL in Quantum Technologies over time: 2006-2010 vs. 2021-2025

- Since we have not enough observations for 2001-2005 to compute many of the indicators, we start with the five-year bracket 2006-2010.
- NPL QT publications improved in all dimensions except DDR.
- A lower DDR value implies more specialization in terms of cited material and less interdisciplinarity.
- ARC value has increased steadily over time, exceeding the world level starting in the 2011-2015 period, reaching a high of 1.45 for 2021-2025.
- The score for policy citations is exceptionally high already for 2006-2010 and grew further for the most recent years.



Benchmarking of NPL publication output, comparison between Quantum Technologies and Non-Quantum technologies (2001–2025)

- We compare NPL publications for the whole time-span of the study and distinguish between QT research and all other fields covered by NPL.
- NPL QT and non-QT ARC are identical: 1.27 (QT) and 1.27 (non-QT).
- QT exceeds non-QT for CiteScore, HCP 10% and Policy Citations, with Policy at 4.59 versus 2.26.
- Non-QT is more interdisciplinary in both dimensions, diversity of authors (2.03 vs. 1.54) and references (1.39 vs. 0.54).



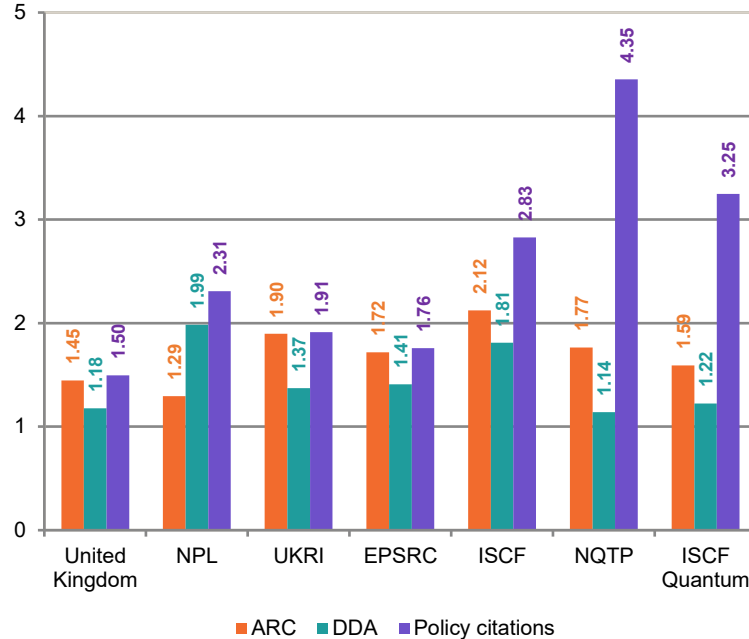
NPL publications relative to comparators

UKRI, EPSRC, ISCF, NQTP, ISCF Quantum

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Scientific performance of NPL and other comparators in all research fields (2001-2025)

- NPL has 9,727 publications overall, less than UKRI, EPSRC and the United Kingdom, so the comparison is most useful on *relative performance*.
- NPL records a DDA of 1.99, above the United Kingdom (1.18), UKRI (1.37) and EPSRC (1.41).
- NPL also records a policy citations index of 2.31, above the United Kingdom (1.50), UKRI (1.91) and EPSRC (1.76).



Benchmark	Publications
United Kingdom	4,530,339
UKRI	677,177
EPSRC	299,018
ISCF	13,236
NPL	9,727
NQTP	2,517
ISCF Quantum	147

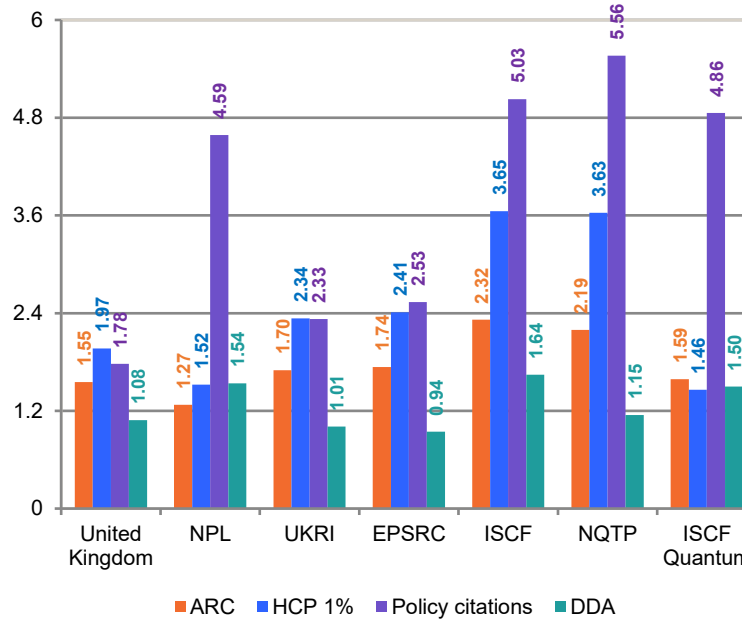
9,727
NPL publications

1.99
NPL DDA

2.31
Policy index

Scientific performance of NPL and other comparators in QT research (2001-2025)

