Benchmarking Scottish Research in Life and Chemical Sciences Sectors

Scottish Enterprise

March 2017

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1 INTRODUCTION

1.1 Background

Scotland's life and chemical sciences industries are proving to be flourishing sectors that are globally ranked and that have strong economic values. In order to capitalize on the strength of these industries, Scottish Enterprise has determined the necessity to demonstrate the strength of the Scottish research aptitude.

Clarivate Analytics is charged to provide an evaluation of Scotland's competitive standings in the life and chemical sciences sectors through a comparison of research and intellectual property indicators of strengths with competing countries or regions. Moreover, this report aims to provide benchmarks for subject categories under the life sciences sector and the chemical sciences sector, with the goal to support Scottish Enterprise in determining the best courses of action to develop these sectors within Scotland.

1.2 About Scottish Enterprise

As Scotland's primary economic development agency, Scottish Enterprise promotes the nation's ability to excel in international markets. Scottish Enterprise's business plan to focus on internationalization, innovation, investment, and inclusive growth has already produced significant economic improvements. Scottish Enterprise partners with public and private sectors to recognize and develop opportunities to build Scotland's international competitiveness and to deliver a positive impact on the Scottish economy.

1.3 About Clarivate Analytics – Formerly the IP & Science Business of Thomson Reuters

Clarivate Analytics, formerly the IP & Science business of Thomson Reuters, provides reporting and consultancy services within Research Analytics using customized analyses to bring together several indicators of research performance in such a way as to enable customers to rapidly make sense of and interpret a wide-range of data points to facilitate research strategy decision-making. We have extensive experience with databases on research inputs, activity and outputs and have developed innovative analytical approaches for benchmarking, interpreting and visualization of international, national and institutional research impact.

For over half a century we have pioneered the world of citation indexing and analysis, helping to connect scientific and scholarly thought around the world. Today, academic and research institutions, governments, not-for-profits, funding agencies, and all others with a stake in research, need reliable, objective methods for managing and measuring performance.

Our consultants have up to 20 years of experience in research performance analysis and interpretation. In addition, the Clarivate regional Sales team will provide effective project management and on-site support to maximize values of our projects and meet the expectations of Scottish Enterprise.

1.4 Scope of this report

This report derives its findings from a set of indicators computed from research publications, patents and their citations. The report provides analyses on publications published and patents filed between 2010 and 2015.

2 METHODOLOGY AND DATA SOURCES

2.1 Definitions

Papers/publications: Clarivate Analytics abstracts publications including research journal articles, editorials, meeting abstracts and book reviews. The terms "paper" and "publication" are often used interchangeably to refer to printed and electronic outputs of many types. In the analyses presented here, the term "paper" is used exclusively to refer to substantive journal articles, reviews and some proceedings papers and excludes editorials, meeting abstracts or other types of publication. **Papers** are the subset of publications for which citation data are most informative and which are used in calculations of citation impact.

Research field: Standard bibliometric methodologies use Web of Science™ journal subject categories (JSCs) as a proxy for research fields.[1] There are 252 journal categories. Journals are assigned to one or more categories, and every article within that journal is subsequently assigned to that category. Papers from prestigious, "multidisciplinary" and general medical journals such as *Nature*, *Science*, *The Lancet*, *The BMJ*, *The New England Journal of Medicine and the Proceedings of the National Academy of Sciences* are assigned to specific categories based on the journal categories of the references cited in the article. The selection procedures for the journals included in the citation databases are documented at the Clarivate master journal list website.

Co-authorship of publications: The metadata associated with every research publication include the addresses of the authors. It is thus possible to develop an analysis of the organizations that co-author publications by extracting and examining these data. Co-authorship is generally accepted as an indicator of collaboration, although there are collaborations that do not result in co-authored publications and co-authored publications which involve limited collaboration. Conceivably other indicators of collaboration such as co-funding and international exchanges could be used but comprehensive and consistent data are not available.

Internationally collaborative publications: The number of internationally collaborative research publications is increasing rapidly. This is because such collaboration provides access to a wider range of resources, including intellectual resources, and accelerates the rate of discovery as well as increasing the intellectual content and therefore the impact of individual outputs. For this reason, internationally collaborative publications tend to be more highly cited than those that are solely domestic. In the analysis, publications will be considered to be international if more than one country is included in the addresses associated with a paper.

Comparator countries and aggregates: Scottish Enterprise has selected countries or country aggregates to compare with Scotland research volume. These countries or aggregates include Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Iran, Israel, Italy, Japan, New Zealand, Republic of Ireland, Russia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, the Netherlands, United Kingdom, USA, G8 and EU-28

EU-28: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, United Kingdom (UK), Austria, Finland, Sweden, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania, and Croatia.

G8: France, Germany, Italy, the UK, Japan, the United States (USA), Canada, and Russia

[1] Essential Science Indicators are defined by a unique grouping of journals with no journal being assigned to more than one field. These fields are focused on the science, technology, engineering and medicine subjects and arts & humanities subjects are excluded. Customized analyses, however, can be designed to include these as an additional category.

2.2 Descriptions of Data Sources

For the evaluation purposes of research activities in Scotland, research publications and citation data were sourced from the Clarivate Analytics Web of Science Core Collection platform. Web of Science Core Collection contains world-class databases covering research published in scholarly journals, books, proceedings, published data sets, and patents. This multidisciplinary platform covers topics within 254 subject categories, from which Scottish Enterprise had selected a subset that represent the sectors of life sciences and chemical sciences.

Web of Science: For the bibliometric analysis, data were sourced from the databases underlying the **Clarivate Analytics Web of Science**, which gives access to conference proceedings, patents, websites, and chemical structures, compounds and reactions in addition to journals. It has a unified structure that integrates all data and search terms together and therefore provides a level of comparability not found in other databases. It is widely acknowledged to be the world's leading source of citation and bibliometric data. The Web of Science Core Collection is part of the Web of Science, and focuses on research published in journals and conferences in science, medicine, arts, humanities and social sciences. The authoritative, multidisciplinary content covers over 27,000 of the highest impact journals worldwide, including Open Access journals and over 161,000 conference proceedings. Coverage is both current and retrospective in the sciences, social sciences, arts and humanities, in some cases dating back to 1900. Within the research community, these data are often still referred to by the acronym "ISI".[2] Clarivate has extensive experience with databases on research inputs, activity and outputs and has developed innovative analytical approaches for benchmarking and interpreting international, national and institutional research impact.

Derwent World Patents Index™; a database of patent applications and granted patents from 55 patent jurisdictions around the world. For the purpose of this evaluation, the analysis was constructed around the Derwent World Patents Index (DWPI) database structure. DWPI uses "patent families" as the definition for each record, rather than individual patent publications. Each invention-related patent application and granted patent is added to the DWPI family as it is published. This being the case, all counts of records in the study refer to patent families or inventions, and not to individual publications. For example, the European application, European granted patent and the USA granted patent for a single invention family is counted as "1" in all the analyses in this report unless stated otherwise. This provides a more accurate measure of the level of inventive activity from an entity within the technical space, and a truer picture of the overall level of innovation across the field as a whole. As each DWPI record contains potentially many individual publication events, this report uses the earliest known priority filing date for each patent family. The tables and charts included in the report use this date unless otherwise noted, as it provides the most accurate indication of the time of the inventive activity. Each record is therefore a unique article in the body of scientific literature. The date the journal containing the article was published is used throughout the report in all timelines and charts. The collection collation method is provided in Appendix B.1.

