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BIBLIOMETRICS: A PILOT STUDY FOR NPL'S PUBLICATIONS OVER 2000-2023

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Bibliometrics: A Pilot Study for NPL’s Publications over 2000-2023.

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ABSTRACT
This paper details a comprehensive analysis of the National Physical Laboratory's (NPL) publication output from 2000 to 2023, focusing on four key areas: research output and quality, research topics, collaboration patterns, and alternative metrics. In addition, it performs a benchmark study by comparing NPL's publication output with that of major National Metrology Institutions (NMIs) such as the National Institute of Standards and Technology (NIST), the German National Metrology Institute (PTB), the Korea Research Institute of Standards and Science (KRISS), and the National Institute of Metrology (NIM). To construct the underlying dataset, three prominent bibliometric databases—Dimensions.ai, Clarivate's Web of Science, and Elsevier's Scopus—are queried. A unique list of NPL's publications is generated by de-duplicating Digital Object Identifiers (DOIs). The analysis reveals that NPL has published a total of 8,525 papers during the specified period. While engineering and physical sciences, along with chemical sciences, account for the majority of publications, there is a notable upward trend in biomedical and clinical sciences, as well as information and computer sciences, particularly post-2010.

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This paper builds upon the foundation laid by the report "Bibliometrics for Spending Review 2021," authored by Jenny Wooldridge. Her meticulous construction of the National Physical Laboratory's (NPL) publication list spanning from 2000 to 2020 served as a cornerstone for this study. The insights gleaned from both the report and the accompanying data significantly contributed to the development of this research. I extend my sincere gratitude to Jenny for her invaluable contributions.

Approved on behalf of NPLML by
David Skelton, Strategic Programme Leader.

CONTENTS

ABBREVIATIONS

ANZSRC	: Australian and New Zealand Standard Research Classification
Altmetrics	: Alternative Metrics
ARWU	: Academic Ranking of World Universities
CNCI	: Category Normalized Citation Impact
DOIs	: Digital Object Identifiers
DORA	: San Francisco Declaration on Research Assessment
DSIT	: Department for Science, Innovation and Technology
FCR	: Field Citation Ratio
FoR	: Field of Research
FWCI	: Field-Weighted Citation Impact
HMT	: His Majesty's Treasury
JIF	: Journal Impact Factor
KRISS	: Korea Research Institute of Standards and Science
MNC	: Mean Normalised Citations
NIM	: National Institute of Metrology
NIST	: National Institute of Standards and Technology
NMS	: The National Measurement System
NMSt	: National Measurement Strategy
NMIs	: National Metrology Institutions
NPL	: National Physical Laboratory
PSREs	: Public Sector Research Enterprises
PTB	: German National Metrology Institute
R&D	: Research and Experimental Development
SDGs	: Sustainable Development Goals
UN	: United Nations
WoS	: Web of Science
SED	: Science & Engineering Directorate

EXECUTIVE SUMMARY

The National Measurement System (NMS) serves as the cornerstone of the UK's scientific infrastructure, housing cutting-edge laboratories that champion measurement science and technology. These facilities provide the nation with standards of measurement 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) committed to delivering impactful research, products, and services to the UK. With a rich history dating back to its establishment as a government laboratory[1] in 1900. Its research contributions span diverse fields such as physical science, materials science, computing, and bioscience, with applications ranging from ship design to global positioning.

This pilot study while building upon "Bibliometrics for Spending Review 2021" (Wooldridge, 2021) report, aims to provide empirical evidence of NPL's publication output across four primary domains: research output and quality, research topics, collaboration patterns, and alternative metrics. The findings of this study will help His Majesty's Treasury (HMT) and Department for Science, Innovation and Technology (DSIT) with evidence aligned with the value-for-money framework.

To construct a comprehensive dataset, a unique compilation of NPL's publications is assembled using three prominent bibliometric databases: Dimensions.ai, Clarivate's Web of Science, and Elsevier's Scopus. Analysis reveals that from 2000 to 2023, NPL has published 8,525 papers, showing an upward trend with an average incremental growth of 16 ± 1.8 publications per year. Over the years, the number of publications has notably increased, with nearly 100 papers authored in 2000, rising to an average of 424 over the last three years.

Furthermore, the study highlights NPL's impressive performance across various metrics. Notably, NPL exhibits an average Field Normalized Citation Rate (FCR) of 2.80 for journal articles, which significantly surpasses the global average of 1.64. Additionally, approximately 23% of NPL's papers are published in journals within the top quartile of the Journal Impact Factor (JIF) spectrum. Moreover, the collaboration between NPL and industry partners in research publications has seen a remarkable increase from 2% to 14% over the study period, underscoring NPL's strong ties with industry. Furthermore, NPL's research papers have accumulated citations in 361 patents spanning from 2000 to 2021, showcasing its substantial impact on innovation and technological progress. Finally, in comparative terms, NPL ranks first for both international and industrial collaborations when compared to other prominent metrology institutes such as the National Institute of Standards and Technology (NIST) of the USA, the German National Metrology Institute (PTB), the Korea Research Institute of Standards and Science (KRISS), and the National Institute of Metrology (NIM) of China.

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

1 INTRODUCTION

This paper aims to provide robust evidence for the upcoming Spending Review regarding the publication output of the NPL, employing metrics such as FCR, Alternative Metrics (altmetrics), United Nations Sustainable Development Goals (UN SDGs), collaboration with industry, and patent citations. It builds upon the groundwork laid by a previous report (Wooldridge, 2021) prepared for the 2021 Spending Review, refining both the constructed database and the analysis methodologies employed to provide a more comprehensive bibliometric examination of NPL's publication landscape. Additionally, this endeavour aligns with the Evaluation Framework for NMS, as outlined by King et al. (2023), highlighting the significance of bibliometrics as pivotal indicators within the framework's evaluation mechanism, particularly concerning the domain of research.[2]

The database developed for this project will serve as a valuable resource for various applications beyond the scope of this study. One such application includes the creation of output-focused metrics to support the implementation of the new National Measurement Strategy (NMSt) at both departmental and programme levels. By leveraging the data collected in the database, policymakers and project managers can effectively monitor and evaluate the progress and impact of initiatives outlined in the NMSt.

This paper progresses as follows: The context section provides an overview of the Background and Literature in Bibliometrics, explaining the metrics employed and other pertinent information such as the organizational structure of NPL and the Field of Research (FoR) categories utilized in the study. Following this, the third section delves into the data sources and the curation process involved in generating the unique list of NPL publications. Subsequently, the fourth section delineates the analysis across five subsections: research output and quality, research topics, collaboration, altmetrics, and a comparative analysis of NMIs. Finally, the concluding section synthesizes the study's findings, discusses any caveats, and outlines potential avenues for future research.

2 CONTEXT

2.1 BACKGROUND AND LITERATURE REVIEW

In the mid-20th century, bibliometrics emerged, focusing on analyzing bibliographic data and citation patterns. Eugene Garfield's work in the 1960s introduced citation indexing and led to the creation of the Science Citation Index (SCI) in 1964, marking the beginning of systematic citation analysis.

Over the following decades, bibliometrics advanced significantly. The 1970s saw the introduction of the Journal Impact Factor (JIF) (Garfield, 1972), and the 1980s witnessed the development of citation databases like WoS and Scopus. By the 1990s, bibliometric research expanded to include co-citation analysis and author impact metrics (White & McCain, 1998), (Garfield, 2006).

In the 21st century, bibliometrics evolved with the rise of internet-based technologies. The emergence of altmetrics in the 2000s complemented traditional citation-based metrics. Continued advancements in data analytics and machine learning in the 2010s led to more sophisticated approaches to evaluating research impact (Priem et all, 2011), (Nawi, 2023).

[2] The logic model set in Evaluation Framework for the NMS defines four main activities as “Research”, “Innovation”, “Trade & Standards” and “Knowledge Transfer”.

Bibliometric indicators are increasingly applied in research evaluation and policy contexts, including assessing scientific performance, allocating research funding, and informing policy decisions (Aksnes, Langfeldt, & Wouters, 2019). Bibliometric studies have also become vital for government organizations, offering quantitative insights into research productivity, impact, and collaboration networks. By analysing bibliometric data, governments can prioritize funding, benchmark performance, and inform policy decisions.

The recent Government document, in this context, evaluates the UK's research performance using bibliometric data from 1996 to 2020, comparing it to other G7 countries and key global players like Brazil, China, and India. While the UK's annual research publication count is increasing, its share of world publications is slightly declining compared to other nations. Despite this, the UK maintains the highest Field-Weighted Citation Impact (FWCI) among comparators, although its share of highly cited publications has slightly decreased. (DSIT, 2022).

Another study explores the potential of online attention metrics to complement citation data in evaluating research quality and societal impact. The study finds that altmetric data, particularly for cited research, strongly correlates with expert panel scores for societal impact but not for research quality. This suggests that altmetric data could be valuable in assessing impact alongside traditional citation metrics (Jenny Wooldridge, 2018).

2.2 METRICS AND STRUCTURES USED IN THE STUDY

2.2.1 Citation Indicators

Citations are important in bibliometrics as they serve as indicators of the impact, relevance, and influence of scholarly publications within their respective fields. However, citation rates are known to differ between research areas, and so a thorough citation impact analysis requires the use of field normalisation techniques. This process involves creating global averages of total citations for specific research areas and publication years, often while considering document types such as articles or reviews. Subsequently, the total citations received by the publication under scrutiny are divided by the global average to generate a quotient citation value, indicating performance that surpasses the average when the value exceeds one.

FWCI metric, as provided by Scopus, offers insight into the relative citation impact of a researcher's publications compared to the average citations received by similar publications within the Scopus database. By accounting for variations in research behaviour across different disciplines, FWCI provides a normalized measure that facilitates fair comparisons of citation impact across diverse fields of study (Elsevier, 2023).

Web of Science (WoS) generates a Citation Normalization and Contextualization Index (CNCI) score, which standardizes citations based on publication year, document type, and research category. In cases where a publication spans multiple categories, the CNCI score employs a harmonic average of expected citations. However, access to the CNCI score is limited to Clarivate's InCites package, to which NPL lacks a subscription. Nonetheless, Clarivate offers a condensed list of field-baselined citations by year for 22 high-level field categories within their "Essential Science Indicators" publication. Additionally, WoS provides a mapping of Journal Names to Research Categories (InCites Essential Science Indicators, 2024).

In this study, to establish baseline citation rates, the sources were matched, and the data was integrated with individual publication data from WoS. This process yielded baseline citation rates for each paper, enabling the normalization of citation counts and calculation of the Mean Normalized Citations (MNC)

Dimensions provides a normalized citation metric called the FCR, which is customized to various research fields using the Australian and New Zealand Standard Research Classification (ANZSRC) codes. This classification employs a machine learning model trained on manuscript text, ensuring precise normalization across diverse disciplines. Moreover, world averages are computed using the geometric mean rather than the arithmetic mean for citations, reducing the impact of highly cited outlier publications on CNCI calculations. This renders the FCR a more accurate impact score, particularly for research published in multidisciplinary journals. However, there are instances of missing FCR values for papers unclassified to a field of research, and the normalization does not consider document type, indicating a simplification in Dimensions' coding system (Dimensions, 2024).

2.2.2 Journal Impact Factor

The Journal Impact Factor (JIF) is a widely used metric in academia to evaluate the relative importance of scholarly journals within a specific field. It is calculated based on the average number of citations received by articles published in a journal over a certain period. However, it's important to recognize the limitations and caveats associated with relying solely on JIF for research assessment.

The San Francisco Declaration on Research Assessment (DORA) emphasizes the need to consider multiple factors when evaluating research impact, rather than relying solely on metrics like JIF. Caveats of JIF include its susceptibility to manipulation through self-citations, its inability to capture the quality or impact of individual articles, and its bias towards disciplines with higher citation rates. As such, while JIF can provide some insights into journal influence, it should be used cautiously and in conjunction with other qualitative and quantitative measures to assess research impact accurately and fairly (Zeqiri, 2024).

2.2.3 Alternative Metrics

While citations gauge scholarly impact within the scientific community, altmetrics tally online mentions of research across various platforms, including social media, mainstream media, and online reference managers (Our Sources, 2024). Altmetrics thereby offer insights into the broader discussion and utilization of research beyond academic circles. Moreover, studies have indicated that altmetrics can forecast future citation rates in certain scenarios (D. B. T. Robinson, 2021) and are correlated with peer review assessments of research impact (Jenny Wooldridge, 2018), particularly for publications highlighted in news coverage.

2.2.4 New Zealand Standard Research Classification

The ANZSRC is the collective name for a set of three related classifications developed for use in the measurement and analysis of research and experimental development (R&D) undertaken in Australia and New Zealand (Australian Government, 2024). Dimensions use ANZSRC codes as FoR to tag the publications (See Appendix-1).

2.2.5 United Nations Sustainable Development Goals

Dimensions offers an additional classification system, assigning documents to the United Nations Sustainable Development Goals (SDGs) (United Nations, 2024). These goals encompass various areas such as ending hunger and poverty, promoting gender equality, enhancing education quality, and fostering sustainable communities (See Appendix-2).

2.2.6 NPL's Sectors

As of 2023, NPL's Science & Engineering Directorate (SED) consists of 11 directorates and 35 scientific groups. The groups are allocated to four sectors (Appendix-3):

- Advanced Manufacturing
- Digital & Quantum technologies
- Health & Life Sciences
- Energy & Environment

These are defined operationally, by looking at the sub-parts of NPL that are accounted for by each sector. The operational parts of NPL are the Departments, representing specific, permanent scientific areas of expertise. A similar, simplified version of this table can be found within (Dias & King, 2024), which draws on the same knowledge.

3 CREATION OF THE MAIN LIST FOR NPL'S PUBLICATIONS

3.1 BIBLIOMETRIC DATABASES USED

For this analysis, data were extracted from three scientific databases, namely WoS, Elsevier's Scopus and Dimensions.ai:

- Clarivate's Web of Science: WoS is a traditional science index which holds data on 171 million records from a curated list of 34 thousand journals, with details of cited references between publications (Web of Science Group, 2023).

- Elsevier's Scopus: Elsevier's Scopus has 55 million records from 5 thousand publishers, covering the fields of science, technology, medicine, social sciences, and arts & humanities (Elsevier, 2023).

- Dimensions.ai: Dimensions.ai is a newer research discovery tool which collates 138 million publications collected from 87 thousand journals (Dimensions, 2024).

3.2 PUBLICATION LIST FOR NPL

A comprehensive publication list spanning from 2000 to 2023 was compiled for NPL by consolidating and eliminating duplicates from three designated sources. Deduplication was executed through the utilization of Digital Object Identifiers (DOIs). Additionally, leveraging the DOIs within this dataset facilitated an assessment of content coverage and metadata accuracy across Scopus, Dimensions, and WoS. Subsequently, after establishing the unique set of publications along with their corresponding DOIs, a query was executed on Dimensions' metadata to extract essential variables including citation counts, journal names, authors, affiliations, among others. This invaluable dataset served as the foundation for subsequent analyses.

3.3 DISTRIBUTIONS FOR PUBLICATIONS IN SCIENTIFIC DATABASES

Figure 1 shows the distribution of NPL's publication across Dimensions, WoS and Scopus databases. Our analysis is conducted using all publications which are equal at 8,525 publications which equates the summation of "A + B + C + D + E + F + G" on Table 1.