- NPL contributes 683 QT publications, ahead of ISCF Quantum (111) and above ISCF (608), but below NQTP (1,779), EPSRC (9,257), UKRI (10,502) and the United Kingdom (27,016).
- NPL has a QT DDA of 1.54, above the United Kingdom (1.08), UKRI (1.01), EPSRC (0.94) and NQTP (1.15).
- NPL has a QT policy citations index of 4.59, above the United Kingdom (1.78), UKRI (2.33) and EPSRC (2.53), while below ISCF (5.03) and NQTP (5.56).



Benchmark	QT publications
United Kingdom	27,016
UKRI	10,502
EPSRC	9,257
NQTP	1,779
NPL	683
ISCF	608
ISCF Quantum	111

683

NPL QT pubs

1.54

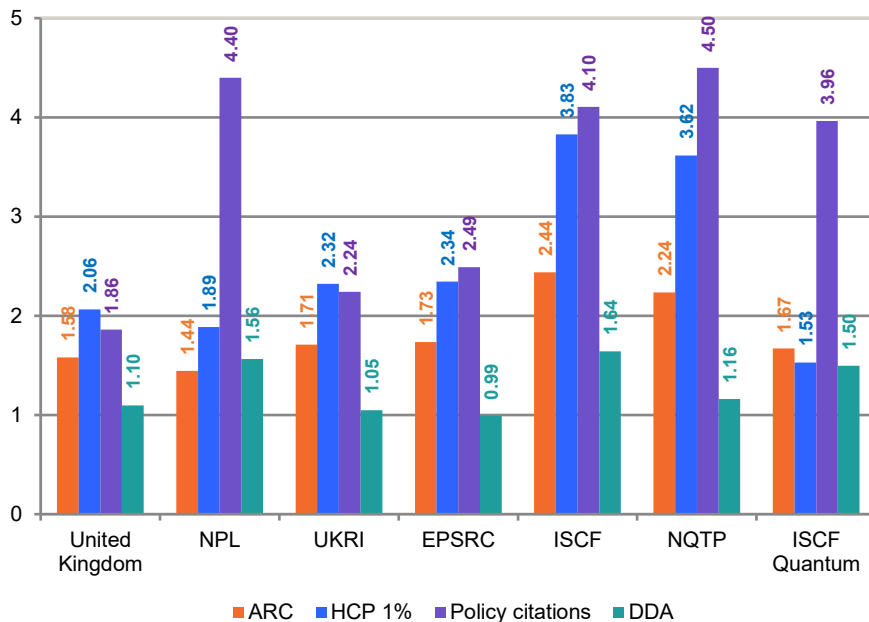
QT DDA

4.59

QT policy

Scientific performance of NPL and other comparators in research related to Quantum Technologies in the most recent decade (2016-2025)

- NPL has 409 QT publications in 2016-2025.
- NPL improves from an ARC of 1.27 in 2001-2025 to 1.44 in 2016-2025, and from an HCP 1% index of 1.52 to 1.89.
- NPL remains strong on recent QT DDA (1.56) and policy citations (4.40), staying above the United Kingdom, UKRI and EPSRC on both measures.



409

NPL recent QT
pubs

1.44

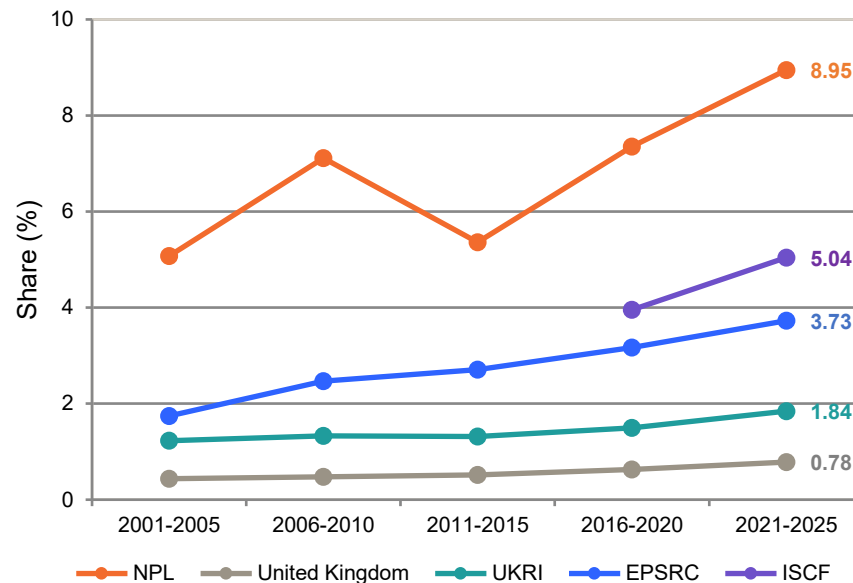
Recent QT ARC

1.89

Recent HCP 1%

The importance of QT-related research relative to the whole research output of NPL and selected comparators (2001-2025)