Scotland economic data: The following standard economic factors, including selected Research and Development (R&D) economic factors, were also used to compute relative research productivity and efficiency: Gross Domestic Product (GDP) in 2015 Q4 value[3,4], Gross Domestic Expenditure on R&D (GERD) excluding

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[2] The origins of citation analysis as a tool that could be applied to research performance can be traced to the mid-1950s, when Eugene Garfield proposed the concept of citation indexing and introduced the Science Citation Index, the Social Sciences Citation Index and the Arts & Humanities Citation Index, produced by the Institute of Scientific Information – ISI (now part of Clarivate Analytics).

[3] http://www.gov.scot/Topics/Statistics/Browse/Economy/QNA2015Q4, Supplementary Table, Table 9 Column M. In this publication, historical GDP figures are adjusted to 2015 Q4 value.

[4] For a more detailed description on GDP calculation, please refer to Scottish Government's website at http://www.gov.scot/Topics/Statistics/Browse/Economy/GDP/GDPcalc.

Private Non-Profit sector (PNP)[5], Business Enterprise Expenditure on R&D (BERD)[6], Government Expenditure on R&D (GovERD)[6], Higher Education Expenditure on R&D (HERD)[6], and R&D personnel and Researchers (full-time equivalent)[7]. These numbers were obtained from Scottish Government's official website. At the time of report, Scottish GDP, Business Enterprise Expenditure on R&D, and R&D Personnel data were available up to 2015. Gross Domestic Expenditure on R&D excluding Private Non-Profit sector, Government Expenditure on R&D and Higher Education Expenditure on R&D data were available up to 2014. When financial data were compared to other countries, exchange rates available at the Organization for Economic Co-operation and Development (OECD)'s data portal were used.

Comparator countries economic data: For each comparator country, GDP, GERD excluding PNP, BERD, GovERD, HERD, and R&D personnel and Researchers data publicly available on OECD's data portal at the time of analysis were used with the some exceptions[8].

2.3 Metrics

Citation count: The citation count is the number of times that a citation has been recorded for a given publication since it was published. Not all citations are necessarily recorded since not all publications are indexed. However, the material indexed by Clarivate is estimated to attract about 95% of global citations.

Citation impact: "Citations per paper" is an index of academic or research impact (as compared with economic or social impact). It is calculated by dividing the sum of citations by the total number of papers in any given dataset (so, for a single paper, raw impact is the same as its citation count). Citation count declines in the most recent years of any time-period as papers have had less time to accumulate citations (i.e., papers published in 2007 will typically have more citations than papers published in 2010).

Normalized citation impact (NCI): Citation rates vary between research fields and with time. Consequently, analyses must take both field and publication year into account. In addition, the type of publication will influence the citation count. For this reason, only citation counts of papers (as defined above) are used in calculations of citation impact. The standard normalization factor is the world average citations per paper for the year and journal category in which the paper was published. This normalization is also referred to as "rebasing" the citation count. since an article may be assigned to more than one journal categories, the average NCI across all journal categories to which an article is assigned is calculated and used as the paper-level NCI.

Clarivate Invention Strength Index: The Clarivate Analytics Invention Strength Index is applied to each patent family (**invention**) within the three patent collections. This is used to measure the various characteristics that act as proxies for the commercial behavior behind and the utility of an individual piece of intellectual property.

In addition to the manually assigned technical categories, the scoring mechanism provides a method of filtering the final datasets for individual patent families that may wish to be further reviewed. It can be very difficult to deal with a list of 20,000 patents (as an example) relevant to the space and know where to start – the Strength Index provides a ranking mechanism in which to prioritize more resource intensive processes or expertise.

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[5] http://www.gov.scot/Topics/Statistics/Browse/Business/RD/GERDTables Table 3A, and http://www.gov.scot/Topics/Statistics/Browse/Business/RD/BERDTables Table 1A

[6] http://www.gov.scot/Topics/Statistics/Browse/Business/RD/GERDtable1

[7] European Commission eurostat, *Total R&D personnel and researchers by sectors of performance, sex and NUTS 2 regions*, http://ec.europa.eu/eurostat/data/database

[8] Taiwan's GDP data were obtained from the government's website (https://eng.stat.gov.tw). For India, Iran and Singapore, GDP data were obtained from World Bank's World Development Indicator database. Brazil, India and Iran were excluded from GERD, BERD, GovERD, HERD, and R&D personnel and Researchers analysis as these data were not available at OECD's data portal. Moreover, the United States does not report total R&D Personnel so only Researchers data were used in the analysis.

At a high level, the metrics that make up the Strength Index cover the level of investment by the applicant, downstream 3rd party impact, commitment and success/patentability of the patent applications, the breadth of the technology covered by the invention and how the patent has been prosecuted and/or asserted.

Specifically, the Invention Strength Index measures:

- **Citation per patent**: Based on the Derwent Patent Citations Index, this measurement acts as proxy for the impact a particular invention or patent family is having within its technical field. This is also known as **Patent Citation Impact** since it follows the same idea as publication Citation Impact mentioned above. The metric uses frequency rather than the raw number of citation events to take account of age bias. On its own, citation is not necessarily an indicator of intrinsic value of the Intellectual Property (IP), but in combination with other measurements can identify potentially high value IP. Furthermore, where individual patent families or portfolios are highly cited by 3rd parties, but lacking in other metrics, it can point to IP strategy changes or opportunities to exploit the IP strategies of others.
- **Geographic Market Protection**: Measuring the number of different geographic locations or legal jurisdictions into which the patent has been filed. This is also known as geographic filing breadth. This measurement is strongly associated within increasing costs, and therefore a method of identifying patented subject matter that is more strategic (or conversely, more speculative) to the patent applicant.
- **Grant success/grant commitment and granted patent locations**: Measures and scores the patent family based on the location and number of granted patents that exist within the family, e.g. granted in the USA, at the European Patent Office, in Japan etc. Some locations are more important than others, particularly when assessing enforcement potential, licensing opportunity or market applicability, and this can be incorporated into the model.
- **Technical Coverage (also known as Technical Breadth)**: Measures the number of different technology areas in which a patent family or invention is relevant. This is based on the DWPI Classification, a manually applied classification, therefore broader and more insightful than other classification schemes. All other items being equal, a technically broad patent provides the owner with greater assertion opportunity, and therefore maps to more valuable IP.
- **Market Protection Time**: Based on the amount of remaining enforcement opportunity the patent has left. All other measurements being equal, a granted patent with only a few years of protection remaining before expiry is less valuable than one with many years of potential protection remaining. **Recency** is also used to refer to market protection time – the more recent a given patent is the longer the market protection time.
- **Novelty:** The Novelty of a portfolio is measured by calculating the proportion of granted patents versus application present in a portfolio.

These measurements are combined together statistically, typically self-referential to the dataset at hand, to provide an overall strength score per patent family. The family definition used is specific to the DWPI which provides for a synonymous relationship between each family and an individual “invention” – e.g. one specific set of claims language in each legal jurisdiction in which protection has been sought. This strength score is then aggregated across portfolios and technologies for benchmarking purposes.

2.4 Bibliometrics and citation analysis

Research evaluation is increasingly making wider use of bibliometric data and analyses. Bibliometrics is the analysis of data derived from publications and their citations. Publication of research outcomes is an integral part of the research process and is a universal activity. Consequently, bibliometric data have a currency across subjects, time and location that are found in few other sources of research-relevant data. The use of bibliometric analysis, allied to informed review by experts, increases the objectivity of, and confidence in, evaluation.