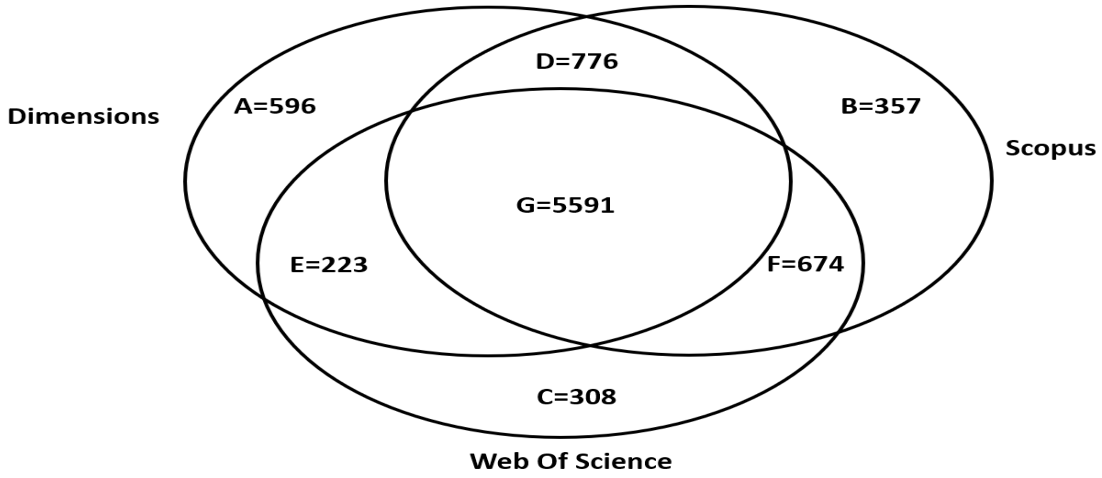

Figure 1 Coverage Analysis of Publications in Dimensions, Web of Science and Scopus on Venn Diagram.

Table 1 presents the distribution for the publications across the databases, which denotes that Scopus alone hosts almost 87%, Dimensions hosts 84% and WoS hosts almost 80% of NPL's publications. Furthermore, only about 66% of NPL affiliated publications are hosted by all three sources.

Table 1 Publications Coverage

Publication Coverage	Venn Diagram Representation	Number of Publications	Publication Percentage
All	A + B + C + D + E + F + G =	8,525	100%
Only Dimensions	A + D + E + G =	7,186	84%
Only Scopus	B + D + G + F =	7,398	87%
Only Web of Science	C + E + G + F =	6,796	80%
Scopus & Dimensions	D + G =	6,367	75%
Scopus & Web of Science	G + F =	6,265	74%
Web of Science & Dimensions	E + G =	5,814	68%
Web of Science & Dimensions & Scopus	G =	5,591	66%

3.3.1 Comparison of Publication Types

Both WoS and Dimensions offer document classification for their publication records, with WoS employing a wider range of document types, sometimes assigning multiple types to a single document. Table 2 presents a comparative analysis of the classification values provided by WoS and Dimensions.

As depicted in Table 2, almost 76% of the total 5,814 publications (combining categories E and G from Table 1) are labelled as "Articles" or "Article-like" (e.g., Article; Book Chapter, Article; Proceedings Paper, etc.) by both data sources.

Table 2 Comparison of Document Classifications Between Web of Science and Dimensions.

		Dimensions Publication Types						
		article	book	chapter	monograph	preprint	proceeding	Grand Total
Web of Science Publication Types	#NA	0%	0%	0%	0%	0%	0%	**0%**
	Article	66%	0%	0%	0%	0%	0%	**66%**
	Article; Book Chapter	0%	0%	0%	0%	0%	0%	**0%**
	Article; Data Paper	0%	0%	0%	0%	0%	0%	**0%**
	Article; Early Access	0%	0%	0%	0%	0%	0%	**0%**
	Article; Proceedings Paper	9%	0%	0%	0%	0%	0%	**9%**
	Biographical-Item	0%	0%	0%	0%	0%	0%	**0%**
	Book Review	0%	0%	0%	0%	0%	0%	**0%**
	Correction	1%	0%	0%	0%	0%	0%	**1%**
	Editorial Material	4%	0%	0%	0%	0%	0%	**4%**
	Letter	0%	0%	0%	0%	0%	0%	**0%**
	Meeting Abstract	0%	0%	0%	0%	0%	0%	**0%**
	News Item	0%	0%	0%	0%	0%	0%	**0%**
	Proceedings Paper	3%	0%	1%	0%	0%	11%	**15%**
	Reprint	0%	0%	0%	0%	0%	0%	**0%**
	Review	4%	0%	0%	0%	0%	0%	**4%**
	Review; Book Chapter	0%	0%	0%	0%	0%	0%	**0%**
	Review; Early Access	0%	0%	0%	0%	0%	0%	**0%**
	Grand Total	**88%**	**0%**	**1%**	**0%**	**0%**	**11%**	**100%**

Table 3 offers a comparison between the classification values provided by Scopus and Dimensions. According to Table 3, almost 67% of the total 6,367 publications (combining categories D and G from Table 1) are categorized as "Article" by both data sources.

Table 3 Comparison of Document Classifications Between Scopus and Dimensions.

		Dimensions Publication Types						
		article	book	chapter	monograph	preprint	proceeding	Grand Total
Scopus Publication Type	#NA	3%	0%	0%	0%	0%	1%	**4%**
	Article	66%	0%	0%	0%	0%	0%	**67%**
	Book	0%	0%	0%	0%	0%	0%	**0%**
	Chapter	0%	0%	2%	0%	0%	0%	**2%**
	Conference Paper	8%	0%	1%	0%	0%	13%	**21%**
	Data Paper	0%	0%	0%	0%	0%	0%	**0%**
	Editorial	1%	0%	0%	0%	0%	0%	**1%**
	Erratum	1%	0%	0%	0%	0%	0%	**1%**
	Letter	0%	0%	0%	0%	0%	0%	**0%**
	Note	0%	0%	0%	0%	0%	0%	**0%**
	Review	4%	0%	0%	0%	0%	0%	**4%**
	Short Survey	0%	0%	0%	0%	0%	0%	**0%**
	Grand Total	**83%**	**0%**	**3%**	**0%**	**0%**	**14%**	**100%**

3.3.2 Comparison of Publication Years

Further disparities in metadata were noted in the publication years of matched records, attributable to discrepancies in the timestamps logged by the systems during the publication process. For instance, WoS often selected the print publication date over the date of online availability, leading to approximately 7% of publications being listed with a publication year one year later than those recorded in Dimensions, as depicted in Table 4.

Table 4 Comparison of publication years (PY) in records in Dimensions and WoS.

PY_{WoS} - PY_{Dim} < -1	PY_{WoS} - PY_{Dim} = -1	PY_{WoS} = PY_{Dim}	PY_{WoS} - PY_{Dim} = 1	PY_{WoS} - PY_{Dim} < 1
0.2%	0.4%	92.1%	7.2%	0.1%

Upon comparing Scopus and Dimensions, it is evident from Table 5 that Scopus often opted for the latter date, resulting in 7% of publications being listed with a publication year one year later than those recorded in Dimensions.

Table 5 Comparison of publication years (PY) in records in Dimensions and Scopus.

PY_{Scp} - PY_{Dim} < -1	PY_{Scp} - PY_{Dim} = -1	PY_{Scp} = PY_{Dim}	PY_{Scp} - PY_{Dim} = 1	PY_{Scp} - PY_{Dim} < 1
0.1%	0.6%	92.1%	7.0%	0.1%

Misclassifications of publication years, either being later or earlier than those in Dimensions, were infrequent. For the subsequent analysis outlined in this document, the publication year provided by Dimensions was presumed to be accurate.

3.4 CITATION DATA COMPARISON

The total citation counts of matched records from both systems were analyzed. Initially, a linear regression was conducted on the logged citation data, with an increment of one to prevent data loss for publications with no citations. Subsequently, two linear regressions were performed: one on all the data and another on the subset of total citations where the x-axis value exceeded 3.

3.4.1 Dimensions vs. Web of Science

The total citation counts between Dimensions and WoS demonstrate strong agreement, as depicted in Figure 2, which encompasses all citations. The figure indicates a positive correlation between the two data sources, although discrepancies and outliers are primarily observed among lower-cited papers. Notably, performing a linear fit to all the data tends to underestimate the cited counts from Dimensions for higher-performing papers. This discrepancy can be attributed to the broader journal coverage in Dimensions, resulting in a general increase in total citations compared to WoS.

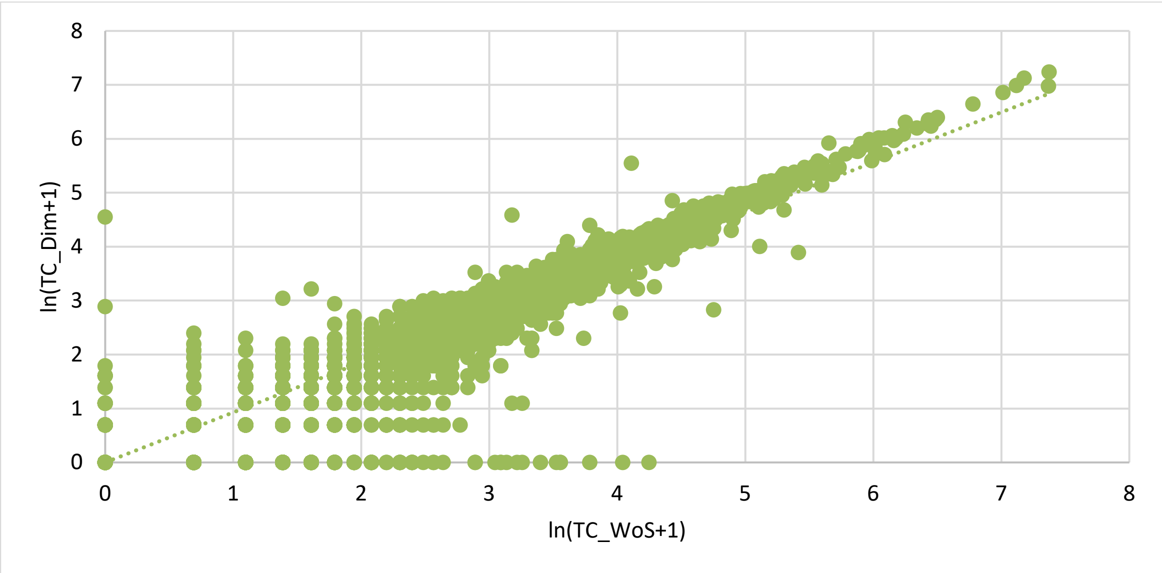

Figure 2 Dimension citations vs. Web of Science Citations for All Data.

This effect dissipates when examining papers with logged total citation counts greater than 3, as illustrated in Figure 3.

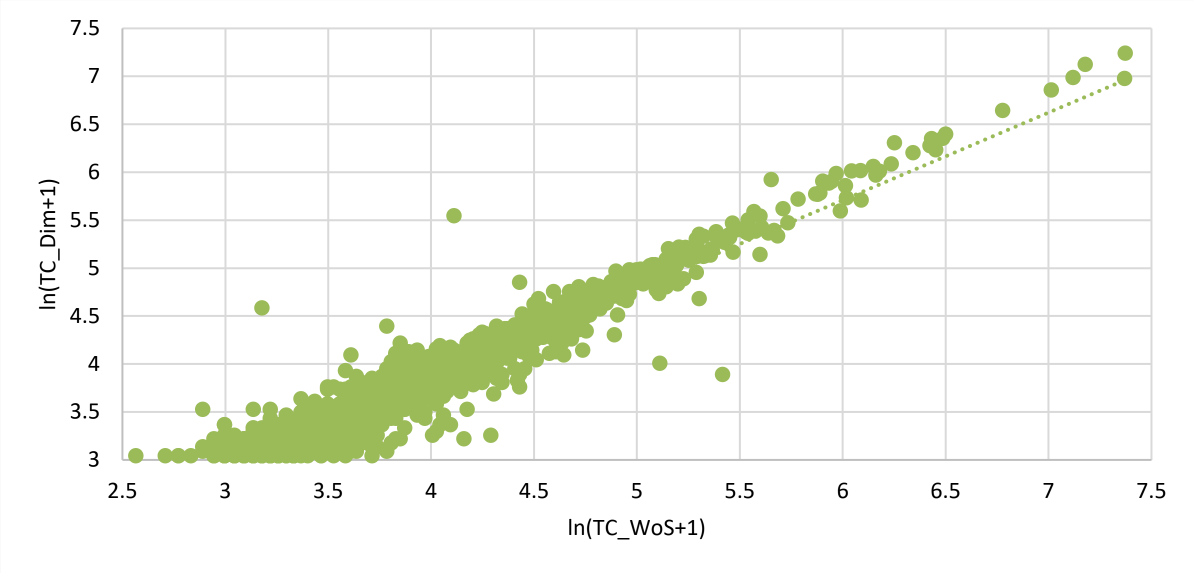

Figure 3 Dimension Citations vs. Web of Science Citations for Citations Greater than 3.

The regression statistics presented in Table 6 confirm the observations. The slope coefficient increases from 0.93 (for all data) to 0.99 (for citations greater than 3), indicating improved consistency between the two data sources.

Table 6 Regression Statistics on Total Citations for Dimensions vs Web of Science Comparison.

	All Data			Ln(TC_{WoS} + 1 >= 3)		
	Coef.	**Std. Err.**	**t Stat**	**Coef.**	**Std. Err.**	**t Stat**
ln(TC_{WoS}+1)	0.93	0.00	259.23	0.99	0.01	124.09
Intercept	0.34	0.01	39.19	0.15	0.03	4.82
F-statistics	67202.41			15399.18		
R-squared	0.91			0.90		
N. Obs.	6796			1639		

3.4.2 Dimensions vs. Scopus

The total number of citations in both Dimensions and Scopus exhibit a strong agreement, as illustrated in Figure 4, indicating a positive correlation between the two data sources. However, discrepancies and outliers are primarily observed among lower-cited papers.

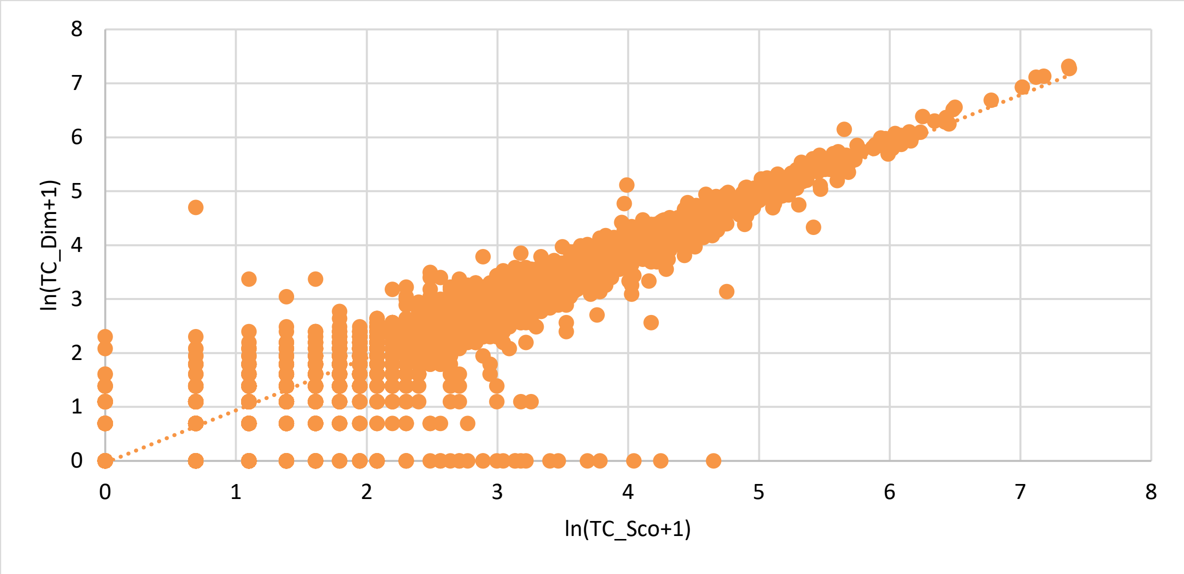

Figure 4 Dimension Citations vs. Scopus Citations for All Data.