- We measure the 'importance' of QT-related research as the share of QT-related publications relative to the total amount of publications of an entity.
- NPL's QT share is consistently above the QT-share of the United Kingdom, UKRI, and EPSRC across the periods depicted.
- By 2021-2025, NPL reaches 8.95% QT share, versus 0.78% for the United Kingdom, 1.84% for UKRI, and 3.73% for EPSRC.
- Specialist programmes such as NQTP and ISCF Quantum are much more QT concentrated, so they serve as specialist rather than system-wide comparators for NPL.



8.95%
NPL 2021-25 QT
share

3.73%
EPSRC 2021-25

1.84%
UKRI 2021-25

The uptake of open access

over time and across entities

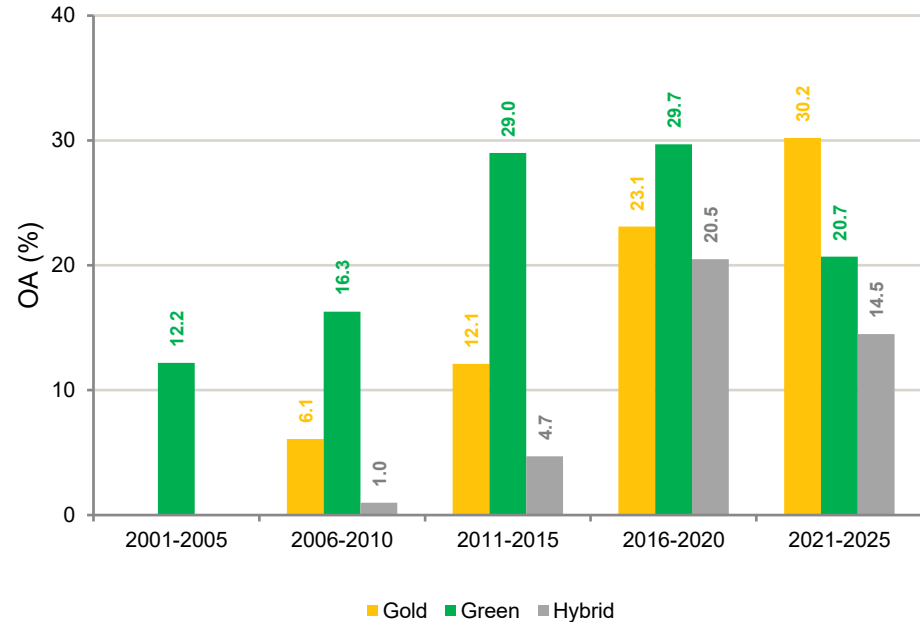
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Gold, green and hybrid open access of NPL QT publications (2001–2025)

- For NPL QT, green open access leads in 2011–2015 and 2016–2020 at 29.0% and 29.7%.
- Gold open access overtakes green in 2021–2025, reaching 30.2% while green dropped to 20.7%.
- Hybrid open access also expands for NPL QT, peaking at 20.5% in 2016–2020 and reaching 14.5% in 2021–2025.

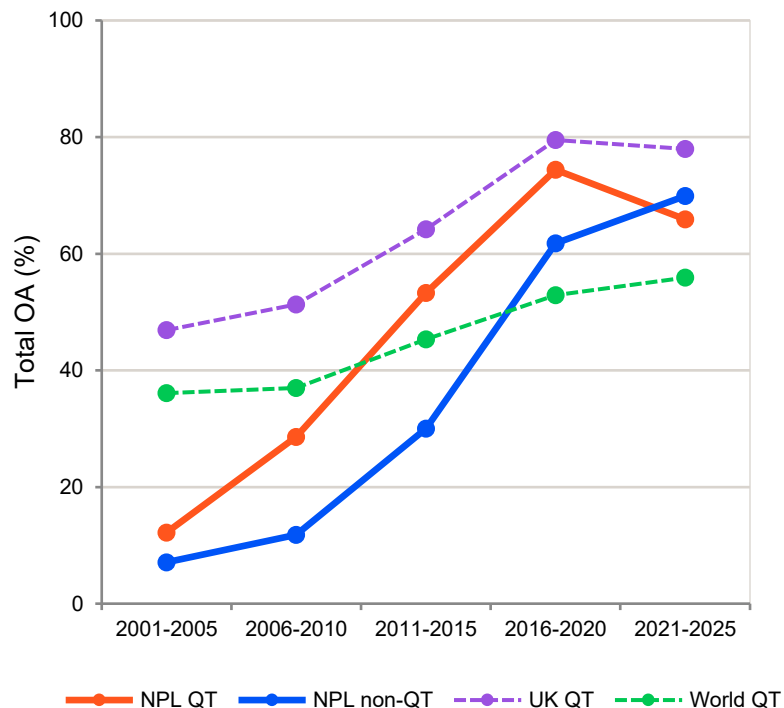
TYPES OF OPEN ACCESS (OA)

Green OA	Authors publish in a journal and share a version of their paper in a free repository, often after an embargo.
Gold OA	The final published article is freely available on the journal's website immediately, usually with an article processing charge (APC).
Hybrid OA	A subscription journal offers authors the option to make individual articles open access for a fee, while the rest of the journal stays behind a paywall.