Research publications accumulate citation counts when they are referred to by more recent publications. Citations to prior work are a normal part of publication and reflect the value placed on a work by later researchers. Some papers get cited frequently and many remain uncited. Highly cited work is recognized as having a greater impact and Clarivate has shown that high citation rates are correlated with other qualitative evaluations of research performance, such as peer review. This relationship holds across most science and technology areas and, to a limited extent, in social sciences and even in some humanities subjects.

Indicators derived from publication and citation data should always be used with caution. Some fields publish at faster rates than others and citation rates also vary. Citation counts must be carefully normalized to account for such variations by field. Because citation counts naturally grow over time, it is essential to account for growth by year. Normalization is usually done by reference to the relevant global average for the field and for the year of publication.

Bibliometric indicators have been found to be more informative for core natural sciences, especially for basic science, than they are for applied and professional areas and for social sciences. In professional areas the range of publication modes used by leading researchers is likely to be diverse as they target a diverse, non-academic audience. In social sciences there is also a diversity of publication modes and citation rates are typically much lower than in natural sciences.

Bibliometrics work best with large data samples. As the data are disaggregated, so the relationship weakens. Average indicator values (e.g., of citation impact) for small numbers of publications can be skewed by single outlier values. At a finer scale, when analyzing the specific outcome for individual departments, the statistical relationship is rarely a sufficient guide by itself. For this reason, bibliometrics are best used in support of, but not as a substitute for, expert decision processes. Well-founded analyses can enable conclusions to be reached more rapidly and with greater certainty, and are therefore an aid to management and to increased confidence among stakeholders, but they cannot substitute for review by well-informed and experienced peers.

2.5 Data collection and disambiguation

Research publication organization unification and classification: Correctly associating research outputs with institutions is an essential component of the analysis process, given that authors represent their institutional affiliations in a variety of ways. The identification of institutions is performed using the author addresses from the Web of Science Core Collection.

Clarivate has, through its Global Institutional Profiles Project, unified data for over 6,000 institutions worldwide – accounting for the majority of academic research produced. In order to produce these unifications, multiple variants for each institution are considered, weighing input from a network of external advisors employed to correctly assign affiliations. As part of this process, Clarivate staff may contact institutions to seek verification of specific unification issues and document changes in organizations and how organizations relate to one another (parent-child relationships). Names and entities are updated to reflect organizational changes, and this unification is applied to addresses in new articles published in the Web of Science. This method relies on the accuracy of this information as provided by the authors; reported institutions may have variant names that are not unified.

Wherever possible, Clarivate used existing institution name unifications (of author-provided address variants) available on the InCites™ platform[9] for the Web of Science Core Collection. In addition, corporate entities are identified as such. Please refer to the InCites Indicators Handbook under the institution section (http://researchanalytics.thomsonreuters.com/m/pdfs/indicators-handbook.pdf).

[9] InCites is a customized, citation-based research evaluation tool enabling analysis of productivity and benchmarking of output against peers worldwide, drawing on data from Web of Science. For more information, please visit http://researchanalytics.thomsonreuters.com/incites/ .

Patent applicant unification: As part of the study, the company names are cleaned and standardized. Assignee names appearing on patent documents are also inconsistent in their formats. Therefore, to the extent possible, formatting anomalies were standardized during the assignee clean-up process, which benefits from the name standardization provided by the DWPI as well as employing additional automated and manual review. Assignee name reformatting reduces the heterogeneity in assignee names to a more manageable and more informative level. Assignee names attached to patent documents reflect the ownership at time of document publication. Changes in ownership (reassignments) that occur after publication may or may not be reflected in the USA reassignment field or in the International Patent Documentation (INPADOC) legal status field. To the extent the information is available in these two fields; the assignee name is updated to reflect the reassignments. It is also expected that in USA applications, many assignees are “unknown” because assignees may not have been registered with the United States Patent and Trademark Office (USPTO) before publication. Usually the absent assignee can be inferred by checking ownership of other patent family members or by observing assignments in other records by the same inventor. All of these methods are used to improve the quality of the assignee data to be used for analysis. Lastly, company name changes, acquisitions and mergers, and hidden relationships are expected to affect true ownership of patent documents that may not be reflected in the collection data per se. For selected higher volume or critical assignees, we relied (if applicable) on information from the Derwent Patent Assignee Code (PACO) system, and also obtained information on acquisitions and other company transactions from outside sources, such as Hoovers Online Business Information and selected company websites. By using these three methods, Clarivate has provided a much more realistic picture of assignee holdings than is obtainable elsewhere, making it possible to gain more insight into the assignee emphasis and filing behavior.

3 BENCHMARKING SCOTTISH RESEARCH IN LIFE SCIENCES

3.1 Life Sciences Research Output and Impact

We analyzed the volume of publications in life sciences and citation indicators in Scotland and selected countries or aggregates. For the benchmarking study, countries of interest, as identified by the Scottish Enterprise, were considered for analysis. Life sciences were defined as a set of research fields based on JSC's (see Table 3.2.1). The results, ranked by total number of research publications are listed in Table 3.1.1. Globally, over 5.5 million publications were produced over the period of 2010 to 2015. During this time Scotland produced 60,537 publications in life sciences. The strongest producer of life science research based on publication volume was the USA at almost two million publications. This is approximately 2.5 times that of the second-placed China. The G8 (USA, UK, Canada, Germany, Italy, Japan, France and Russia) and China together accounted for 67% of all life sciences publications during this period.

Scotland's contribution to the UK publications was about 14% based on publication volume. Among the European countries in the comparator list, Scotland was more active than Finland and the Republic of Ireland.

While Scotland's output volume was relatively small, Scotland had in general, significant impact in life sciences fields. Scotland ranked highly in terms of the Citation Impact (total citations per publication) (Scotland Citation Impact = 16.14), second only to Switzerland (16.93) on this list. By comparison, the Citation Impact of UK is 14.55, and the USA is 13.65. This speaks to the impact of the Scottish research in general. The NCI takes both field and publication year into account. Again, Scotland ranks highly at third (1.62). The top two countries are Switzerland (1.7) and Denmark (1.64).

The volume of patents for these countries was defined by the number of patents claiming priority in each one. Total citations and average citations to patents originating from the countries of interest are presented to provide a comparative picture.

The analysis shows a very broad distribution of patents between the included countries, with regions such as China, the G8, and the USA ranking highest in terms of patent volume and accounting for a large proportion of the landscape. In terms of patent volume, Scotland ranks quite low in the table at place 27 with a total of 617 patents. Total citations and average citations were calculated from the family citing patents. Based on the citations per patent, Scotland is in third place behind the USA and Denmark who have the highest citations per patent.

Scotland's contribution to the UK patent portfolio is about 5% based on patent volume. Among the European countries, Scotland is more active than Belgium and the Republic of Ireland based on patent volume.

Scottish patents receive relatively more total citations compared to countries such as Switzerland, Israel, Brazil, New Zealand, Singapore, Belgium, the Republic of Ireland, South Africa and Iran, indicating a strong portfolio of inventions. Iran has negligible patent activity in the life sciences domain.