This effect disappears when considering papers with logged total citation counts greater than 3, Figure 5.

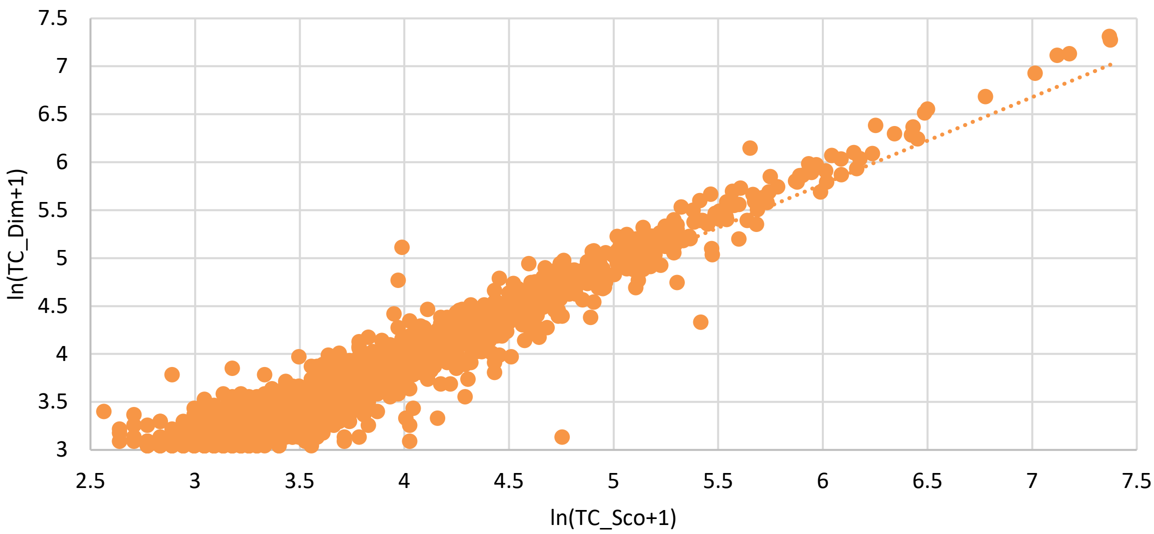

Figure 5 Dimension Citations vs. Scopus Citations for Citations Greater than 3.

The regression statistics presented in Table 7 consolidate the observations. The slope coefficient increases from 0.94 (for all data) to 1 (for citations greater than 3), indicating improved coherence between the two data sources.

Table 7 Regression Statistics on the Total Citation for Dimensions vs. Scopus Comparison.

	All Data			Ln(TC_Sco+1 >= 3)		
	Coef.	**Std. Err.**	**t Stat**	**Coef.**	**Std. Err.**	**t Stat**
ln(TC_Sco+1)	0.94	0.00	284.15	1.00	0.01	135.10
Intercept	0.21	0.01	25.53	0.03	0.03	1.13
F-statistics	80739.01			18252.42		
R-squared	0.92			0.91		
N. Obs.	7134			1886		

3.5 NORMALIZED CITATION DATA COMPARISON

3.5.1 Dimensions vs. Web of Science

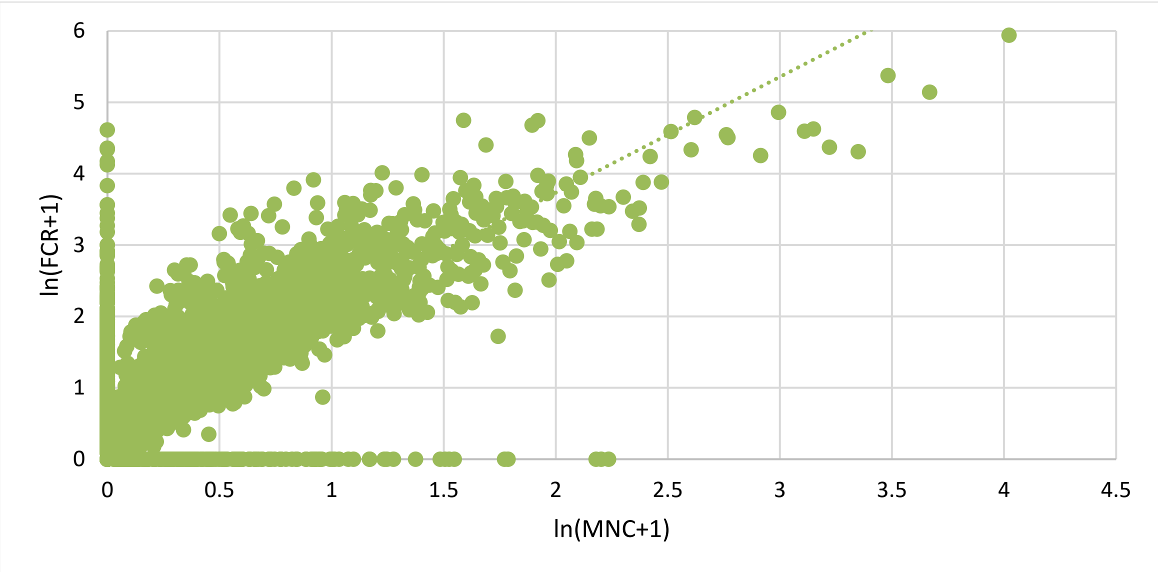

Figure 6 Linear Regressions of Logged Normalised Citation Data in Dimensions (y-axis) and Web of Science (axis) over 2013-2021.

In analysing matched publications with available FCR and MNC values, a linear regression model was applied to all data, as depicted in Figure 6, and to data where FCR is greater than or equal to 1, as shown in Figure 7. Despite the scores being derived from distinct databases using different methodologies, a reasonable agreement is observed within the data. It's noteworthy that FCR scores tend to be numerically larger than MNC data, owing to the disparity between the arithmetic and geometric means of log-normal distributions. However, a distinction between high and low-cited documents is evident, revealing varying gradients in the data, as demonstrated in Table 8.

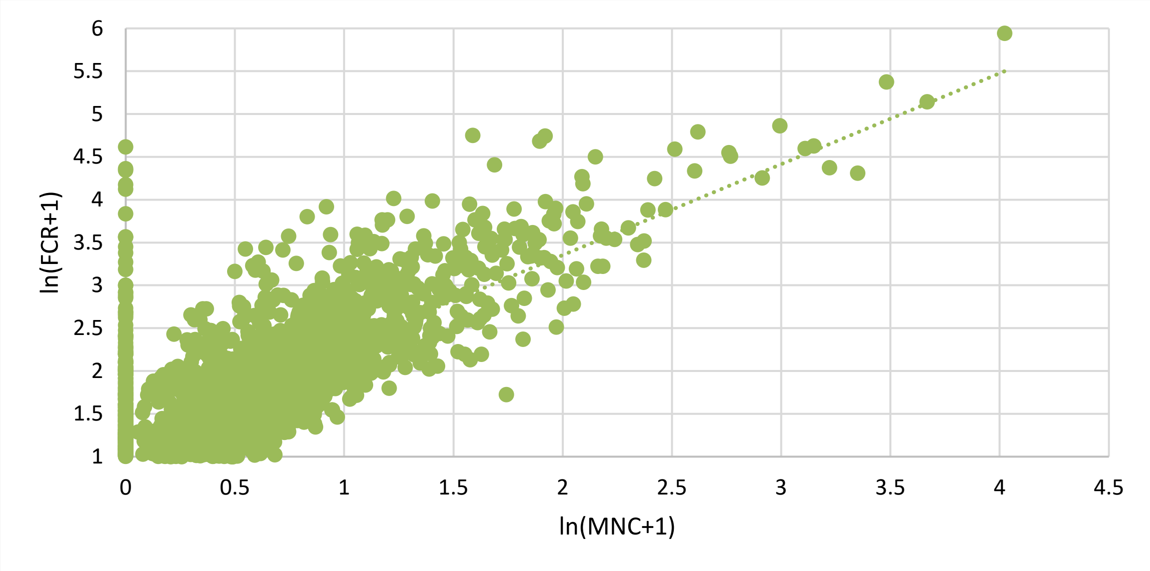

Figure 7 Linear Regressions of Logged Normalised Citation Data in Dimensions (y-axis) and Web of Science (axis) where ln(FCR+1) >= 1, over 2013-2021.

Table 8 Regression Statistics of Dimensions and Web of Science on the Normalised Citation Scores.

	Coef.	Std. Err.	t Stat	Coef.	Std. Err.	t Stat
ln(MNC+1)	1.62	0.02	79.27	1.06	0.02	46.82
Intercept	0.49	0.01	41.68	1.23	0.02	67.05
F-statistics	6282.98			2191.87		
R-squared	0.59			0.52		
N. Obs.	4345			1989		

3.5.2 Dimensions vs. Scopus

Figure 8 compares Dimensions' FCR and Scopus' FWCI for publications released between 2000 and 2021. While the chart doesn't definitively establish a strong positive correlation, it still exhibits a correlation coefficient of 0.68, indicating a moderate degree of correlation.

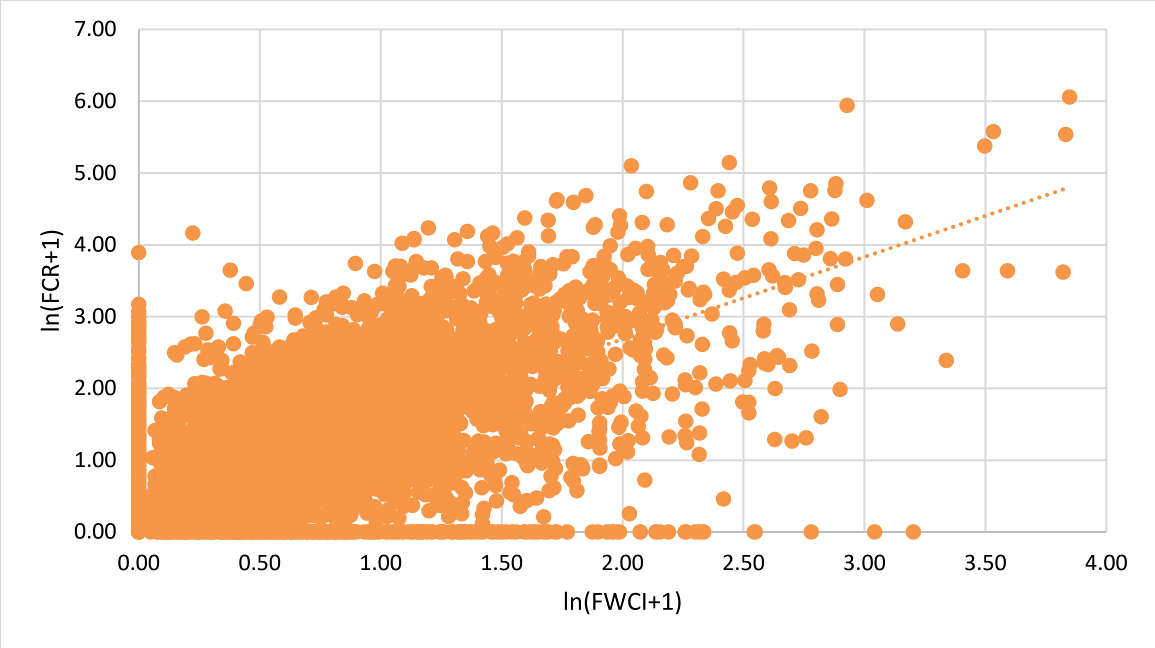

Figure 8 Linear Regressions of Logged Normalised Citation Data in Dimensions (y-axis) and Scopus (axis) over 2000-2021.

The scenario remains consistent when narrowing down the focus to papers with an FCR score greater than 1, as depicted in Figure 9. Interestingly, this time, the correlation value diminishes to 0.60, suggesting a slightly weaker correlation compared to the broader dataset.

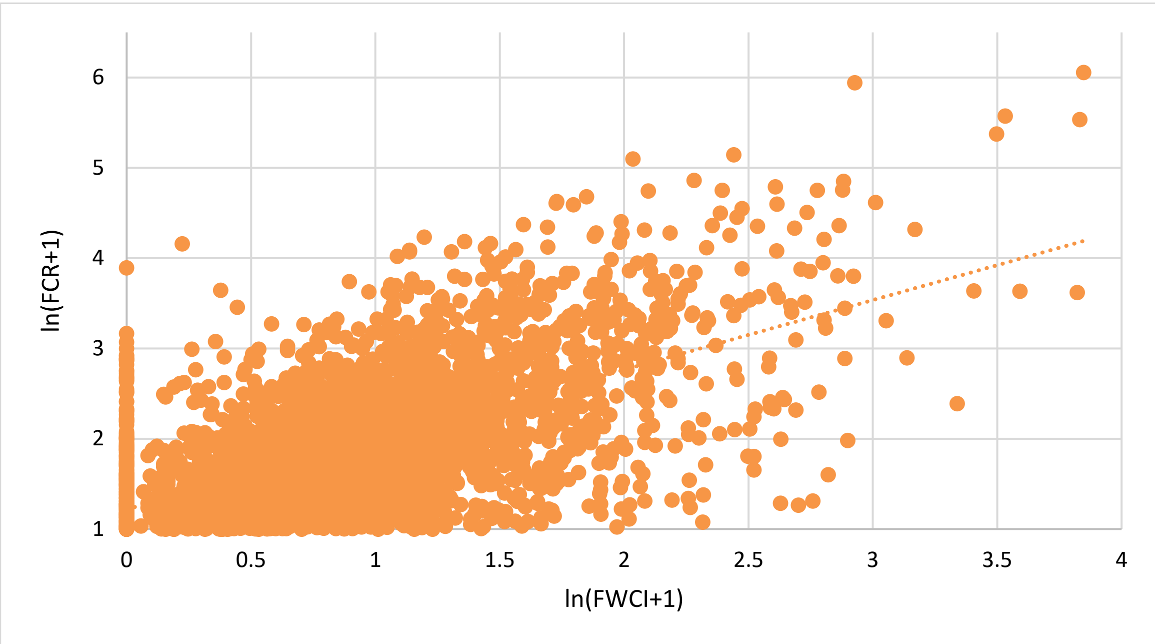

Figure 9 Linear Regressions of Logged Normalised Citation Data in Dimensions (y-axis) and Scopus (axis) Where ln(FCR+1) >= 1 over 2000-2021.

The regression results also confirm the figures in Table 9.

Table 9 Regression Statistics of Dimensions and Scopus on the Normalised Citation.