Open access of NPL and selected comparators' publications, QT versus non-QT (2001–2025)

- NPL QT open access rises from 12.2% in 2001–2005 to 65.9% in 2021–2025.
- NPL non-QT open access rises from 7.1% to 69.9% over the same periods.
- By 2021–2025, NPL trails the UK on QT open access (65.9% versus 78.0%), but remains above the world (55.9%).
- The growth rates of open access among NPL publications exceed the UK and world level. NPL is catching up.



65.9%

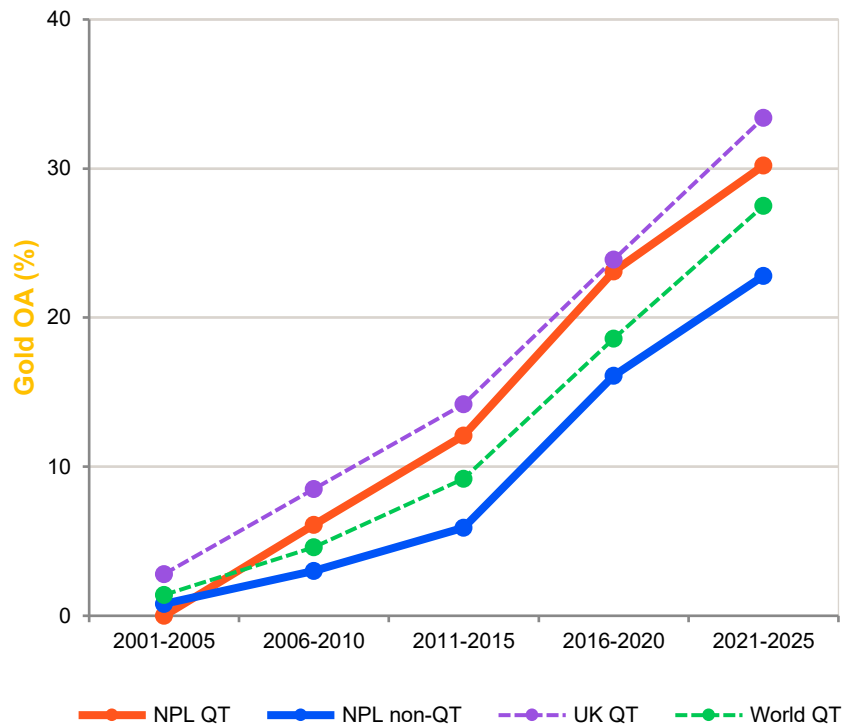
NPL QT OA,

69.9%

NPL non-QT OA

Gold open access of NPL publications, QT versus non-QT by five-year periods, compared to UK and World QT OA shares

- NPL QT gold open access rises from 0% in 2001–2005 to 30.2% in 2021–2025.
- NPL non-QT gold open access also increases, reaching 22.8% in 2021–2025.
- In 2021–2025, NPL QT gold open access exceeds the world QT level (30.2% versus 27.5%) but is below the UK QT level (33.4%).
- A strong upward trend is observable for all comparators.

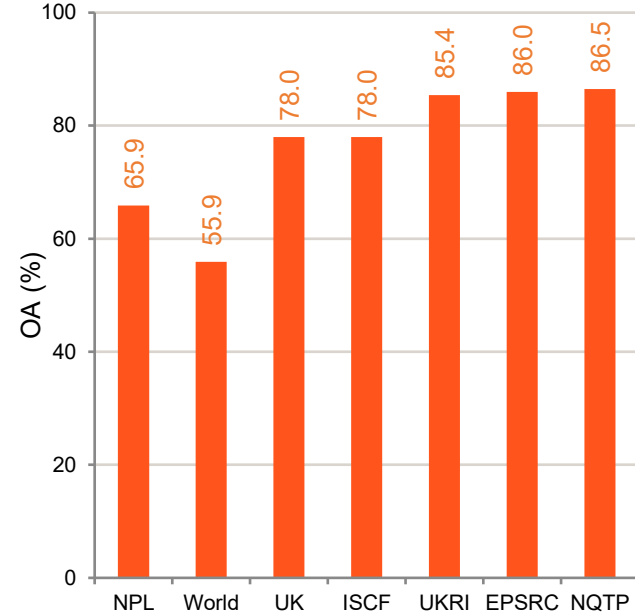


30.2%
NPL QT gold

22.8%
NPL non-QT gold

Open access of NPL and selected comparators' publications in Quantum Tech (2001–2025)