Table 3.1.1 Life sciences research output, patents and impact

Country / Aggregate	Number of Publications	Total Citations	Citation Impact	NCI	Number of Patents	Citations Per Patent
Scotland	60,537	976,953	16.14	1.62	617	2.26
G8	3,209,934	37,393,557	11.65	1.19	504,023	2.40
EU-28	1,981,174	21,645,818	10.93	1.16	86,407	1.23
USA	1,665,924	22,732,602	13.65	1.35	248,888	3.91
China	654,927	5,303,750	8.1	0.95	842,136	0.77
United Kingdom	436,168	6,347,616	14.55	1.47	12,311	1.98
Germany	398,195	5,302,771	13.32	1.36	30,991	1.27
Japan	310,414	2,868,406	9.24	0.93	135,551	0.98
Canada	268,121	3,524,263	13.14	1.36	1,604	0.89
France	258,827	3,455,755	13.35	1.35	13,371	1.28
Italy	255,450	3,075,535	12.04	1.28	6,806	0.78
Australia	224,889	2,803,963	12.47	1.39	4,141	1.24
Spain	205,723	2,398,459	11.66	1.25	5,457	0.47
Brazil	181,511	1,107,380	6.1	0.74	7,624	0.11
India	176,712	1,144,741	6.48	0.72	13,155	0.77
South Korea	175,566	1,507,124	8.58	0.92	97,786	0.62
The Netherlands	166,878	2,656,573	15.92	1.62	1,981	1.08

Country / Aggregate	Number of Publications	Total Citations	Citation Impact	NCI	Number of Patents	Citations Per Patent
Switzerland	114,047	1,930,330	16.93	1.7	1,078	1.23
Sweden	103,511	1,511,267	14.6	1.52	1,973	2.20
Taiwan	86,528	736,563	8.51	0.92	20,445	0.28
Belgium	84,775	1,263,953	14.91	1.54	587	1.01
Iran	72,699	378,583	5.21	0.68	2	0.50
Russia	71,734	432,652	6.03	0.75	54,035	0.26
Denmark	69,842	1,078,456	15.44	1.64	1,482	2.36
Israel	51,708	683,611	13.22	1.32	685	1.25
Finland	46,895	663,231	14.14	1.49	1,083	1.52
South Africa	42,111	408,665	9.7	1.16	655	0.77
New Zealand	39,829	470,955	11.82	1.37	1,079	0.72
Singapore	37,639	586,429	15.58	1.55	635	1.03
Republic of Ireland	32,100	453,664	14.13	1.44	333	1.76

3.2 Life Sciences Research Strengths and Weaknesses by Sub-Category

3.2.1 Research publication strengths and weaknesses

The following tables display the research field included in the life sciences analysis and their respective trends over the 2010 to 2015 period.

The first table shows the relative portion of UK life sciences publications that were Scottish in each year. Since there was a different publication volume in each year, a weighted average was calculated to take this fact into account for each field. As the weighted average is a better overall estimate than a simple unweighted (arithmetic) average, we used the metric to assess our rankings. Unless otherwise stated, the research fields are ranked by the weighted average column.

3.2.1.1 Publication volume: comparing with UK, EU-28

It is observed that in agricultural fields such as Fisheries, Dairy & Animal Sciences Agriculture, Forestry, Soil Science, and Marine & Freshwater Biology, Scotland was a significant contributor to UK research output in terms of publication volume. The proportion of UK publications in these fields that was Scottish ranged from 28% to 42%. On the opposite end in the fields of Horticulture, Psychoanalysis, Agricultural Engineering and Food Science & Technology, Scotland was a relatively small contributor to UK publication volume, accounting for less than 1.3%.

In EU-28 publications in the fields of Fisheries, Ornithology and Primary Health Care, approximately 8% were contributed by Scotland. Scotland was a relatively small contributor to EU-28 research output in Food Science & Technology, Agricultural Engineering, Psychoanalysis, and Horticulture at around 1% in each of these fields. This is similar to the comparison with the UK described above.

Table 3.2.1 Life sciences proportion of Scottish publications out of UK publications