	All Data			Ln(FCR+1 >= 1)		
	Coef.	Std. Err.	t Stat	Coef.	Std. Err.	t Stat
ln(FWCI+1)	1.14	0.01	81.99	0.77	0.02	43.94
Intercept	0.40	0.01	35.17	1.22	0.02	64.34
F-statistics	6722.77			1930.63		
R-squared	0.47			0.36		
N. Obs.	7681			3440		

4 STATISTICS FOR NPL'S PUBLICATIONS

This section delves into the performance evaluation of NPL's research spanning from 2000 to 2023. It provides an overview of critical metrics pertaining to NPL's publications, encompassing FCR and JIF scores, publication counts categorized by FoR and sector, indicators of collaboration activities, and altimetric data associated with publications.

4.1 RESEARCH OUTPUT AND QUALITY

4.1.1 Number of Publications

Figure 10 illustrates NPL's research output from 2000 to 2023, demonstrating a consistent upward trend with an average increase of 16 ± 1.8 publications per year. Notably, the highest numbers of papers were published in 2017 (556) and 2020 (552), with an average of 424 publications over the last three years.

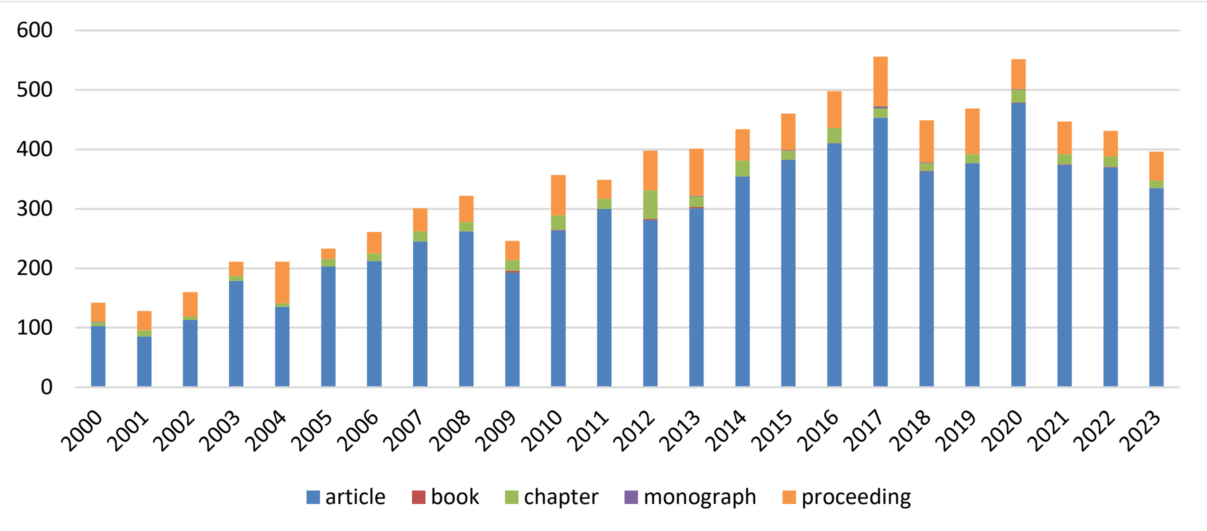

Figure 10 Number of National Physical Laboratory Affiliated Publications over 2000-2023.

4.1.2 Field Weighted Citation Ratio

The FCR scores, applicable to journal articles and conference proceedings published at least two years ago, exhibit relative stability across the entire year range. While a slight decrease is evident in recent years, similar trends are observed across benchmark institutions in this study. This decline may be attributed to the FCR calculation methodology rather than reflecting an actual decrease in research quality. This discrepancy arises because the field normalization process considers publication year, yet the citation accrual pattern follows a non-linear trajectory. Specifically, citations typically peak three years post-publication before gradually decreasing in subsequent years (see Figure 11).

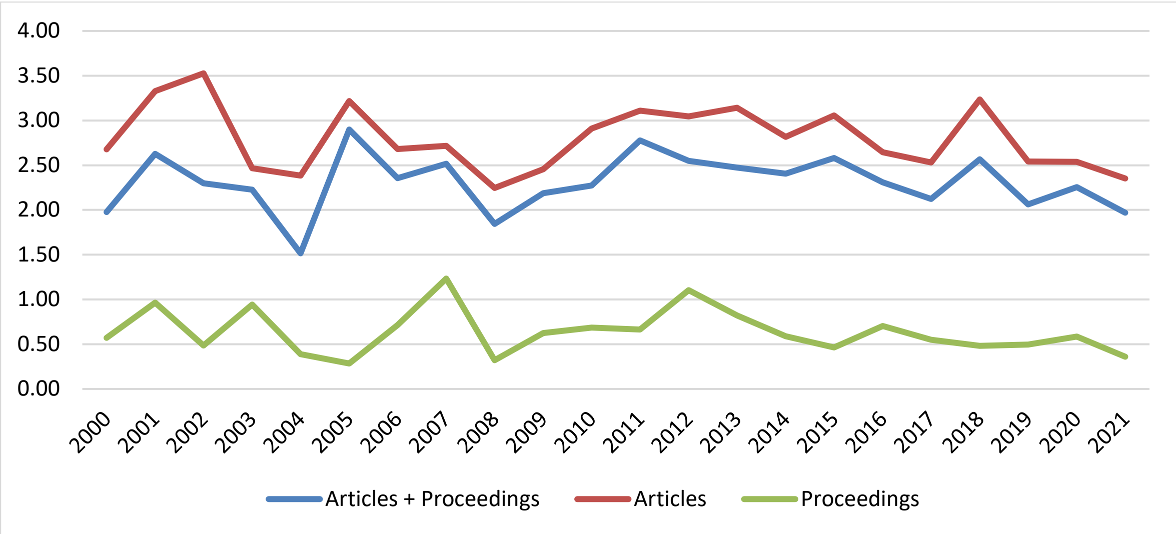

Figure 11 Field Citation Ratios for NPL's Articles and Proceedings over 2000-2021.

Journal articles published by NPL between 2000 and 2021 demonstrate a commendable average FCR score of 2.80, underscoring their significant citation impact, surpassing the global average by 1.7 times, set at 1.64. However, it's noteworthy that NPL's FCR scores fall slightly below the UK average of 2.97, aligning with expectations given the presence of globally renowned academic institutions and universities in the UK.

Table 10 Publication Output and Average FCR Scores for NPL over 2017-2021

DIM_type	article	book	chapter	monograph	proceeding	Total	FCRs[3]
2017	420	0	15	0	74	509	2.53
2018	317	0	7	0	62	386	3.23
2019	353	0	12	0	72	437	2.54
2020	444	0	20	1	51	516	2.54
2021	344	0	11	0	53	408	2.35

Table 10 presents data on publications that are between 3 and 7 years old, indicating an average FCR score of 2.64 for these journal articles.

Furthermore, Table 11 outlines the top ten publications published after 2016, highlighting both their FCR scores (which correlate with total citation counts) and altmetric scores.

[3] Calculated only for using journal articles.

Table 11 Top Ten Papers According to their FCR Scores over 2017-2021.[4]

Pub. Year	DOI	Title	Time Cited	FCR Score	Altmetric Score	Group
2017	10.1088/1361-6463/50/4/043001	The 2017 terahertz science and technology roadmap	1,200	362	8	Electromagnetic Technologies
2018	10.1016/j.physrep.2017.08.004	Micro-combs: A novel generation of optical sources	509	140	31	Optical Frequency Metrology; National Time Scale; Atomic Clocks and Sensors
2018	10.1038/s41586-018-0738-2	Atomic clock performance enabling geodesy below the centimetre level	460	127	854	Optical Frequency Metrology; National Time Scale ;Atomic Clocks and Sensors; Optical Radiation Metrology
2021	10.1038/s41467-021-27045-6	Noise-induced barren plateaus in variational quantum algorithms	306	132	30	Quantum Information Processing
2018	10.1002/mp.13208	Dosimetry of small static fields used in external photon beam radiotherapy: Summary of TRS-483, the IAEA–AAPM international Code of Practice for reference and relative dose determination	200	113.9	0	Medical Radiation Science
2020	10.1186/s40323-020-00147-4	How to tell the difference between a model and a digital twin	296	108	41	Mass Metrology
2020	10.1140/epjqt/s40507-020-0080-0	AEDGE: Atomic Experiment for Dark Matter and Gravity Exploration in Space	199	102	47	Optical Frequency Metrology
2018	10.1038/s41567-017-0042-3	Geodesy and metrology with a transportable optical clock	335	92	491	Optical Frequency Metrology;National Time Scale; Atomic Clocks and Sensors
2020	10.1088/1475-7516/2020/05/011	AION: an atom interferometer observatory and network	198	99	26	Optical Frequency Metrology
2017	10.1038/s41566-017-0009-z	Soliton crystals in Kerr resonators	289	79	43	Optical Frequency Metrology;National Time Scale;Atomic Clocks and Sensors

4.1.3 Journal Impact Factors

Examination of the JIFs for the journals hosting NPL publications indicates that nearly 23% of NPL's papers were published in journals falling within the first quantile of JIF scores from 2000 to 2021, as illustrated in Table 12. This percentage rises to 24% for the period spanning 2010 to 2021.

[4] See Appendix-1 for the Department/Group abbreviations.

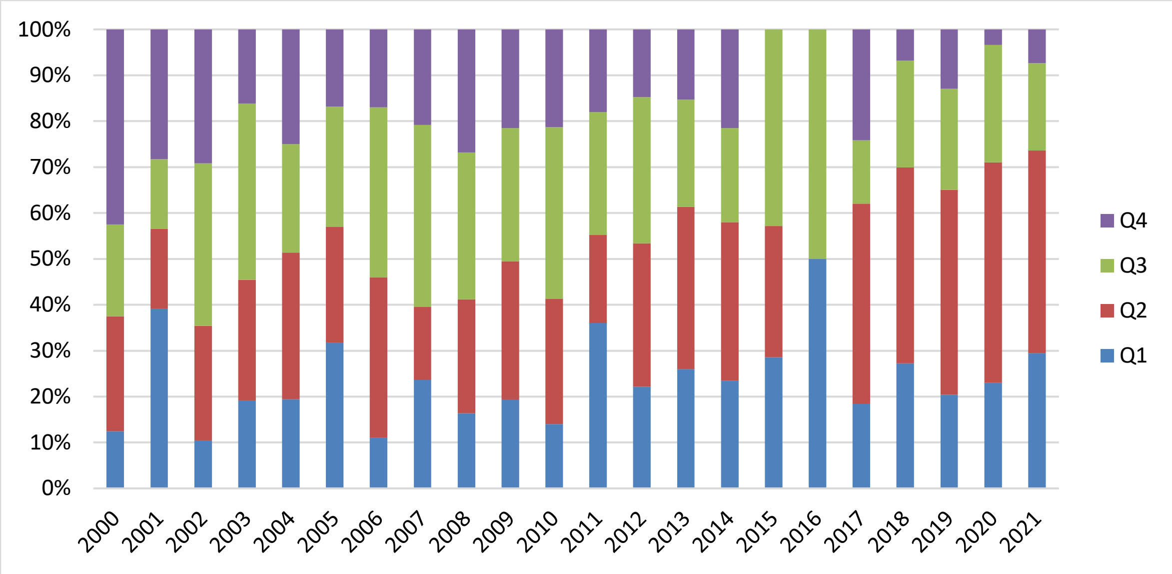

Figure 12 Proportion of Research Outputs Published in Journals According to JIF's Quartile Scores.

4.2 RESEARCH TOPICS

4.2.1 Fields of Research Classification

Publications are categorized according to one or more FoR codes, aligned with the ANZSRC system. Figure 13 illustrates that the thematic focus of NPL's research output has largely remained consistent since 2000, with notable additions including information and computing sciences, biological sciences, and earth sciences around 2005. Consequently, the proportions of publications classified under "Engineering" and "Physical Sciences" have been on a downward trend.

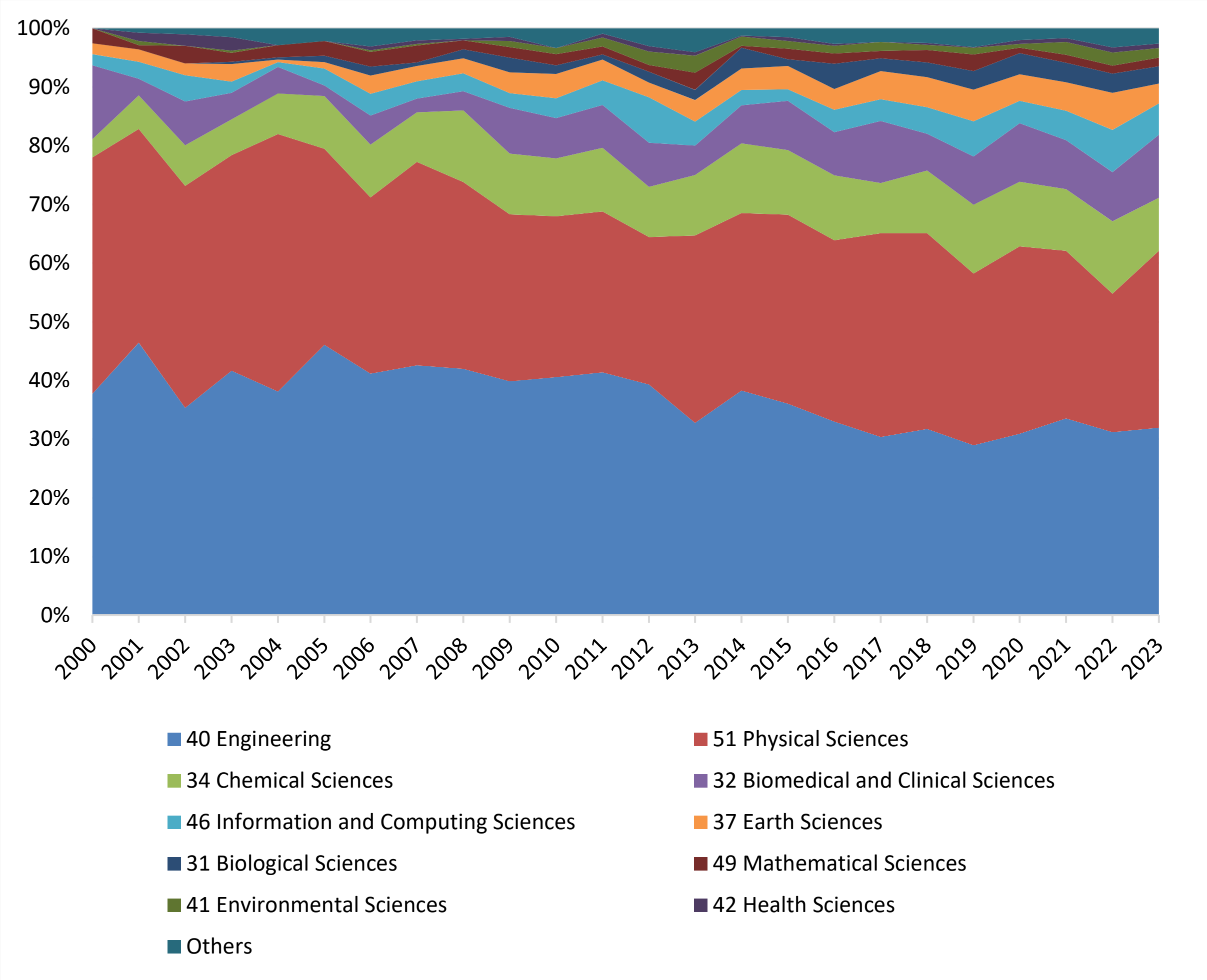

Figure 13 Proportion of NPL Publications Broken-down by Field of Research over 2000-2023.