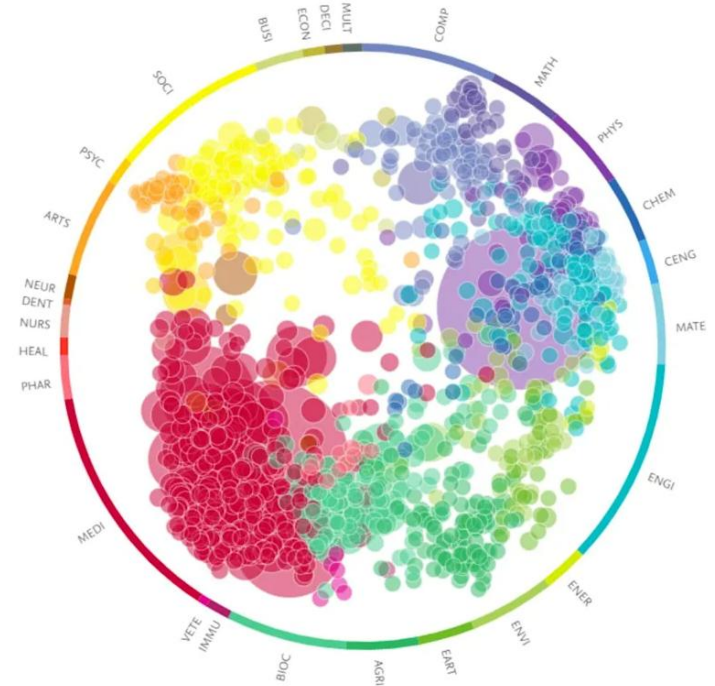
- For NPL's QT publications, 2 out of 3 papers have been published with some kind of open access model (65.9%).
- This sits 10.0 percentage points above the world QT level of 55.9%, but below the UK QT level of 78.0%.
- The highest values shown are NQTP at 86.5% and EPSRC at 86.0%, with UKRI at 85.4%.



Most prevalent topic clusters

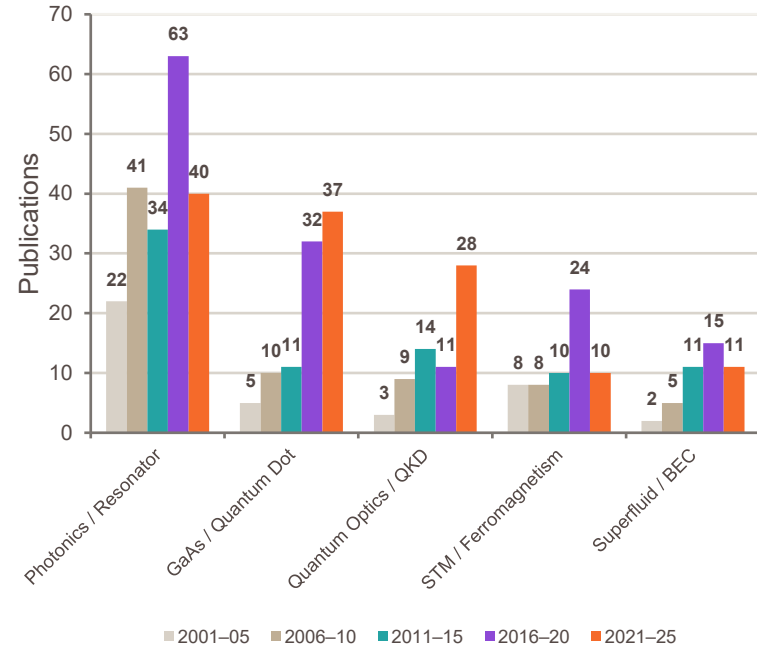
Topic Clustering: Methods

- We rely on the topic clustering by Elsevier's SciVal product.
- A Topic is a collection of publications with a common intellectual interest, based on direct citations, that represent fields of research globally.
- We take the entire citation network within Scopus (>1.5 billion citation links between >59 million Scopus-indexed publications and additional 24+ million non-indexed) and break that network into ~94,000 Topics.
- A Topic is created where the direct citation linkages within the Topic are strong and the direct citation linkages outside the Topic are weak.



Trend in NPL's QT publications across clusters, 2001–2025

- NPL's largest named topic cluster is **Optical Quantum Systems** (Photonics / Optical Resonator / Nonlinear Optics) with 200 papers across the full time-span 2001–2025.
- The next two clusters are **Quantum Device Advancements** (GaAs / Quantum Dot / Indium) with 95 papers and **Quantum Information and Imaging** (Quantum Optics / QKD) with 65 papers in total
- Across named clusters excluding “Others”, these top three account for 360 of 539 publications, i.e., two third (66.8%) of the overall portfolio.
- Recent activity in 2021–2025 remains concentrated in the same three areas, led by 40 papers in **Optical Quantum Systems** (Photonics / Resonator) and 37 in **Quantum Device Advancements** (GaAs / Quantum Dot).