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Fisheries	43.35%	45.02%	41.82%	38.21%	40.28%	44.18%	42.31%	42.14%
Agriculture, Dairy & Animal Science	36.53%	34.11%	37.93%	33.94%	33.09%	32.96%	34.90%	34.76%
Forestry	33.99%	36.36%	33.86%	27.50%	28.73%	31.72%	31.89%	32.03%
Soil Science	28.27%	28.94%	25.24%	30.15%	29.09%	30.81%	28.81%	28.75%
Marine & Freshwater Biology	27.34%	28.99%	29.81%	26.99%	27.94%	26.70%	27.97%	27.96%
Ornithology	27.78%	31.30%	27.82%	21.13%	29.46%	25.64%	27.07%	27.19%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Veterinary Sciences	26.19%	27.18%	23.99%	25.47%	24.57%	23.67%	25.13%	25.18%
Mycology	26.45%	27.59%	32.32%	32.58%	20.66%	13.71%	24.93%	25.55%
Crystallography	30.48%	27.29%	21.85%	22.79%	21.58%	17.79%	24.13%	23.63%
Ecology	23.66%	21.18%	21.50%	21.42%	24.52%	22.65%	22.50%	22.49%
Parasitology	22.00%	23.14%	23.58%	20.39%	22.58%	20.48%	21.99%	22.03%
Agronomy	17.65%	23.23%	20.32%	20.77%	23.21%	24.81%	21.61%	21.67%
Oceanography	19.56%	23.36%	21.52%	21.25%	19.91%	22.21%	21.35%	21.30%
Evolutionary Biology	22.26%	21.26%	21.13%	20.25%	19.55%	20.99%	20.84%	20.91%
Agriculture, Multidisciplinary	30.30%	24.00%	15.31%	12.32%	21.83%	16.02%	20.27%	19.96%
Plant Sciences	19.47%	20.54%	18.67%	20.20%	22.99%	17.11%	19.85%	19.83%
Virology	19.19%	20.28%	17.08%	19.31%	20.84%	20.20%	19.53%	19.49%
Biodiversity Conservation	16.84%	19.93%	19.42%	17.80%	22.29%	18.41%	19.23%	19.11%
Andrology	22.22%	16.67%	31.82%	14.58%	10.00%	18.18%	18.80%	18.91%
Biology	17.64%	17.29%	18.58%	20.61%	16.91%	16.91%	17.93%	17.99%
Reproductive Biology	17.12%	17.91%	16.03%	17.78%	16.28%	17.79%	17.18%	17.15%
Zoology	21.31%	20.80%	19.65%	20.85%	20.39%	20.99%	17.17%	20.66%
Genetics & Heredity	16.94%	17.95%	17.48%	15.93%	16.65%	15.94%	16.80%	16.82%
Primary Health Care	20.51%	18.77%	17.14%	15.24%	16.42%	14.16%	16.58%	17.04%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Geosciences, Multidisciplinary	16.02%	15.00%	16.89%	15.64%	16.53%	17.67%	16.36%	16.29%
Physics, Multidisciplinary	14.24%	16.40%	15.99%	15.83%	18.59%	15.98%	16.22%	16.17%
Endocrinology & Metabolism	15.46%	18.45%	15.09%	16.61%	14.57%	16.85%	16.17%	16.17%
Psychology, Biological	21.35%	13.08%	16.73%	14.23%	15.22%	16.27%	16.03%	16.15%
Cell Biology	16.52%	15.87%	16.50%	15.79%	15.89%	15.47%	15.99%	16.01%
Microbiology	14.88%	17.15%	14.46%	16.31%	17.36%	15.35%	15.92%	15.92%
Anatomy & Morphology	17.57%	14.55%	11.93%	19.33%	10.67%	21.77%	15.92%	15.97%
Environmental Sciences	16.88%	16.82%	15.11%	14.42%	16.10%	15.39%	15.75%	15.79%
Biochemistry & Molecular Biology	16.66%	15.27%	16.22%	15.22%	15.42%	15.02%	15.65%	15.64%
Peripheral Vascular Disease	16.10%	12.98%	14.73%	14.78%	17.15%	17.56%	15.58%	15.55%
Developmental Biology	14.96%	17.04%	14.00%	15.29%	15.96%	13.56%	15.27%	15.13%
Horticulture	10.08%	15.56%	16.19%	12.84%	21.78%	14.29%	14.96%	15.12%
Water Resources	16.22%	13.58%	13.82%	15.43%	13.33%	17.30%	14.94%	14.95%
Multidisciplinary Sciences	16.31%	16.37%	17.01%	14.36%	14.16%	10.65%	14.34%	14.81%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Geriatrics & Gerontology	11.38%	15.19%	16.42%	14.23%	14.12%	14.21%	14.33%	14.26%
Environmental Studies	12.49%	13.40%	14.65%	14.02%	16.37%	14.38%	14.33%	14.22%
Biochemical Research Methods	14.70%	14.25%	16.19%	14.01%	13.45%	13.16%	14.33%	14.29%
Limnology	16.67%	10.07%	18.32%	13.84%	13.70%	12.61%	14.09%	14.20%
Biotechnology & Applied Microbiology	13.60%	11.73%	14.46%	14.37%	14.67%	15.53%	14.06%	14.06%
Pathology	14.22%	14.59%	13.80%	14.26%	13.66%	13.38%	13.99%	13.98%
Substance Abuse	14.98%	11.31%	18.53%	11.65%	13.66%	13.25%	13.70%	13.90%
Toxicology	14.56%	12.45%	13.99%	13.63%	14.76%	11.99%	13.61%	13.56%
Chemistry, Medicinal	16.82%	15.17%	11.42%	13.72%	12.72%	10.73%	13.48%	13.43%
Agricultural Engineering	11.90%	8.57%	9.62%	7.48%	23.23%	20.62%	13.42%	13.57%
Psychology, Experimental	15.63%	12.32%	13.92%	12.79%	13.90%	11.46%	13.32%	13.34%
Nursing	12.98%	14.13%	11.76%	13.46%	14.51%	12.39%	13.21%	13.21%
Medicine, General & Internal	11.82%	14.46%	14.93%	13.70%	12.53%	11.89%	13.20%	13.22%
Rehabilitation	13.70%	14.91%	12.87%	14.01%	12.31%	11.43%	13.20%	13.21%
Emergency Medicine	16.10%	12.67%	9.15%	11.48%	13.48%	14.87%	13.08%	12.96%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Mathematical & Computational Biology	12.51%	14.93%	13.47%	14.24%	11.74%	11.73%	13.04%	13.10%
Engineering, Environmental	13.14%	13.40%	10.89%	11.67%	12.92%	15.11%	12.93%	12.86%
Health Care Sciences & Services	14.33%	14.06%	12.96%	11.06%	12.88%	12.06%	12.78%	12.89%
Dermatology	9.60%	13.74%	13.96%	11.13%	10.36%	16.94%	12.60%	12.62%
Allergy	11.68%	13.09%	16.29%	11.01%	13.88%	9.54%	12.57%	12.58%
Oncology	12.56%	12.73%	12.66%	12.60%	13.11%	11.38%	12.49%	12.51%
Cardiac & Cardiovascular Systems	13.54%	11.71%	11.08%	12.02%	12.83%	13.06%	12.39%	12.37%
Physiology	13.48%	12.55%	14.78%	10.82%	12.26%	10.46%	12.35%	12.39%
Gerontology	15.42%	9.54%	15.25%	12.37%	12.31%	10.16%	12.34%	12.51%
Public, Environmental & Occupational Health	11.93%	12.02%	12.84%	12.24%	11.92%	12.88%	12.33%	12.31%
Nutrition & Dietetics	12.86%	12.94%	11.93%	11.79%	12.00%	12.24%	12.27%	12.29%
Medical Laboratory Technology	10.92%	15.20%	11.59%	13.25%	10.49%	11.32%	12.18%	12.13%
Psychology, Multidisciplinary	13.72%	16.35%	13.05%	11.07%	10.92%	9.55%	12.11%	12.44%
Anesthesiology	13.77%	13.90%	12.32%	11.72%	11.80%	9.82%	12.07%	12.22%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Immunology	11.23%	12.80%	12.70%	12.17%	12.59%	10.39%	11.97%	11.98%
Microscopy	8.53%	10.95%	14.93%	13.56%	10.00%	16.42%	11.97%	12.40%
Nanoscience & Nanotechnology	12.20%	12.09%	13.63%	11.15%	10.85%	11.75%	11.92%	11.94%
Biophysics	13.14%	11.83%	13.10%	11.47%	11.45%	10.47%	11.91%	11.91%
Obstetrics & Gynecology	11.89%	11.90%	10.88%	11.66%	13.76%	11.27%	11.89%	11.89%
Ophthalmology	13.25%	11.46%	11.37%	11.40%	12.17%	11.17%	11.79%	11.80%
Critical Care Medicine	11.17%	11.80%	10.34%	12.69%	12.61%	11.60%	11.74%	11.70%
Social Sciences, Biomedical	14.75%	7.43%	12.06%	10.58%	12.87%	12.04%	11.61%	11.62%
Orthopedics	11.20%	11.49%	12.51%	11.86%	11.34%	10.97%	11.58%	11.56%
Ergonomics	14.08%	13.26%	7.36%	11.93%	8.75%	11.63%	11.40%	11.17%
Psychology	13.97%	11.11%	10.98%	11.41%	10.61%	10.59%	11.36%	11.45%
Gastroenterology & Hepatology	11.48%	10.90%	12.44%	11.26%	11.50%	10.44%	11.34%	11.34%
Food Science & Technology	12.25%	11.46%	10.89%	11.02%	12.07%	10.33%	11.33%	11.34%
Clinical Neurology	11.57%	11.08%	11.14%	11.81%	11.36%	10.63%	11.26%	11.26%
Infectious Diseases	9.31%	12.29%	12.15%	10.54%	12.15%	10.75%	11.22%	11.20%
Robotics	13.69%	9.93%	7.79%	6.86%	11.40%	13.11%	11.19%	10.46%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Cell & Tissue Engineering	11.38%	6.99%	13.55%	10.07%	10.81%	12.81%	11.16%	10.94%
Imaging Science & Photographic Technology	7.82%	13.29%	13.33%	10.03%	9.22%	13.21%	11.15%	11.15%
Respiratory System	11.10%	9.80%	10.76%	11.96%	11.66%	11.25%	11.12%	11.09%
Neurosciences	11.10%	11.92%	11.56%	10.68%	10.53%	10.72%	11.07%	11.09%
Medicine, Research & Experimental	12.68%	10.49%	11.15%	10.57%	10.47%	11.12%	11.05%	11.08%
Urology & Nephrology	9.31%	10.63%	11.49%	11.55%	11.14%	12.06%	11.05%	11.03%
Computer Science, Cybernetics	10.67%	14.80%	13.04%	9.57%	11.52%	7.72%	11.00%	11.22%
Otorhinolaryngology	11.90%	9.05%	14.36%	9.22%	10.34%	10.50%	10.86%	10.89%
Paleontology	8.42%	9.38%	10.83%	11.72%	11.49%	12.47%	10.78%	10.72%
Anthropology	9.36%	12.50%	10.05%	11.97%	10.71%	9.25%	10.64%	10.64%
Surgery	9.51%	9.93%	10.71%	11.74%	10.72%	11.14%	10.62%	10.63%
Pharmacology & Pharmacy	10.93%	11.12%	10.56%	11.16%	10.04%	9.21%	10.50%	10.50%
Transplantation	11.14%	8.79%	11.90%	8.57%	10.31%	11.66%	10.45%	10.40%
Psychology, Developmental	14.87%	7.67%	10.33%	8.65%	12.19%	9.67%	10.41%	10.56%
Entomology	7.95%	8.31%	13.27%	11.18%	9.18%	9.35%	9.88%	9.87%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Pediatrics	12.19%	10.23%	7.85%	9.51%	10.23%	9.25%	9.87%	9.88%
Dentistry, Oral Surgery & Medicine	9.18%	11.01%	8.77%	9.96%	8.88%	11.32%	9.86%	9.85%
Sport Sciences	10.20%	8.98%	10.61%	9.85%	9.66%	9.49%	9.79%	9.80%
Engineering, Biomedical	9.23%	11.39%	10.22%	8.46%	9.80%	9.69%	9.77%	9.80%
Medical Informatics	10.18%	10.73%	12.77%	9.23%	7.08%	8.05%	9.59%	9.67%
Hematology	10.87%	11.30%	10.74%	9.24%	8.33%	6.60%	9.48%	9.51%
Tropical Medicine	8.17%	8.77%	9.67%	7.16%	12.37%	10.10%	9.46%	9.37%
Rheumatology	8.48%	9.43%	10.91%	12.37%	10.93%	4.93%	9.45%	9.51%
Psychiatry	9.04%	9.23%	8.91%	8.71%	8.49%	8.83%	8.85%	8.87%
Integrative & Complementary Medicine	3.70%	10.43%	4.96%	11.02%	11.50%	8.66%	8.52%	8.38%
Psychology, Mathematical	10.29%	17.02%	14.29%	2.38%	3.33%	3.64%	8.41%	8.49%
Materials Science, Biomaterials	7.79%	9.31%	7.45%	9.48%	8.35%	7.19%	8.28%	8.26%
Psychology, Clinical	8.47%	8.63%	8.27%	7.60%	7.56%	7.44%	7.97%	7.99%
Radiology, Nuclear Medicine & Medical Imaging	6.22%	7.83%	8.75%	7.11%	8.08%	8.75%	7.84%	7.79%
Psychology, Applied	7.16%	6.38%	6.77%	8.66%	9.12%	6.94%	7.53%	7.51%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Neuroimaging	4.87%	6.77%	8.33%	5.90%	7.80%	6.67%	6.81%	6.72%
Psychology, Psychoanalysis	3.64%	0.00%	4.88%	13.11%	0.00%	3.45%	3.84%	4.18%