4.2.2 United Nations – Sustainable Development Goals

In the NPL dataset, a total of 788 papers are aligned with UN SDGs, with a significant increase observed after 2010. These papers primarily address issues related to affordable and clean energy, climate action, and health and well-being. It's noteworthy that the Atmospheric Environmental Science and Thermal & Radiometric Metrology departments play a prominent role in contributing to these publications.

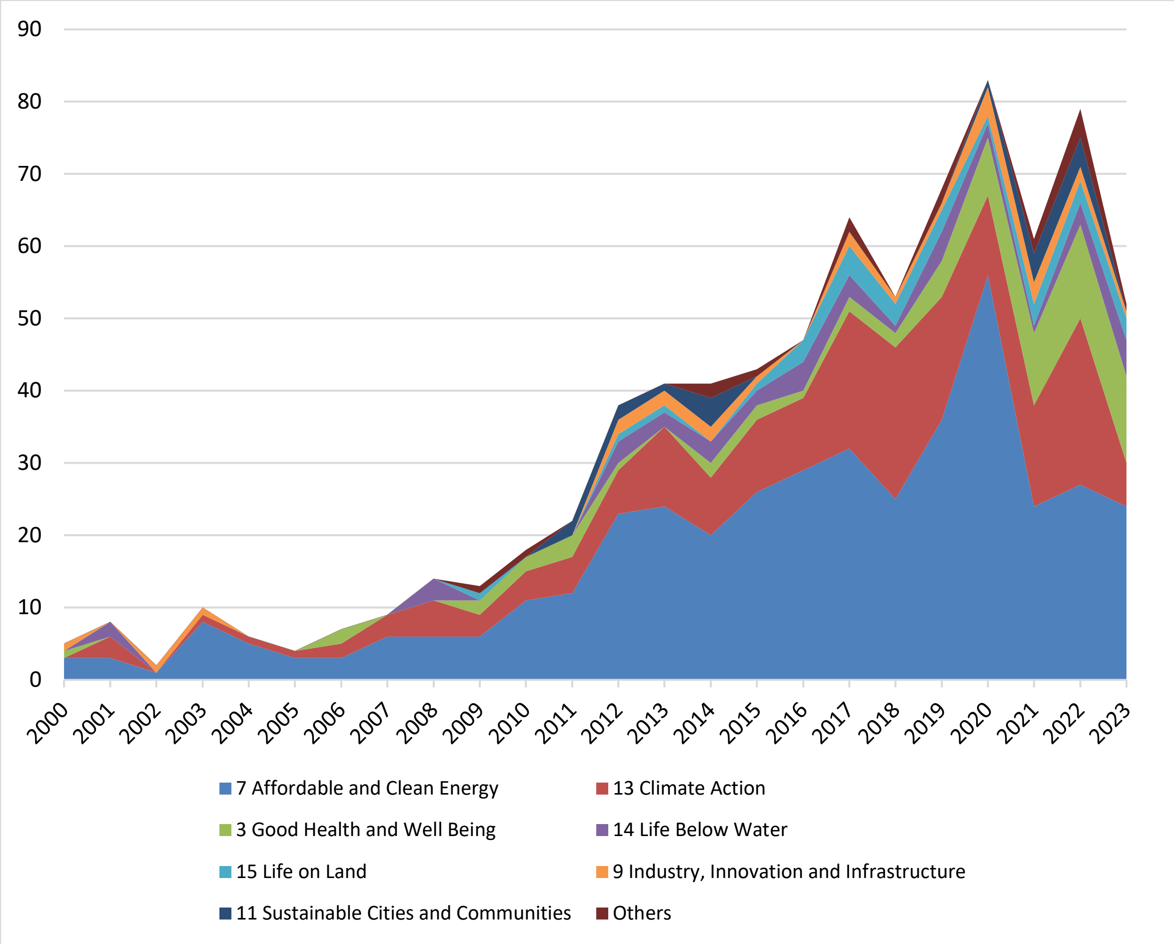

Figure 14 Count of NPL Publications Tagged Against UN Sustainable Development Goals over 2000 - 2023.

4.2.3 Sectors of NPL

Research conducted at NPL can also be categorized based on the authorship of publications aligned with NPL's science areas. The research groups within NPL's Science and Engineering Directorate are classified as contributing to one or more of four key sectors. Figure 14 illustrates the publication counts by sector for the period 2000-2023, highlighting the significant growth observed in the Life Sciences & Health sector.

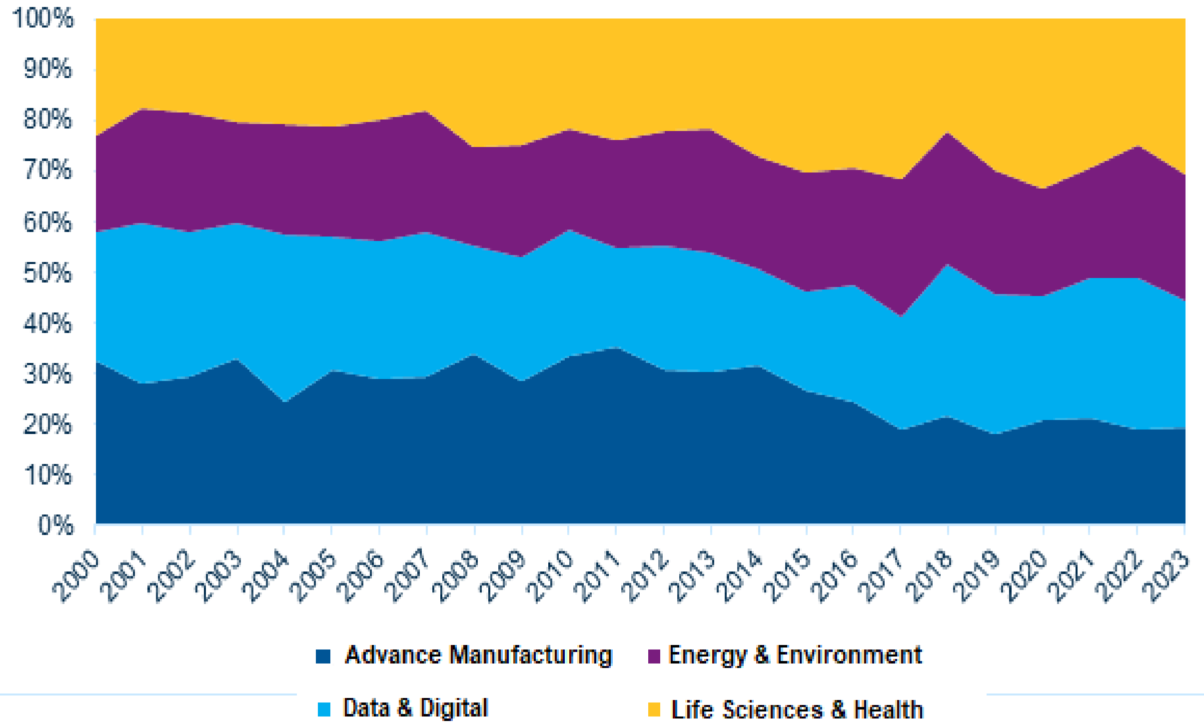

Figure 15 Publication Count by NPL Sector, assigned via the Authoring Research Area over 2000 - 2023.

4.3 COLLABORATION

Analysis of co-authoring institutions provides further insights into the changes undergone by NPL over the past 23 years. Dimensions employs Grid IDs (Global Research Identifier Database, 2024) to tag its publication affiliation data, offering unique identifiers for research organizations. While the database encompasses details on research-active companies, its coverage is typically more extensive for universities and public sector research enterprises (PSREs). Consequently, the analysis of industrial co-authors may underestimate the actual extent of industrial research collaboration.

4.3.1 Collaboration with the Industry

Each organization identifier in the Grid database is accompanied by metadata specifying the type and country of the organization. Analysing the Grid ID metadata indicates that co-authorship with industry partners in research publications surged from 2% to 14% over the entire period, as illustrated in Figure 16.

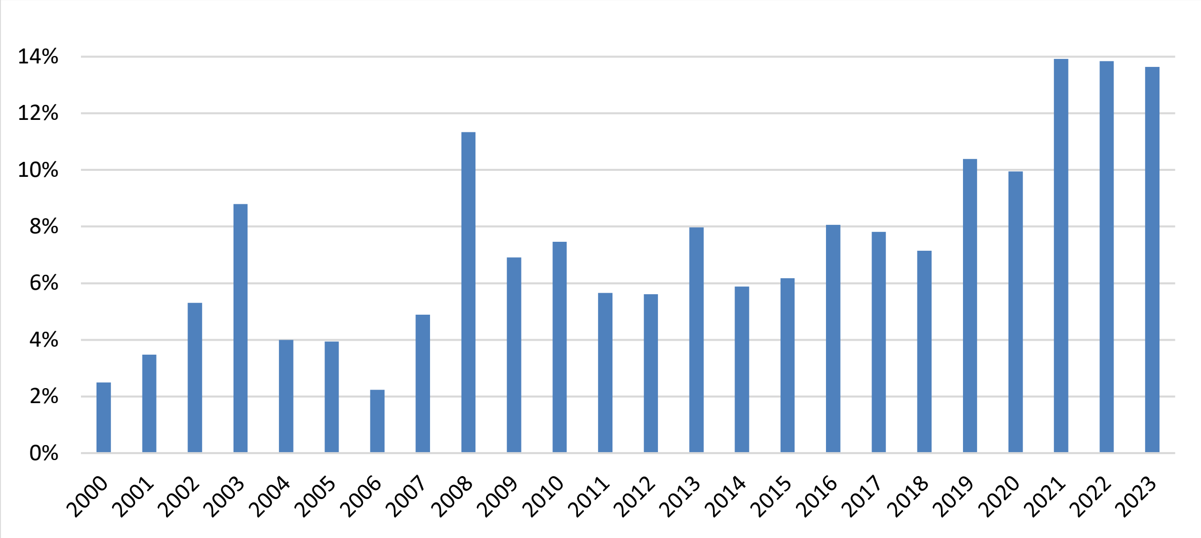

Figure 16 Percentage of Publications Co-authored with One or More Industrial Partners over 2000-2023.

Focusing on industrial co-authors reveals details on a total of 264 companies, among which 178 collaborated on at least one publication with NPL during the period from 2019 to 2023. Figure 17 offers an overview of these collaborating companies, with AstraZeneca, TopGan, and Rolls-Royce ranking in the top three with 20, 13, and 9 unique publications, respectively.

Figure 17 Companies Collaborated with NPL at Least 2 or More Publications over 2019-2023.

4.3.2 International Collaborations

Concurrently, there is a consistent rise in the proportion of publications with at least one international co-author from 2000 to 2023, as depicted in Figure 18. While the percentage of publications with one or more international co-authors stood at nearly 25% in 2000, it has surged to 60% by 2023.

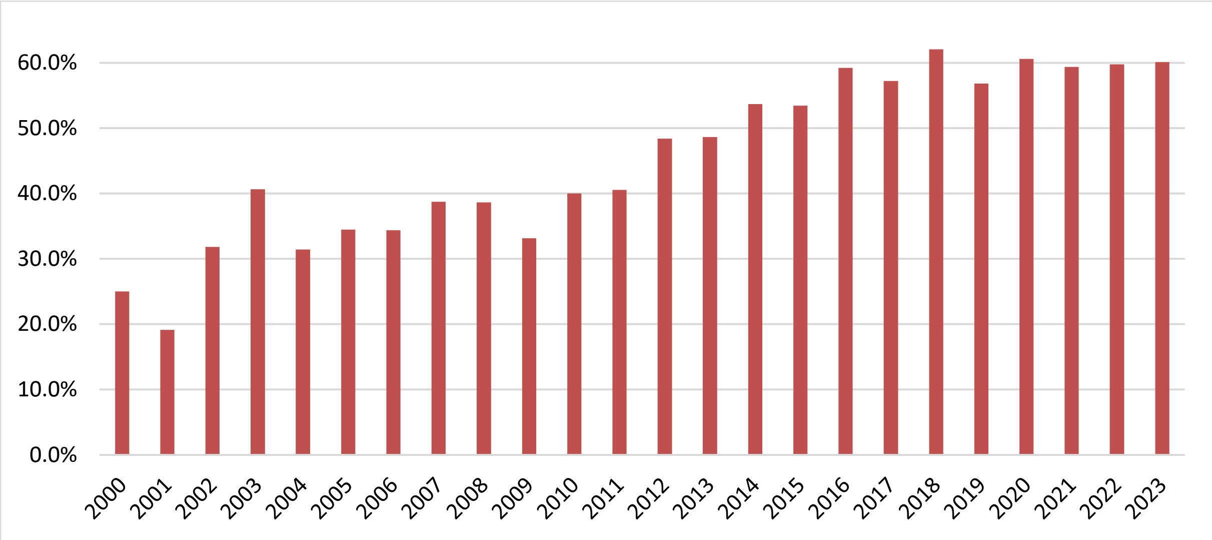

Figure 18 Percentage of Publications with One or More International Co-authors over 2000-2023.

4.3.3 Internal Work

Analysing publications where only NPL's Grid ID is present indicates a trend towards increasing collaboration among NPL authors over the years. In 2023, only 9% of publications were authored solely by NPL, reflecting a significant shift towards collaborative research efforts.

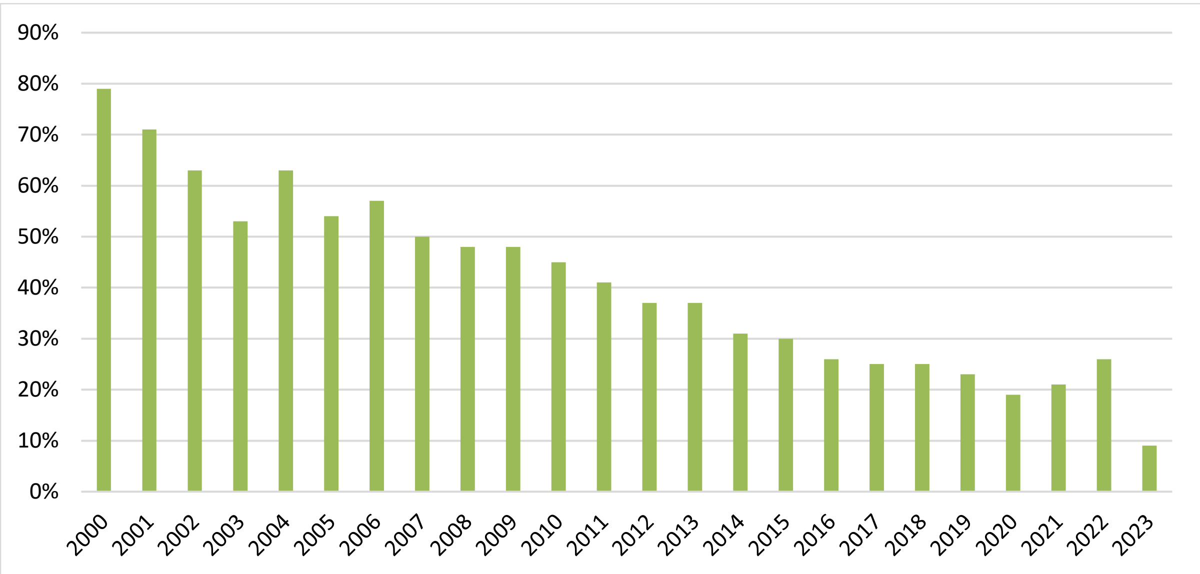

Figure 19 Percentage of Publications with Only NPL Authors over 2000-2023.