200

Papers in the largest cluster #108

66.8%

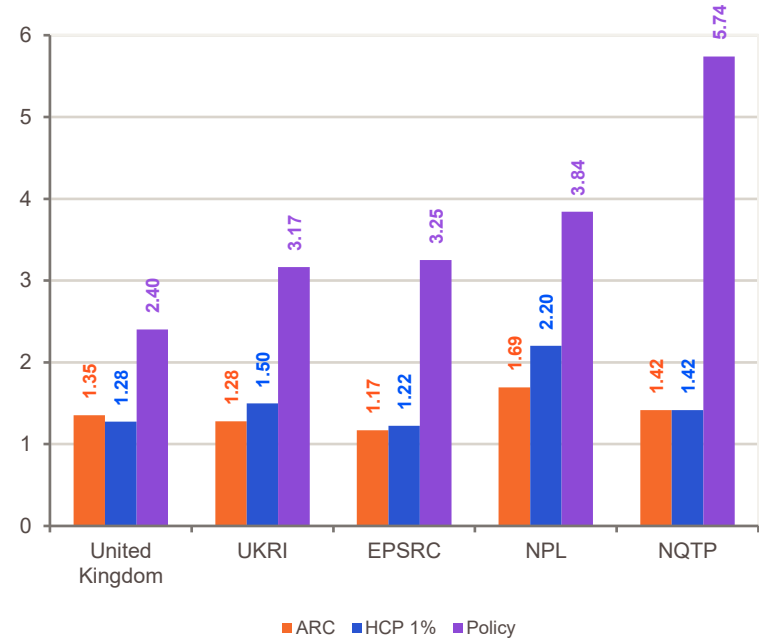
Top-3 share of named clusters

40

2021–25 papers in largest cluster

Scientific performance of NPL and other comparators, cluster 108: Optical Quantum Systems (2001–2025)

- For NPL, this is the largest topic cluster in the workbook, with 200 publications across 2001–2025.
- NPL leads the benchmark set on conventional and high-end impact, with ARC 1.69, HCP 10% 2.15 and HCP 1% 2.20.
- Policy citations for NPL reach 3.84, above the United Kingdom, UKRI and EPSRC, although below NQTP at 5.74.
- Private citations are comparatively modest for NPL at 1.15, below UKRI 1.67 and EPSRC 1.69.



1.69
NPL ARC

2.20
NPL HCP 1%

3.84
NPL Policy Citations

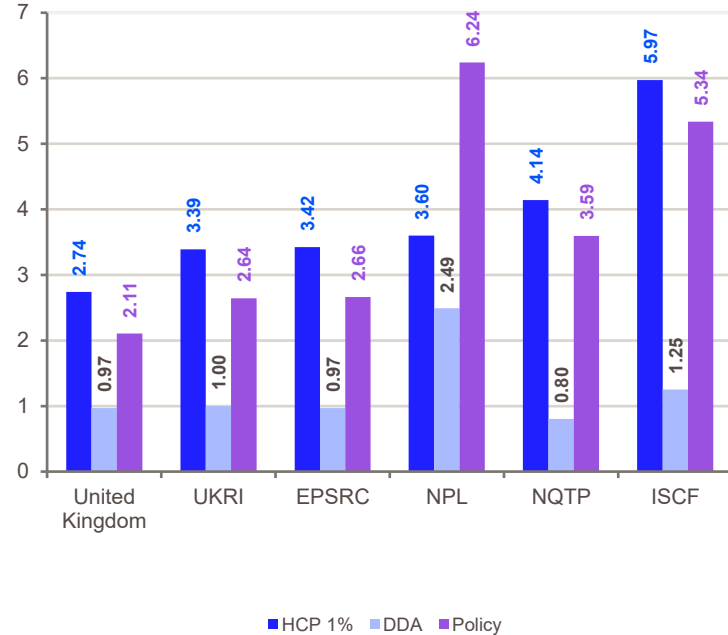
Scientific performance of NPL and other comparators, cluster 9: Quantum Information and Imaging (2001–2025)

- Topics of cluster 9: Quantum Information and Imaging (Quantum Optics, Quantum Key Distribution, Photonics)
- NPL publishes 65 papers in this cluster, making it smaller than the related cluster 108 ("Photonics, Optical Resonator, Nonlinear Optics) but still one of NPL's main named topics.
- This is NPL's strongest cluster for policy attention: policy citations reach 6.24, the highest value in the peer set shown.
- NPL also records the highest DDA at 2.49 and a very strong HCP 1% score of 3.60.
- By contrast, NPL's ARC of 1.99 trails UKRI, EPSRC, NQTP and ISCF, while DDR is 0 in the workbook.