Table 3.2.2 Life sciences proportion of Scottish publications out of EU-28 publications

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Fisheries	8.53%	9.82%	8.94%	7.55%	6.71%	8.02%	8.29%	8.26%
Ornithology	8.40%	7.61%	7.58%	5.85%	8.32%	7.97%	7.60%	7.62%
Primary Health Care	9.82%	9.04%	6.57%	7.54%	7.48%	6.37%	7.54%	7.80%
Parasitology	7.70%	8.12%	7.86%	6.21%	6.96%	6.96%	7.25%	7.30%
Evolutionary Biology	7.04%	6.99%	6.70%	6.90%	6.71%	7.00%	6.89%	6.89%
Ecology	6.18%	6.03%	6.05%	6.10%	7.15%	6.95%	6.43%	6.41%
Biodiversity Conservation	5.32%	6.81%	5.80%	5.81%	7.53%	6.15%	6.27%	6.24%
Social Sciences, Biomedical	7.82%	4.19%	6.48%	5.78%	6.59%	6.32%	6.21%	6.20%
Veterinary Sciences	5.94%	5.93%	5.50%	6.05%	5.74%	6.01%	5.86%	5.86%
Marine & Freshwater Biology	5.63%	5.62%	5.64%	4.94%	5.18%	5.22%	5.37%	5.37%
Nursing	5.34%	6.16%	5.07%	5.09%	5.60%	4.66%	5.30%	5.32%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Biology	4.80%	5.22%	5.33%	6.12%	5.17%	5.13%	5.29%	5.29%
Oceanography	4.63%	5.77%	5.18%	5.49%	4.81%	5.41%	5.23%	5.22%
Health Care Sciences & Services	5.88%	5.75%	4.92%	4.16%	5.04%	5.43%	5.14%	5.20%
Psychology, Biological	5.98%	3.87%	5.79%	4.76%	4.92%	5.39%	5.11%	5.12%
Medicine, General & Internal	4.18%	5.45%	5.66%	5.56%	5.22%	4.55%	5.09%	5.10%
Virology	4.94%	5.40%	4.06%	4.92%	5.46%	5.13%	4.99%	4.99%
Substance Abuse	5.25%	4.27%	6.34%	3.98%	4.60%	5.32%	4.91%	4.96%
Genetics & Heredity	4.89%	5.14%	4.91%	4.53%	4.69%	4.55%	4.78%	4.79%
Psychology, Experimental	5.90%	4.43%	4.91%	4.54%	4.74%	3.85%	4.70%	4.73%
Environmental Studies	4.08%	4.39%	5.21%	4.87%	4.93%	4.46%	4.68%	4.66%
Zoology	5.06%	4.96%	4.78%	4.16%	4.38%	4.37%	4.61%	4.62%
Multidisciplinary Sciences	6.24%	5.50%	5.02%	4.24%	4.22%	3.31%	4.47%	4.76%
Crystallography	5.81%	4.76%	3.81%	4.10%	4.05%	3.37%	4.41%	4.32%
Tropical Medicine	3.83%	3.86%	4.25%	3.21%	5.55%	5.09%	4.35%	4.30%
Developmental Biology	4.35%	5.04%	3.81%	4.18%	4.19%	3.07%	4.13%	4.10%
Public, Environmental & Occupational Health	3.93%	3.90%	4.29%	4.00%	3.72%	4.37%	4.04%	4.03%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Agriculture, Dairy & Animal Science	4.56%	4.01%	4.59%	3.63%	3.53%	3.44%	3.97%	3.96%
Gerontology	5.02%	3.02%	4.48%	3.94%	4.24%	3.28%	3.96%	4.00%
Soil Science	3.84%	4.70%	3.30%	4.15%	3.27%	3.70%	3.83%	3.83%
Rehabilitation	4.05%	4.35%	3.66%	4.25%	3.21%	3.18%	3.76%	3.78%
Cell Biology	3.92%	3.72%	3.80%	3.72%	3.66%	3.61%	3.73%	3.74%
Psychology	4.59%	3.94%	3.48%	3.80%	3.06%	3.41%	3.66%	3.71%
Anthropology	2.85%	3.93%	3.38%	4.00%	4.15%	3.64%	3.66%	3.66%
Psychology, Developmental	4.83%	3.04%	3.74%	3.04%	4.19%	3.17%	3.65%	3.67%
Geriatrics & Gerontology	2.81%	3.84%	3.82%	3.46%	3.67%	3.66%	3.57%	3.54%
Mathematical & Computational Biology	3.60%	3.94%	3.62%	3.87%	3.14%	3.24%	3.56%	3.57%
Reproductive Biology	3.44%	3.76%	3.14%	4.07%	3.31%	3.24%	3.50%	3.49%
Geosciences, Multidisciplinary	3.78%	3.25%	3.52%	3.28%	3.38%	3.66%	3.48%	3.48%
Endocrinology & Metabolism	3.28%	3.85%	3.14%	3.73%	3.14%	3.63%	3.47%	3.46%
Biochemistry & Molecular Biology	3.83%	3.44%	3.43%	3.25%	3.34%	3.24%	3.42%	3.42%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Emergency Medicine	4.15%	3.41%	2.39%	2.73%	3.06%	4.64%	3.42%	3.40%
Ophthalmology	3.98%	3.42%	3.32%	3.40%	3.12%	3.26%	3.41%	3.42%
Infectious Diseases	2.73%	3.69%	3.50%	3.08%	3.54%	3.48%	3.35%	3.34%
Peripheral Vascular Disease	3.21%	2.61%	2.91%	3.28%	3.57%	4.04%	3.26%	3.27%
Psychology, Multidisciplinary	3.85%	4.63%	3.53%	3.00%	2.61%	2.52%	3.21%	3.36%
Mycology	3.52%	3.36%	3.82%	3.60%	2.70%	1.97%	3.15%	3.16%
Microbiology	2.95%	3.45%	2.79%	3.10%	3.30%	3.05%	3.11%	3.11%
Plant Sciences	3.06%	3.26%	2.78%	3.08%	3.48%	2.60%	3.04%	3.04%
Respiratory System	2.80%	2.53%	2.91%	3.11%	3.37%	3.15%	2.98%	2.98%
Pathology	2.95%	3.00%	3.16%	2.92%	2.89%	2.86%	2.97%	2.96%
Obstetrics & Gynecology	2.97%	2.90%	2.60%	3.14%	3.39%	2.70%	2.95%	2.95%
Ergonomics	4.17%	3.01%	1.74%	3.43%	2.02%	2.73%	2.89%	2.85%
Psychology, Clinical	3.07%	3.28%	2.93%	2.62%	2.76%	2.72%	2.89%	2.90%
Orthopedics	2.66%	2.82%	3.18%	3.06%	2.89%	2.55%	2.86%	2.86%
Physics, Multidisciplinary	2.37%	2.78%	2.93%	2.69%	3.29%	2.98%	2.85%	2.84%
Limnology	2.88%	2.24%	3.63%	3.04%	2.92%	2.27%	2.84%	2.83%