4.4 ALTERNATIVE METRICS SCORE FOR NPL

4.4.1 All Types of the Mentions

Figure 20 illustrates the proportions of NPL's publications cited across various platforms, including news articles, blogs, policy documents, patents, and social media platforms such as Twitter, Facebook, and LinkedIn. The data reveals a notable increase in the percentages of NPL's publications cited across these diverse platforms, particularly after 2011, with a continued upward trend observed through 2021. Notably, 2,095 NPL publications (30%) have received at least one online mention within the Altmetric.com database, highlighting the broad reach and impact of NPL's research outputs.

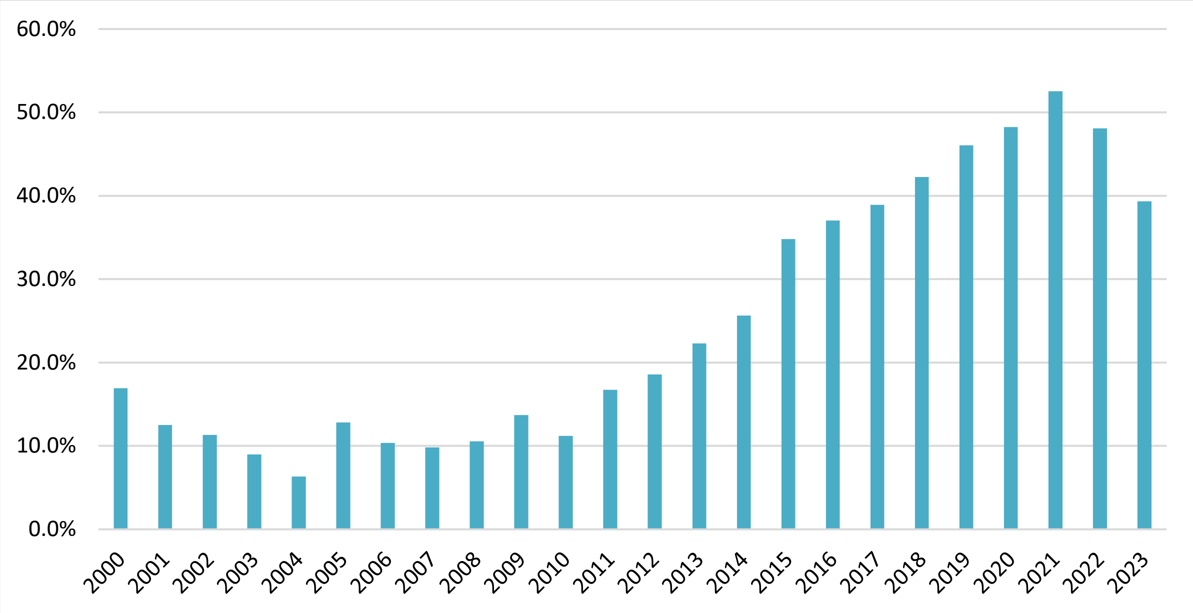

Figure 20 Percentages of NPL's Publications Cited by "All Type of the Mentions" over 2000-2023.

The percentages of NPL’s publications cited by "All Types of Mentions" peaked in 2021 before entering a decreasing trend. This trend is consistent with the overall increase in the total number of publications produced. As more publications are released, there is a higher likelihood of them being mentioned or cited in various contexts.

4.4.2 Mentions by the News

Figure 21 illustrates the evolving landscape of online engagement with research publications, particularly in mainstream news, as tracked by Altmetric.com since 2011. While historical mentions have been noted in some media sources, the emphasis is on real-time interactions, reflecting the dynamic nature of online engagement. The graph shows a rising trend in the proportion of NPL's papers mentioned in the news, reaching levels between 8% and 10% over the last three years.

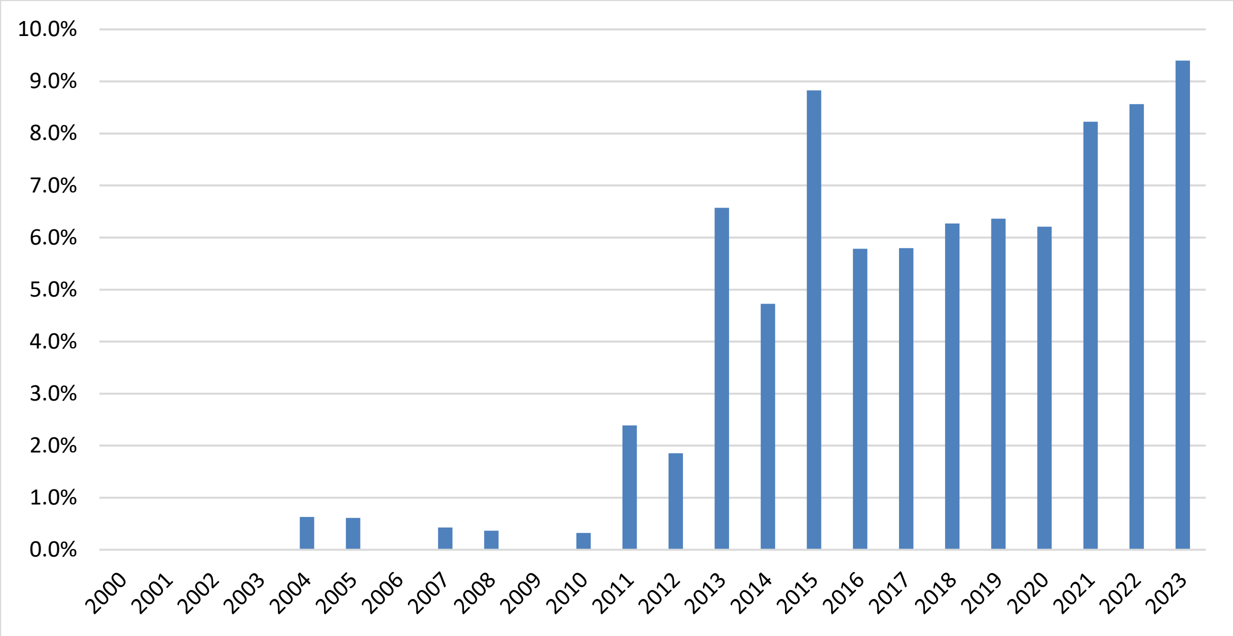

Figure 21 Percentages of NPL's Publications Cited by "News" over 2000-2023.

4.4.3 Mentions by Policy Documents

Historical data is available for significant data sources like citations in governmental policy documents, as depicted in Figure 22. The figure indicates that approximately 4% of NPL's papers published in 2011 received mentions in policy documents, underscoring the relevance of NPL's research in informing governmental decisions and initiatives. Unlike citations between research papers, it typically takes nearly four years for a paper to be cited by a policy document, which explains the relatively lower values observed for the years 2021 to 2023.

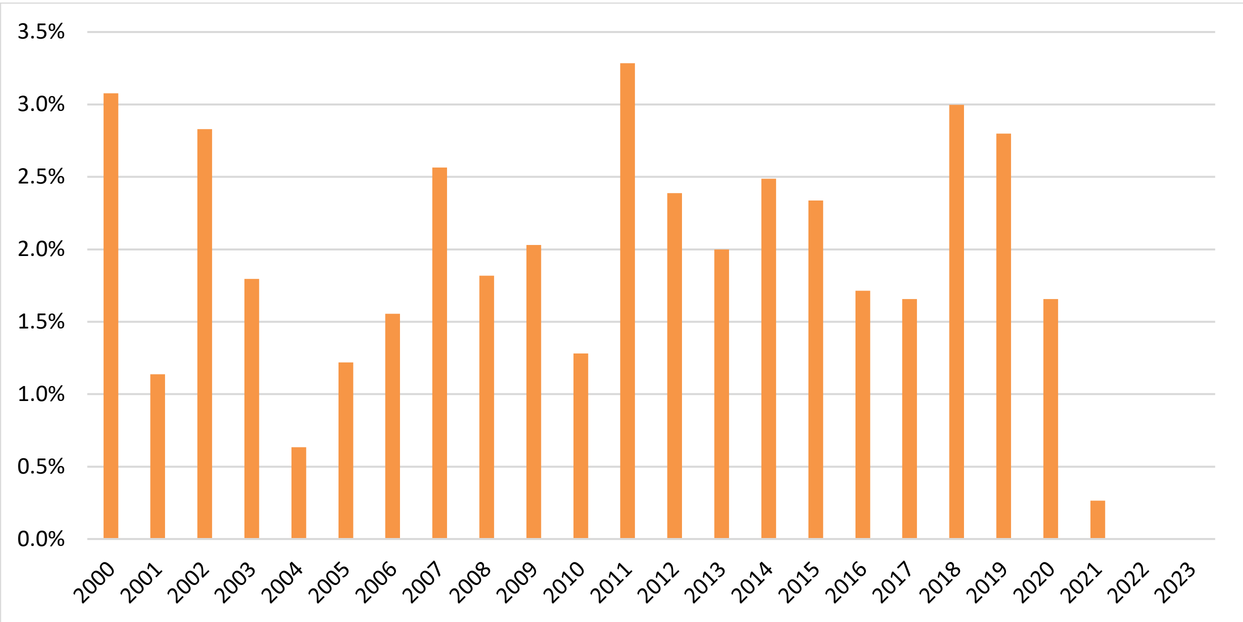

Figure 22 Percentages of NPL's Publications Cited by "Policy Documents" over 2000-2023.

4.4.4 Mentions by Patents

Papers published by NPL from 2000 to 2021 have been cited in 361 patents, as depicted in Figure 23. This figure illustrates the percentages of publications cited by patents over the years. Unlike citations between research papers, it typically takes nearly four years for a paper to be cited by a patent (similar to policy documents), which explains the relatively lower values observed for the years 2021 to 2023.

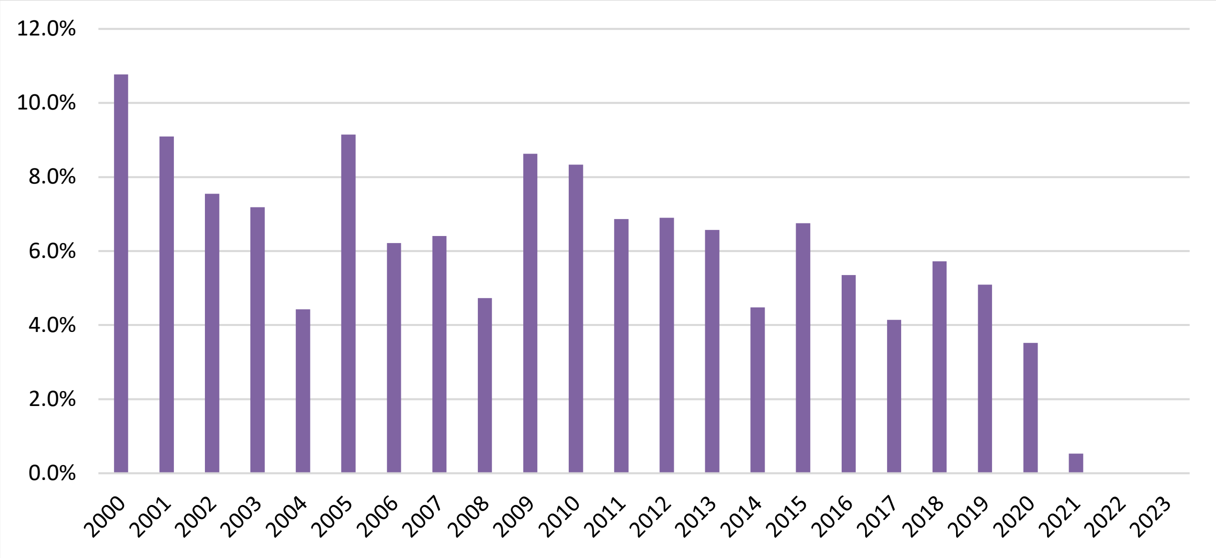

Figure 23 Percentages of NPL's Publications Cited in Patents over 2000-2023.

4.4.5 Altmetric Score

In contrast to paper citations and policy documents, which often take several years to accumulate, altmetrics are typically viewed as a more immediate measure of interest, with many online mentions occurring within a few months of publication. However, it's worth noting that a subset of altmetrics, specifically those related to policy mentions and patent citations, exhibit behaviour similar to traditional citations, with delays between publication and mention dates spanning multiple years, as illustrated in Figure 24.

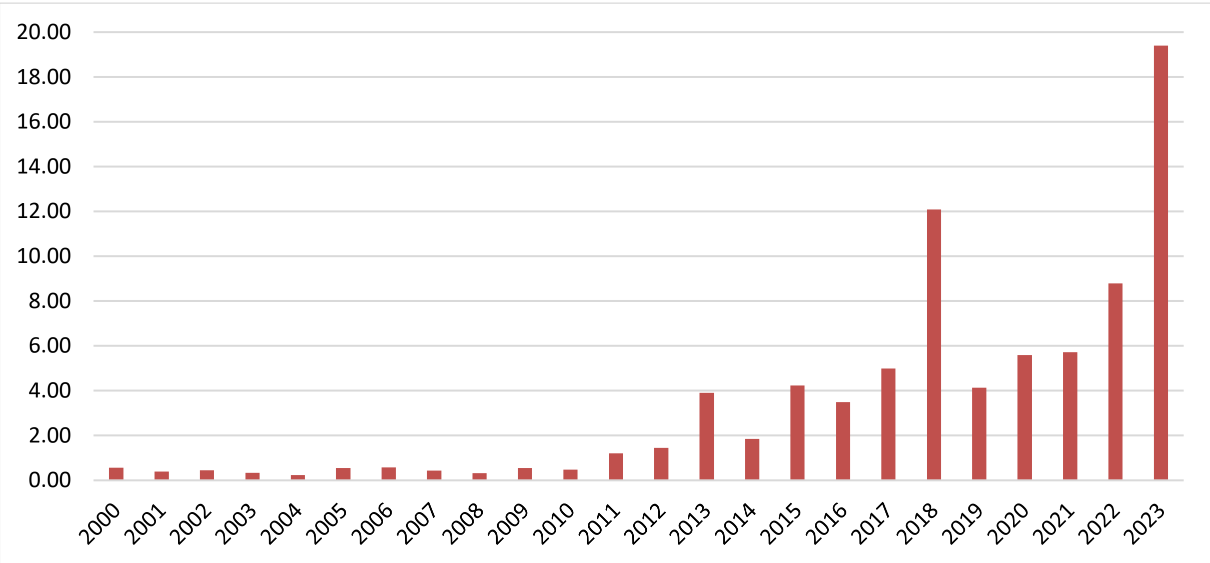

Figure 24 Altmetric Score Average over 2000-2023.

Table 12 presents the top five NPL publications garnering the highest online attention in terms of altmetric scores.

Table 12 Top Ten NPL Publications with the Highest Altmetric Score[5].