3.60
HCP 1%

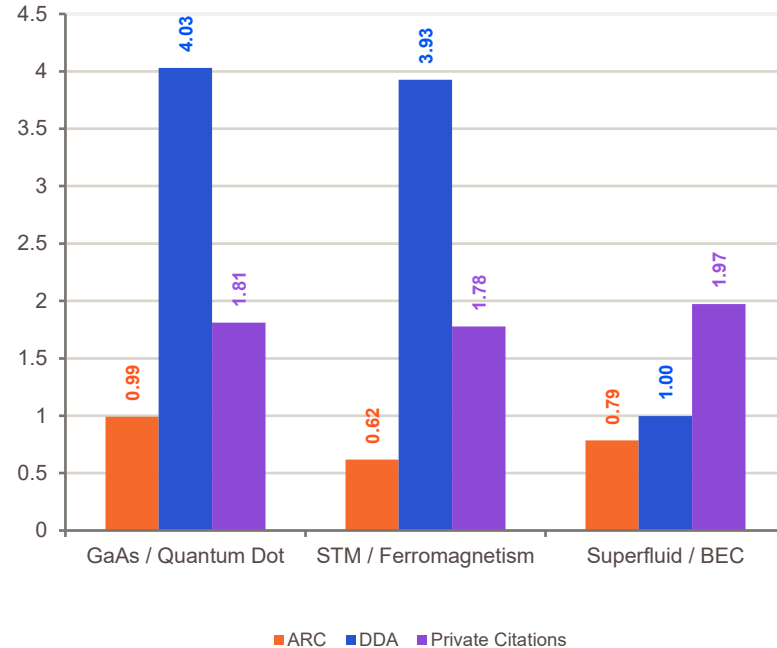
2.49
DDA

6.24
Policy Citations



Selected NPL topic clusters where translational reach diverges from citation impact (2001–2025)

- **Quantum Device Advancements** (*cluster 130: GaAs / Quantum Dot*) combines near-world citation impact with unusually strong translation signals for NPL: ARC 0.99, DDA 4.03, policy citations 3.46 and private citations 1.81.
- **Quantum Transport and Nanoscale Patterning** (*cluster 434: STM / Ferromagnetism*) shows an even sharper split, with DDA 3.93 and private citations 1.78 despite ARC 0.62, HCP 10% 0.52 and HCP 1% 0.
- **Quantum Atom Manipulation** (*cluster 52: Superfluid / BEC*) remains below world on citation impact, but private citations reach 1.97 and DDR 1.81.
- Together these clusters suggest that some of NPL's topic strength is more visible in downstream and non-academic signals than in citation averages alone.



Contributions to standardization

As captured by citations through ISO standards

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Citations from ISO standards to NPL research output (2001-2025)

- The analysis did not detect citations from ISO standards to NPL publications in Quantum Technologies
- 144 Publications from NPL's non-QT research fields have been cited by 183 times by 79 ISO standards (one publication can be cited by more than one ISO standard)
- ISO citations are concentrated in non-QT journals, led by *Surface and Interface Analysis* with 28 cited publications, ahead of *Metrologia* with 17 and *Measurement Science and Technology* with 12.

ISO Standards citing the most NPL publications

Standard	Topic	NPL Citations
14187	<i>Surface chemical analysis - Characterization of nanostructured materials</i>	13
8529	<i>Neutron reference radiations fields</i>	12
23173	<i>Surface chemical analysis - Electron spectroscopies - Measurement of the thickness and composition of nanoparticle coatings</i>	10

183

ISO citations of NPL Publications

144

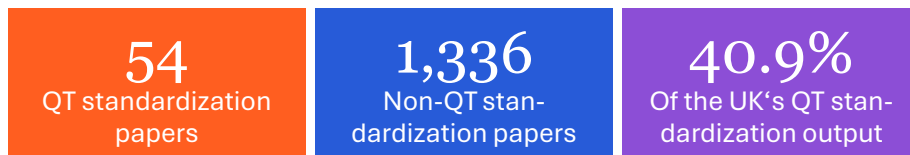
Non-QT publications cited by ISO

79

Standards influenced by NPL research

Benchmarking of NPL standardization-related publication output, comparison between QT and Non-QT

- NPL contributes 1,336 non-QT publications and 54 QT publications related to standardization across 2001-2025.
- While contributing 3.2% of the United Kingdom's non-QT standardization output, NPL's QT-research stands for 40.9% of the nation's standardization publications in the field of quantum technologies.
- By that, NPL is outperforming all selected comparators in its contribution of publications addressing standardization issues in QT.
- With a policy citations score of 5.93 for NPL's QT standardization research and 2.42 for non-QT standardization research, NPL is leading across comparators in terms of policy uptake of its standardization papers