Paleontology	2.22%	2.45%	2.82%	3.03%	3.01%	3.34%	2.83%	2.81%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Biochemical Research Methods	3.00%	2.99%	3.18%	2.66%	2.50%	2.48%	2.81%	2.80%
Sport Sciences	2.85%	2.43%	3.19%	2.89%	2.83%	2.66%	2.80%	2.81%
Psychiatry	2.70%	2.95%	2.73%	2.78%	2.66%	2.82%	2.77%	2.77%
Nutrition & Dietetics	2.90%	2.96%	2.74%	2.62%	2.63%	2.81%	2.77%	2.78%
Cell & Tissue Engineering	2.75%	1.58%	3.68%	2.50%	2.71%	3.14%	2.77%	2.73%
Environmental Sciences	3.03%	2.86%	2.63%	2.40%	2.81%	2.80%	2.75%	2.75%
Immunology	2.53%	2.88%	2.89%	2.73%	2.92%	2.51%	2.75%	2.75%
Physiology	3.01%	2.67%	3.09%	2.37%	2.70%	2.40%	2.70%	2.71%
Neurosciences	2.72%	2.90%	2.86%	2.61%	2.53%	2.55%	2.69%	2.70%
Anatomy & Morphology	3.66%	2.30%	1.85%	3.30%	1.94%	3.02%	2.68%	2.68%
Critical Care Medicine	2.18%	2.46%	2.16%	2.86%	2.84%	3.15%	2.62%	2.61%
Cardiac & Cardiovascular Systems	2.66%	2.25%	2.23%	2.48%	2.83%	3.00%	2.58%	2.58%
Anesthesiology	2.45%	2.64%	2.69%	2.60%	2.43%	2.51%	2.55%	2.55%
Oncology	2.59%	2.58%	2.51%	2.58%	2.67%	2.35%	2.54%	2.55%
Biotechnology & Applied Microbiology	2.46%	2.12%	2.44%	2.30%	2.36%	2.50%	2.53%	2.36%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Clinical Neurology	2.46%	2.37%	2.48%	2.69%	2.72%	2.47%	2.53%	2.53%
Microscopy	2.45%	2.12%	3.17%	1.91%	2.42%	3.22%	2.52%	2.55%
Pediatrics	2.99%	2.53%	1.97%	2.44%	2.61%	2.53%	2.51%	2.51%
Forestry	2.91%	2.78%	2.03%	2.06%	2.40%	2.82%	2.49%	2.50%
Psychology, Applied	2.40%	2.39%	2.24%	2.70%	2.94%	2.12%	2.48%	2.47%
Toxicology	2.90%	2.22%	2.54%	2.41%	2.69%	2.08%	2.47%	2.47%
Water Resources	2.70%	2.12%	2.25%	2.49%	2.46%	2.70%	2.46%	2.45%
Surgery	2.12%	2.23%	2.52%	2.65%	2.40%	2.49%	2.40%	2.40%
Allergy	1.87%	2.10%	3.11%	2.03%	2.96%	2.12%	2.36%	2.37%
Otorhinolaryngology	2.64%	1.87%	2.92%	2.09%	2.20%	2.20%	2.32%	2.32%
Dentistry, Oral Surgery & Medicine	2.20%	2.71%	2.06%	2.42%	1.90%	2.55%	2.30%	2.31%
Rheumatology	1.98%	2.24%	2.59%	2.92%	2.75%	1.21%	2.27%	2.28%
Biophysics	2.53%	2.26%	2.43%	2.01%	2.21%	2.00%	2.24%	2.24%
Andrology	2.19%	1.89%	2.86%	4.07%	0.69%	1.25%	2.24%	2.16%
Computer Science, Cybernetics	2.34%	3.08%	2.52%	1.80%	2.16%	1.86%	2.24%	2.29%
Medicine, Research & Experimental	2.59%	2.09%	2.25%	2.19%	1.95%	2.29%	2.22%	2.23%
Dermatology	1.64%	2.21%	2.41%	2.09%	1.83%	3.07%	2.20%	2.21%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Pharmacology & Pharmacy	2.35%	2.32%	2.23%	2.31%	2.10%	1.93%	2.20%	2.21%
Gastroenterology & Hepatology	2.05%	2.05%	2.45%	2.16%	2.38%	2.04%	2.19%	2.19%
Chemistry, Medicinal	2.91%	2.68%	1.87%	2.16%	1.92%	1.61%	2.18%	2.19%
Medical Informatics	2.65%	2.19%	2.95%	1.80%	1.48%	2.09%	2.15%	2.19%
Agronomy	1.93%	2.91%	2.13%	1.97%	2.26%	1.81%	2.14%	2.17%
Urology & Nephrology	1.76%	1.98%	2.19%	2.20%	2.18%	2.54%	2.14%	2.14%
Hematology	2.19%	2.31%	2.20%	2.05%	1.74%	1.42%	1.99%	1.99%
Psychology, Mathematical	2.81%	3.57%	3.07%	0.52%	0.83%	0.83%	1.96%	1.94%
Agriculture, Multidisciplinary	3.04%	2.52%	1.26%	1.08%	2.00%	1.42%	1.87%	1.89%
Medical Laboratory Technology	1.88%	2.34%	1.80%	2.06%	1.42%	1.67%	1.86%	1.86%
Transplantation	1.90%	1.32%	1.96%	1.47%	2.19%	2.33%	1.85%	1.86%
Nanoscience & Nanotechnology	1.87%	1.77%	2.15%	1.75%	1.66%	1.83%	1.83%	1.84%
Engineering, Environmental	1.83%	1.83%	1.52%	1.56%	1.80%	2.35%	1.82%	1.81%
Integrative & Complementary Medicine	0.75%	2.22%	1.25%	2.16%	2.29%	1.77%	1.80%	1.74%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Neuroimaging	1.30%	1.72%	2.32%	1.52%	2.01%	1.69%	1.78%	1.76%
Engineering, Biomedical	1.67%	2.09%	1.70%	1.43%	1.93%	1.68%	1.74%	1.75%
Materials Science, Biomaterials	1.43%	2.18%	1.51%	1.84%	1.59%	1.40%	1.64%	1.66%
Entomology	1.42%	1.38%	2.09%	1.85%	1.43%	1.24%	1.57%	1.57%
Imaging Science & Photographic Technology	1.20%	1.45%	2.20%	1.29%	1.33%	1.92%	1.55%	1.57%
Radiology, Nuclear Medicine & Medical Imaging	1.17%	1.42%	1.72%	1.31%	1.47%	1.69%	1.47%	1.46%
Robotics	1.53%	0.76%	0.85%	0.73%	1.50%	1.68%	1.29%	1.17%
Food Science & Technology	1.26%	1.24%	0.99%	1.06%	1.06%	0.93%	1.09%	1.09%
Agricultural Engineering	1.05%	0.80%	0.86%	0.52%	1.54%	1.54%	1.06%	1.05%
Psychology, Psychoanalysis	0.72%	0.00%	0.70%	2.74%	0.00%	1.21%	0.92%	0.89%
Horticulture	0.66%	0.77%	0.77%	0.81%	1.08%	0.65%	0.79%	0.79%