Title	Pub_Date	Alt_Score	News	X	Mendeley Reads	Citations	Group .
Air-quality networks collect environmental DNA with the potential to measure biodiversity at continental scales	01-06-23	1617	222	70	50	10	Air Quality and Aerosol Metrology
Highlighter: An optogenetic system for high-resolution gene expression control in plants	21-09-23	1365	181	70	18	1	Biometrology
The dietary sweetener sucralose is a negative modulator of T cell-mediated responses	15-03-23	1153	86	1345	115	21	National Centre of Excellence in Mass Spectroscopy Imaging (NiCE-MSI)
Laser scanning reveals potential underestimation of biomass carbon in temperate forest	19-12-22	1075	24	1583	141	22	Central Other Operations
Atomic clock performance enabling geodesy below the centimetre level	28-11-18	854	100	63	236	460	Optical Frequency Metrology ; National Time Scale; Atomic Clocks and Sensors; Optical Radiation Metrology
Antimicrobial peptide capsids of de novo design	22-12-17	749	89	65	113	64	National Centre of Excellence in Mass Spectroscopy Imaging (NiCE-MSI)
Charge quantum interference device	09-04-18	551	75	20	104	50	Quantum Electrical Metrology ; Quantum Information Processing ; Quantum Materials and Sensors
Geodesy and metrology with a transportable optical clock	12-02-18	491	59	69	221	334	Optical Frequency Metrology National Time Scale Atomic Clocks and Sensors
Essential elements of radical pair magnetosensitivity in Drosophila	22-02-23	414	66	105	51	23	Biometrology
The increasing atmospheric burden of the greenhouse gas sulfur hexafluoride (SF6)	23-06-20	410	45	28	66	59	Emissions and Atmospheric Metrology
A comparison of future realizations of the kilogram	24-01-18	406	51	1	16	26	Mass Metrology
No increase in global temperature variability despite changing regional patterns	24-07-13	365	11	706	415	199	Data, Analytics and Modelling Informatics
Rapid detection of cocaine, benzoylecgonine and methylecgonine in fingerprints using surface mass spectrometry	01-01-15	331	30	46	148	93	Biometrology Electronic and Magnetic Materials
Optical interferometry–based array of seafloor environmental sensors using a transoceanic submarine cable	19-05-22	326	38	63	56	35	Data, Analytics and Modelling Optical Frequency Metrology Atomic Clocks and Sensors

[5] See Appendix-1 for the Department/ Group abbreviations.

4.5 BENCHMARKING NPL'S PERFORMANCE[6]

To assess NPL's performance relative to its counterparts, datasets from Dimensions were obtained for the following NMIs: NIST (United States), PTB (Germany), NIM (China), and KRISS (South Korea). Additionally, data for the University of Cambridge, focusing on the Physical Sciences field of research, were included to provide a benchmark for the performance of a leading UK physics department. It's important to note that while comparisons are made, the differing roles of NMIs and universities mean that direct comparability may be limited. No adjustments have been made to scale the results by funding or staff size.

4.5.1 Research Output and Quality

Publication Counts and Estimates

Publication counts for NPL, and the five other research organisations were extracted from Dimensions for the period 2000-2023. Forecasts of research outputs for the period 2024 to 2028 were made via analysis of simple autoregressive (AR) model:

$$\Delta P_t = \alpha + \beta \Delta P_{t-1} + \gamma t + u \qquad \text{(eqn 1)}$$

in which the change in publication output P in any year t can be described in terms of the change in publication output from the previous year plus a linear term for the year. The regression was made for the observed data in the years 2000-2023 (t = 0-28) and forecast were made for the next five years 2024-2028 (n = 1-5) calculated as:

$$\Delta \hat{P}_{t+n} = (\alpha + \gamma t) \sum_{i=0}^{n-1} \beta^i + \beta^n \Delta P_t \qquad \text{(eqn 2)}$$

The 95% confidence interval on the forecast can be calculated as ±1.96$SE(t,n)$, where the standard error is calculated by:

$$SE(t,n) = \sigma_\beta \sqrt{\sum_{i=0}^{n-1} \beta^{2i}} \qquad \text{(eqn3)}$$

where σ_β is the standard error on the coefficient as calculated from the regression output in equation 1.

Completing this analysis for all the institutions, the publication counts over 2000-2023 are plotted in Figure 25, and the point and upper/lower bands predictions for 2024-2028 are depicted in Figure 26.

[6] Given the distinct nature of NMIs compared to academic institutions, it would be inappropriate to rely on world average scores in this context. Instead, the field of physical sciences within the University of Cambridge is filtered and utilized as a benchmark against which to compare NPL's performance, offering a more relevant comparison within the academic landscape.

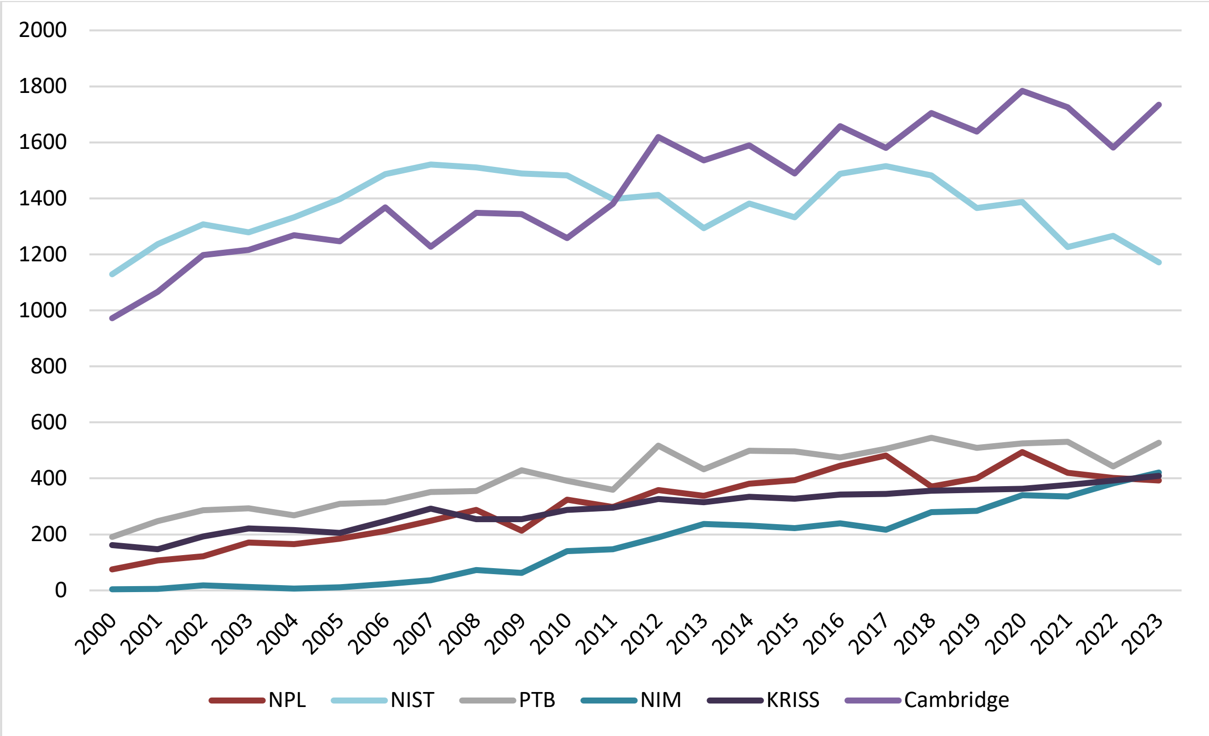

Figure 25 Research Publication Counts in 2000-2023 Across NPL, NIST, PTB, KRISS, NIM and Cambridge/Physical Sciences over 2000 - 2023.

In terms of publication count growth, NIM exhibits the most rapid increase among NMIs, averaging approximately 19% annually. NPL follows closely behind NIM with an average growth rate of around 16% per year. PTB and KRISS trail NPL with growth rates of approximately 14% and 10%, respectively.

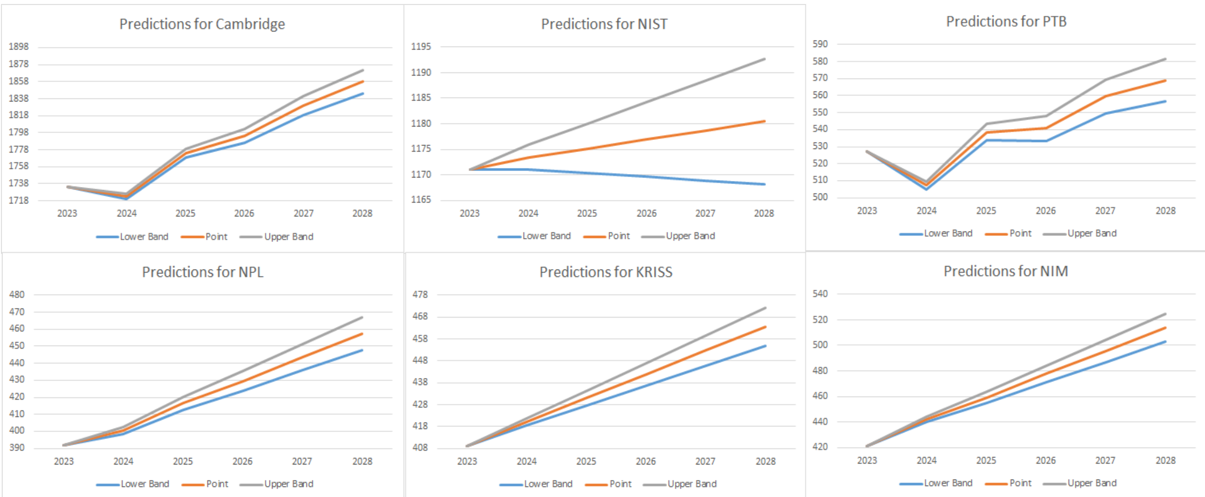

Figure 26 Point and Upper/Lower Band Predictions for the Publication Counts for Six Institutions for 2024-2028.

Projections outlined in Figure 26 indicate that by 2028, NPL is expected to have approximately 458 publications, with a range of ±10 publications (lower bound around 448 and upper bound around 468).

Field Citation Ratio Comparison

FCR values retrieved from Dimensions for each publication year were subjected to a moving average over the preceding five years to mitigate noise, as illustrated in Figure 27. Across all organizations, there is a consistent trend of increasing output year by year, while research quality, as indicated by FCR, remains relatively stable. However, there appears to be a slight decline in FCR values in the most recent years, as previously noted. Notably, FCR values for PTB and NPL exhibit similarity, with NIST slightly ahead, and NIM and KRISS trailing behind.

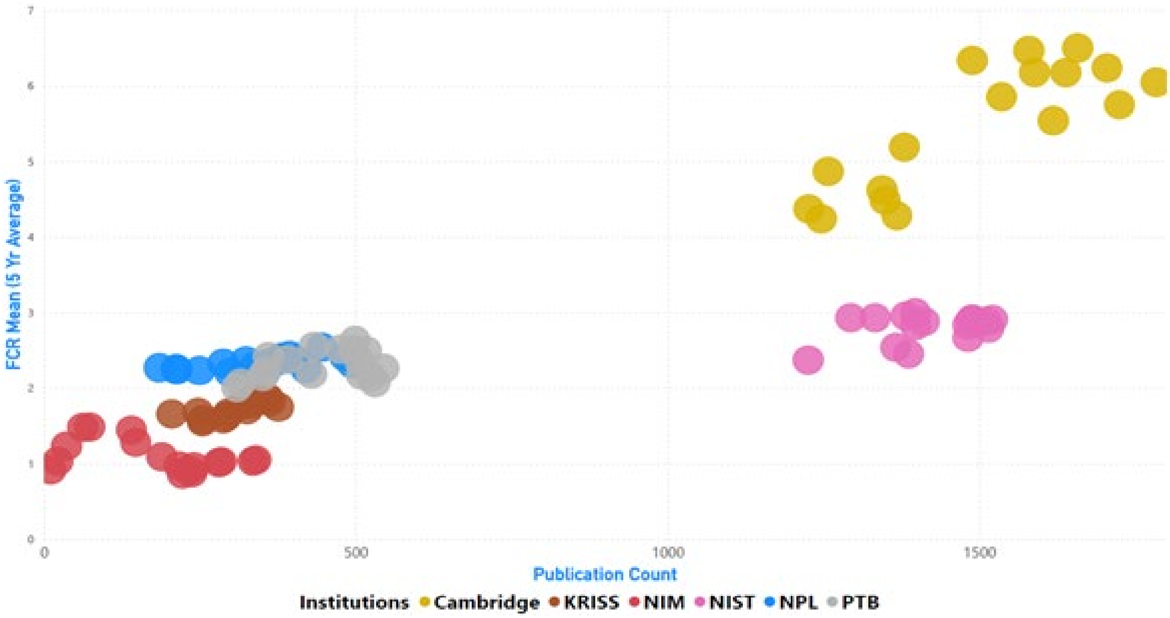

Figure 27 Field Citation Rate Comparison Across Institutions over 2005-2021

4.5.2 Research Topics

Data extracted from Dimensions was utilized to examine potential institutional variations in the number of publications associated with the UN SDGs. Institutional searches were conducted, including Cambridge University with results confined to the Physical Sciences research field. All papers published between 2019 and 2023 were analysed collectively. Table 13 provides insights into the total publication output, the percentage of papers tagged against one or more SDGs, and the p-value obtained from a chi-squared contingency test for the significance of SDG versus non-SDG paper counts for each institution when compared against NPL.

Table 13 Chi-square Significance Test on Publication Percentage Tagged to UN Development Goals.

Variables	Unique Paper Count	SDG Count	% SDG	Chi-square p-value
NPL	2,109	320	15%	
CAMBRIDGE	8,454	452	5%	0.06364 (Not Sig.)
NIST	6,416	741	12%	0.00865 (*)
PTB	2,535	322	13%	0.00402 (*)
KRISS	1,899	275	15%	0.00032 (*)
NIM	1,762	240	14%	0.00159 (*)

NPL exhibits the highest proportion of papers tagged to SDGs, and statistically significant differences were observed when compared to each of the other institutions, except for Cambridge University (Table 13). This discrepancy could be attributed to the publication set for Cambridge being confined solely to the physical sciences, thereby limiting the inclusion of more applied research topics within their data. Furthermore, while NPL boasts the largest percentage of tagged papers, it's worth noting that in terms of research output levels (Table 14), NIST and Cambridge still have a larger absolute number of SDG-relevant publications.

Table 14 Counts of Publications Tagged Against UN SDGs by Institution and Goal Category.

UN Goals	NPL	CAMBRIDGE	NIST	PTB	KRISS	NIM
2 Zero Hunger	1	1	5	2	3	9
3 Good Health and Well Being	45	44	108	77	59	58
4 Quality Education	5	1	9	1	1	1
6 Clean Water and Sanitation			5	4		1
7 Affordable and Clean Energy	153	352	357	166	178	134
8 Decent Work and Economic Growth				1		
9 Industry, Innovation and Infrastructure	10	1	104	19		3
10 Reduced Inequalities	1	5		2		
11 Sustainable Cities and Communities	7		27	1	3	6
12 Responsible Consumption and Production	2	3	20	2	1	
13 Climate Action	67	21	76	40	24	17
14 Life Below Water	15	14	24	3	5	8
15 Life on Land	14	5	5	3	1	3
16 Peace, Justice and Strong Institutions		5	1	1		
Total	**320**	**452**	**741**	**322**	**275**	**240**

4.5.3 Collaboration

The dataset was further analysed to examine features related to the listed Grid IDs for co-authoring institutions, as outlined in earlier sections of this paper. The following metrics were constructed:

- The percentage of publications featuring only one Grid ID, identified as that of the home institution. This metric reflects the proportion of published work without external co-authors.
- The percentage of publications with at least one international co-author, from the perspective of the home institution.
- The percentage of publications with at least one external co-author from industry. However, it's important to note that due to the skewed coverage of the Grid database towards research organizations and universities, this metric may underestimate the actual level of academic collaboration with industrial partners.