Standardization publications across entities

Non-QT		Quantum Tech	
Entity	Publications	Entity	Publications
World	374,306	World	1,221
United Kingdom	41,194	United Kingdom	132
UKRI	4,042	NPL	54
EPSRC	1,522	UKRI	23
NPL	1,336	EPSRC	16
ISCF	173	ISCF	9
NQTP	7	NQTP	2
ISCF Quantum	0	ISCF Quantum	1

The economic impact of NPL research

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Economic impact evidence linked to NPL publications

Descriptive analysis of publications linked to commercial products through patent citations and virtual patent marking

Publication	Year	Type	Research signal	Product linkage in supplied content
Measurement of pH. Definition, standards, and procedures	2003	Review	FWCI 44.6; 99th citation percentile	19 cited patents; one product-linked patent, tied to Seoul Semiconductor
Refractive index mapping of layered samples using Optical coherence refractometry	2009	Conference paper	0 citations; citation percentile N/A	Supplied content notes two linked products owned by FlatFrog Laboratories AB
HTS/Ferroelectric microwave phase shifters	1997	Article	7 citations; 42th citation percentile	One product-linked patent, tied to nine products owned by BlackBerry

- The evidence base in the supplied content is narrow but tangible: three NPL publications show downstream product links.
- The linked products span semiconductors, consumer electronics, and software-linked microwave applications.
- The strongest research-side signal is the 2003 pH recommendations review, with very high field-weighted impact and a 99th citation percentile.
- None of the product-linked publications in the supplied content come from the Quantum Technologies dataset.

Case 1: Measurement of pH. Definition, standards, and procedures

Publication profile

- NPL author: Milton M.J.T.
- Journal: Pure and Applied Chemistry (2003)
- Document type: Review
- DOI: 10.1351/pac200274112169
- FWCI: 44.56
- Citation percentile: 99th

Patent and product link

- Product-linked patent: US-7382004-B2, "Semiconductor sensing device".
- Applied for by Sensor Electronic Technology Inc. in 2003.
- The supplied content links this patent to a product owned by Seoul Semiconductor.
- No specific product information available in the supplied content.

1

Patent linked to a product in IPRoduct

19

Patents listed in the supplied content

Patent-owner landscape named in the supplied content

Owner	Count
ExxonMobil Chemical Patents Inc	8
BASF SE	5
ExxonMobil Technology and Engineering Co	1
F Hoffmann La Roche AG	1
Roche Diagnostics GmbH	1
Ventana Medical Systems Inc	1
Roche Diagnostics Operations Inc	1
Roche Diagnostics Hematology Inc	1
Sensor Electronic Technology Inc	1
Puma SE / Schlumberger Technology Corp / Micron Technology Inc	1 each

Case 2: Refractive index mapping of layered samples using Optical coherence refractometry

Publication profile

- NPL authors: Tedaldi, Matthew; Woolliams, Peter; Hart, Christan; Beaumont, Andrew; Tomlins, Pete
- Proceedings of SPIE - The International Society for Optical Engineering (2009)
- Document type: Conference paper
- DOI: 10.1117/12.809090
- FWCI / citations: 0 citations
- Citation percentile: N/A

48

Patent citations listed

2

Products noted in
IPProduct

Product-link summary from the supplied content

- The supplied content lists a long set of patent citations associated with this paper, largely US patents.
- It additionally notes that patents US-9442574-B2, US-8581884-B2, and US-9626040-B2 are linked to two products in the IPProduct database.
- Those products are identified as the FlatFrog F-Line series.
- The product owner is FlatFrog Laboratories AB, described in the supplied content as a Swedish-based consumer electronics company.

Selected patents from the citation list

US10739916 | US12282653 | US10761657 | US10474249 | US10496227 |
US10606416
US11281338 | US11893189 | US12189906 | US10146376 | US11943563 |
US10019113
US10775935 | US11256371 | US9639210 | US10481737 | US11474644 |
US12056316

Case 3: HTS/Ferroelectric microwave phase shifters

Publication profile

- NPL authors: Abbas, Farhat; Gallop, J.C.; Langham, C.D.
- Journal: Cryogenics (1997)
- Document type: Article
- DOI: 10.1016/S0011-2275(97)00042-8
- Citations: 7
- Citation percentile: 42th

11

Patent citations listed

1

Product-linked patent
noted

9

Products
tied to the
patent

Patent and product link

- The supplied content lists repeated citations to US6377142 and one citation to WO0024080.
- Product-linked patent: US-6377142-B1, "Voltage tunable laminated dielectric materials for microwave applications".
- Applied for by Paratek Microwave Inc. in 1999.
- The supplied content links this patent to nine products owned by BlackBerry, described as a Canadian-based computer software company.

Bibliometric assessment of the National Physical Laboratory's contribution to Quantum Technologies

Authors:

Benedikt Schmal

Guillaume Roberge

Note:

All data shown in this presentation – together with all additional analyses – can be found in the accompanying data book. All data and insights are computed and prepared by Science-Metrix/Elsevier using Scopus data.

Date:

31 March 2026

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