Table 15 Percentages of Publications Published, Alone, International and by the Industry.

Percentages of Publications	NPL	CAMBRIDGE	NIST	PTB	KRISS	NIM
% Alone	12%	13%	22%	20%	13%	19%
% International	60%	56%	38%	57%	30%	19%
% Industry	13%	4%	9%	9%	5%	4%

The results for these metrics are summarized in Table 15. It's worth noting the substantial variations in the absolute research output of NIST and Cambridge compared to the other NMIs, which means even smaller percentage values translate to significant numbers of publications. For instance, NIST's 599 publications with industry partners far exceed NPL's 264. However, in relative terms, NPL ranks first for both international and industrial collaborations.

4.5.4 Altmetrics

Institutional-level searches were conducted using Grid IDs for the comparator organizations, and statistics for the coverage of altmetrics data were plotted as described in Section 3.4. The analysis focused on the percentages of publications with any online attention and the percentage of papers cited in news media, using data from the period 2019-2023. However, due to substantial delays observed between publication dates and citations in patents and government policy documents, publications spanning from 2000 to 2023 were examined for these variables. The findings are illustrated in Figure 28 and Figure 29.

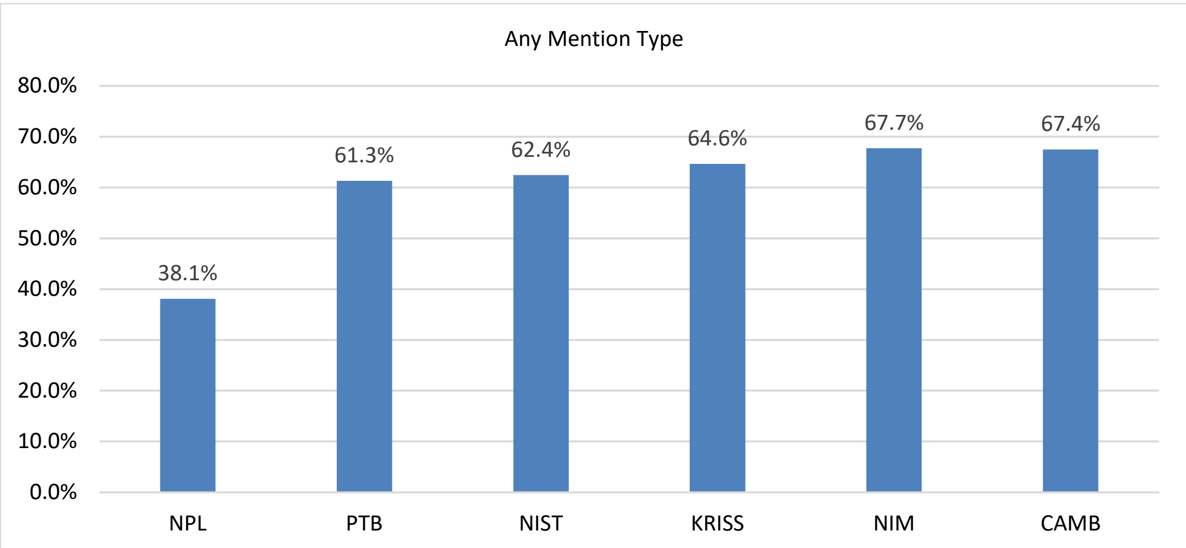

Figure 28 Proportion of Publications from 2019-2023 that have Any Recorded Online Attention.

While all institutions surpass NPL significantly in terms of the proportion of publications with a non-zero altmetric score, this metric alone may not offer substantial insights into the actual engagement or impact of research beyond academia. Institutions could achieve high scores simply by implementing basic communication strategies, such as tweeting links to departmental papers upon publication. Therefore, our analysis prioritizes three other metrics: the proportion of institutional papers featured in mainstream news sources, cited in governmental policy documentation, or referenced as prior art in patents (owned by any entity, not necessarily linked to the publishing institution). According to Figure 27, NIST leads in the percentage of papers discussed in news stories, with a rate of 12.3%, closely followed by Cambridge at 11.6%. PTB, KRISS, and NPL trail behind, with rates of 9.8%, 8.4%, and 6.3%, respectively.

Policy documentation citations account for a very small fraction of research output, usually less than 3% across institutions. While NPL appears to rank third in this category with 1.8%, closer examination reveals that approximately 20% of these mentions pertain to historical progress reports or annual reviews for the NMS hosted on the gov.uk website, rather than actual policy documents. Due to the limited number of publications involved in this category, it is probable that the performance across the six organizations is relatively comparable.

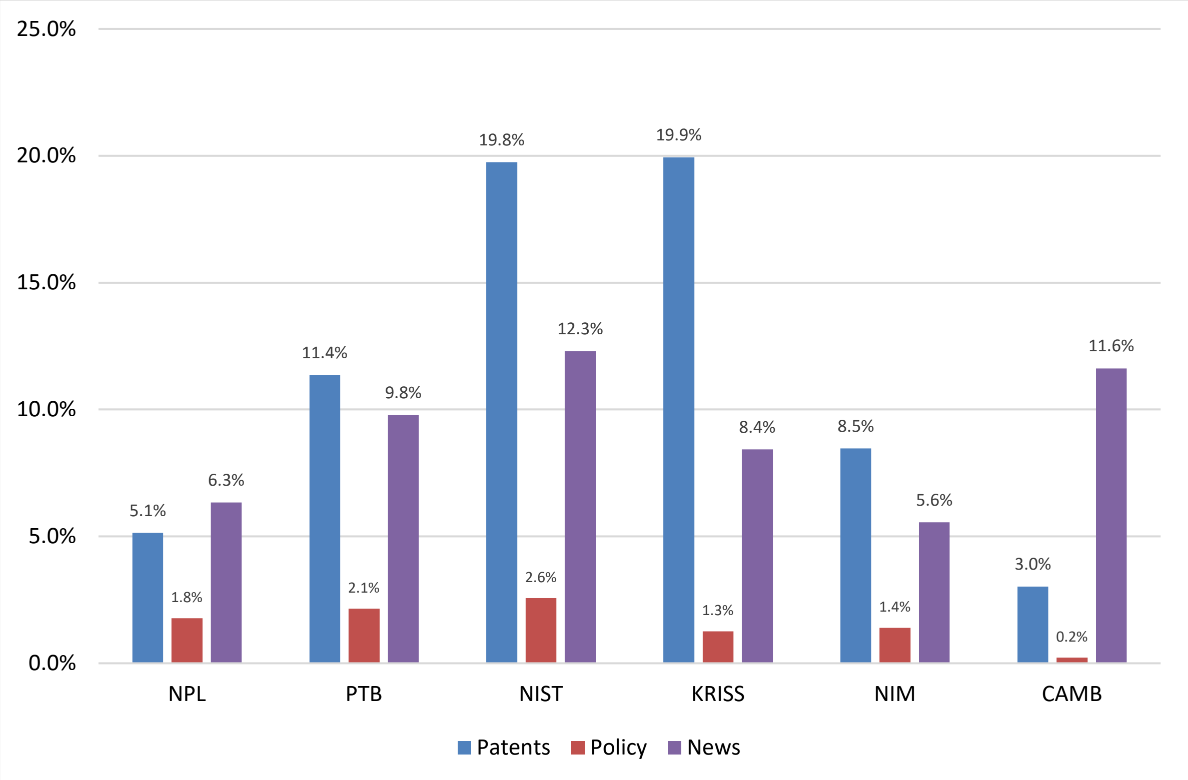

Figure 29 Proportion of Publications that are Mentioned in the News (2019-2023 publication years), in Policy Documentation (2000-2023 publication years) or Cited in Patents (2000-2023 Publication Years).

The last metric examines publication citations in patent applications, revealing KRISS and NIST as the most effective in translating their measurement-related science into innovation, with an average of nearly 20% of their publications cited as prior art. Following closely are PTB and NIM with rates of 11.4% and 8.5% respectively. NPL ranks fifth in this metric, recording a value of 5.1%.

5 CONCLUSION

This paper presents a thorough evaluation of NPL's publications, encompassing citation and altmetrics analyses. Comparative assessments are conducted against leading NMIs and the physical sciences output of Cambridge University. Our analysis reveals several noteworthy findings.

Research output at NPL has shown consistent growth over the years, with an average annual publication incremental growth of approximately 16 papers since 2000. In 2023 alone, NPL contributed a total of 396 papers to the scholarly literature. While overall growth remains steady, there are variations across different sectors within NPL. Notably, the Life Sciences & Health sector emerges as a rapidly expanding area of publication production, highlighting the institute's adaptability and responsiveness to evolving research trends. Publications aligned with the UN's Sustainable Development Goals (SDGs), particularly those related to "affordable and clean energy" and "climate action," have experienced significant growth at NPL since 2010. Moreover, collaborations with UK pharmaceutical companies are notably prevalent in this domain, showcasing NPL's engagement with industry partners in addressing critical global challenges.

NPL's research quality, assessed through normalized citation analysis, consistently shows strength, averaging 2.8 from 2000 to 2021[7]. This indicates notable performance compared to the global average citation score of 1.64. Comparable trends in FCRs were noted among other NMIs, with NIST leading in performance, while NPL and PTB demonstrate similar quality scores over time.

Institutional analysis of publication co-author metadata underscores NPL's steady improvement in collaboration measures since 2000. Notably, the proportion of publications authored solely by NPL has decreased, while collaborations with international and industrial partners have increased substantially. Altmetrics analysis through Altmetric.com reveals significant impact for NPL publications. Over 6% of NPL publications from 2019-2023 are discussed in mainstream news stories, highlighting their visibility and societal relevance. Additionally, roughly 2% of NPL publications from 2000-2023 are cited in governmental policy documentation, underscoring their influence on policymaking. Furthermore, over 5% of NPL publications from 2000-2023 are cited within patent applications, indicating their significance in driving innovation and technology transfer.

Overall, the analysis underscores NPL's significant contributions to research output, collaboration, and societal impact, positioning it as a vital player in the scientific community and innovation landscape.

Two main caveats warrant attention in this study. The first pertains to the allocation of GRID identifiers to entities. Dimensions, the publication database utilized in this study, assigns GRID IDs to entities listed in publications. However, entities lacking GRID IDs pose a challenge as their information cannot be captured automatically, necessitating manual intervention that consumes significant time. Consequently, industrial collaborations may be underrepresented, as some UK companies lack GRID IDs. Similarly, international collaborations may also be underrepresented due to the absence of GRID IDs for certain international entities. The second caveat concerns author affiliations. Instances may arise where a Ph.D. student or some guest scientists, formerly associated with the NPL, continues to list NPL as their affiliation even after departing from the institution. This scenario could artificially inflate the count of publications affiliated with NPL.

[7] Calculated only for the journal articles.

Potential areas for future research could encompass the development of a sophisticated panel data econometric model aimed at uncovering the underlying factors influencing publication quality. By employing panel data techniques, longitudinal data spanning multiple time periods and entities can be analysed, thus providing a robust framework for investigating the dynamic relationships between various determinants and publication quality metrics. The use of econometric modelling techniques offers the opportunity to incorporate quantitative measures of publication quality, such as citation counts or JIFs, alongside relevant covariates representing institutional, individual, and environmental characteristics.

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APPENDIX-1: NPL'S STRUCTURE

Departments	Groups	Advanced Manufacturing	Data & Digita	Enegry & Environment	Life Sciences & Health
Atemospheric Environmental Sciences	Air Quality and Aerosol Metrology			1	
Atemospheric Environmental Sciences	Emissions and Atmospheric Metrology			1	
Atemospheric Environmental Sciences	Gas Metrology			1	
Central Operations	Central Other Operations				
Chemical & Biological Sciences	Biometrology				1
Chemical & Biological Sciences	NiCE-MSI				1
Chemical & Biological Sciences	Surface Technology	1			1
Data Science	Data, Analytics and Modelling		1		
Data Science	Informatics		1		
Electromagnetic & Electrochemical Technologies	Electrochemistry	1		1	
Electromagnetic & Electrochemical Technologies	Electronic and Magnetic Materials	1			
Electromagnetic & Electrochemical Technologies	Electromagnetic Measurements		1		
Electromagnetic & Electrochemical Technologies	Electromagnetic Technologies		1	1	
Materials & Mechanical Metrology	Advanced Engineering Materials	1			
Materials & Mechanical Metrology	Dimensional Metrology	1			
Materials & Mechanical Metrology	Mass Metrology	1			
Materials & Mechanical Metrology	Manufacturing Metrology	1			
Medical, Marine & Nuclear	Medical Radiation Physics				1
Medical, Marine & Nuclear	Medical Radiation Science				1
Medical, Marine & Nuclear	Nuclear Metrology			1	1
Medical, Marine & Nuclear	Ultrasound and Underwater Acoustics			1	1
NPL Engineering	Chief Engineering Unit	1			
NPL Engineering	Engineering Design	1			
NPL Engineering	Engineering Manufacturing	1			
Quantum Technologies	Quantum Computing Curcuites		1		
Quantum Technologies	Quantum Electrical Metrology		1		
Quantum Technologies	Quantum Information Processing		1		
Quantum Technologies	Quantum Materials and Sensors		1		
Time & Frequency	Atomic Clocks and Sensors		1		
Time & Frequency	National Time Scale		1		
Time & Frequency	Optical Frequency Metrology		1		
Training	Training Delivery		1		
Thermal & Radiometric Metrology	Climate and Earth Observation			1	
Thermal & Radiometric Metrology	Optical Radiation Metrology			1	
Thermal & Radiometric Metrology	Temperature and Humidity	1			

APPENDIX-2 UN SDGS

1. No Poverty: End poverty in all its forms everywhere.
2. Zero Hunger: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
3. Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages.
4. Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5. Gender Equality: Achieve gender equality and empower all women and girls.
6. Clean Water and Sanitation: Ensure availability and sustainable management of water and sanitation for all.
7. Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable, and modern energy for all.
8. Decent Work and Economic Growth: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.
9. Industry, Innovation, and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
10. Reduced Inequality: Reduce inequality within and among countries.
11. Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient, and sustainable.

APPENDIX-3 ANZSRC CODES AS FOR

Code	Research Field
30	AGRICULTURAL, VETERINARY AND FOOD SCIENCES
31	BIOLOGICAL SCIENCES
32	BIOMEDICAL AND CLINICAL SCIENCES
33	BUILT ENVIRONMENT AND DESIGN
34	CHEMICAL SCIENCES
35	COMMERCE, MANAGEMENT, TOURISM AND SERVICES
36	CREATIVE ARTS AND WRITING
37	EARTH SCIENCES
38	ECONOMICS
39	EDUCATION
40	ENGINEERING
41	ENVIRONMENTAL SCIENCES
42	HEALTH SCIENCES
43	HISTORY, HERITAGE AND ARCHAEOLOGY
44	HUMAN SOCIETY
45	INDIGENOUS STUDIES
46	INFORMATION AND COMPUTING SCIENCES
47	LANGUAGE, COMMUNICATION AND CULTURE
48	LAW AND LEGAL STUDIES
49	MATHEMATICAL SCIENCES
50	PHILOSOPHY AND RELIGIOUS STUDIES
51	PHYSICAL SCIENCES
52	PSYCHOLOGY