3.2.1.2 NCI: comparing with UK and EU-28

When looking at the NCI, we computed a ratio between the metric of Scotland and of the UK. The top field was Mathematical Psychology at a ratio value of 2.12. Other top fields were Public, Environmental & Occupational Health (1.55), General & Internal Medicine (1.50), Biological Psychology (1.49), and Andrology (1.41).

When comparing NCI of Scotland and of EU-28 aggregate, General & Internal Medicine, Mathematical Psychology, and Public, Environmental & Occupational Health were the top three fields. Scottish publications in these fields were cited more than twice of EU-28 average, indicating Scotland's impact in these areas.

Table 3.2.3 Life sciences ratio of NCI of Scottish publications relative to the UK

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Psychology, Mathematical	1.25	3.59	0.69	1.67	2.05	0.54	2.12	1.63
Public, Environmental & Occupational Health	0.96	0.93	2.41	1.16	1.47	1.84	1.55	1.46
Medicine, General & Internal	1.71	2.06	2.12	0.56	1.24	0.90	1.50	1.43
Psychology, Biological	1.11	1.23	1.04	3.29	0.80	0.92	1.49	1.40
Andrology	1.66	2.02	1.23	0.00	0.91	0.19	1.41	1.00
Cardiac & Cardiovascular Systems	1.31	1.46	1.55	1.35	1.39	1.34	1.39	1.40
Gastroenterology & Hepatology	1.06	1.39	1.32	1.44	1.43	1.42	1.35	1.35
Genetics & Heredity	1.40	1.19	1.41	1.37	1.27	1.23	1.31	1.31
Reproductive Biology	1.07	1.14	1.28	1.39	1.73	1.27	1.31	1.31
Peripheral Vascular Disease	1.26	1.09	1.08	1.69	1.43	1.16	1.30	1.29

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Pharmacology & Pharmacy	1.27	1.02	1.02	1.56	1.33	1.57	1.30	1.29
Rheumatology	1.04	1.47	1.97	1.27	1.19	0.46	1.29	1.23
Entomology	1.03	1.12	1.88	1.48	1.03	0.77	1.29	1.22
Respiratory System	1.45	1.04	1.31	1.09	1.09	1.49	1.24	1.25
Anesthesiology	1.02	0.95	0.88	1.23	1.72	1.62	1.22	1.23
Clinical Neurology	1.43	0.85	1.24	1.17	1.31	1.16	1.20	1.19
Cell & Tissue Engineering	0.96	0.63	1.21	1.47	1.31	1.19	1.19	1.13
Social Sciences, Biomedical	1.02	1.29	1.19	1.49	1.04	1.21	1.19	1.21
Obstetrics & Gynecology	1.24	1.15	1.27	1.20	1.21	1.07	1.19	1.19
Toxicology	1.53	0.97	1.37	1.14	1.10	0.96	1.18	1.18
Urology & Nephrology	1.22	0.98	1.05	1.31	1.04	1.41	1.18	1.17
Allergy	0.88	1.10	1.26	0.94	1.66	0.82	1.18	1.11
Immunology	1.02	1.12	1.12	1.28	1.46	0.99	1.18	1.17
Psychology, Multidisciplinary	1.14	1.14	0.84	1.49	0.94	1.45	1.17	1.17
Medical Laboratory Technology	1.39	1.53	0.97	1.51	0.55	0.95	1.17	1.15
Hematology	1.00	1.23	1.19	1.54	0.91	1.05	1.16	1.16
Virology	1.02	1.06	1.13	1.15	1.35	1.20	1.16	1.15

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Multidisciplinary Sciences	0.70	0.74	1.24	1.52	1.48	0.90	1.14	1.10
Dermatology	1.39	1.26	1.28	1.22	1.48	0.60	1.14	1.21
Primary Health Care	0.99	1.06	1.32	0.92	1.14	1.40	1.14	1.14
Physics, Multidisciplinary	1.12	0.99	1.24	1.20	1.16	1.07	1.14	1.13
Gerontology	0.75	0.87	0.93	1.22	1.09	1.94	1.13	1.13
Food Science & Technology	1.00	1.37	1.23	0.98	0.93	1.25	1.13	1.13
Ergonomics	1.32	1.25	0.63	1.38	0.62	0.82	1.13	1.00
Limnology	1.20	1.15	1.12	0.80	1.52	0.90	1.12	1.12
Geriatrics & Gerontology	0.66	1.28	0.78	1.22	1.16	1.43	1.12	1.09
Health Care Sciences & Services	1.17	0.92	1.29	1.29	0.94	1.13	1.12	1.12
Biotechnology & Applied Microbiology	0.95	1.54	0.76	1.21	1.09	1.19	1.11	1.12
Mathematical & Computational Biology	0.91	1.89	0.81	0.95	1.22	0.78	1.11	1.09
Psychiatry	0.94	1.06	1.14	0.99	1.08	1.42	1.11	1.10
Nutrition & Dietetics	1.07	1.07	1.17	0.86	1.39	1.14	1.11	1.12
Oncology	1.12	1.23	1.04	1.18	1.15	1.01	1.11	1.12
Biodiversity Conservation	1.23	1.17	1.06	1.23	0.90	1.16	1.11	1.12
Psychology	0.90	0.93	0.83	1.94	0.91	0.92	1.10	1.07

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Surgery	1.08	1.06	1.14	1.17	1.24	0.90	1.10	1.10
Zoology	1.23	0.94	1.09	1.22	1.12	1.02	1.09	1.10
Microbiology	1.13	1.13	1.07	1.09	1.09	1.06	1.09	1.09
Pediatrics	1.25	0.95	0.97	1.13	1.14	1.02	1.09	1.08
Biology	1.11	1.07	1.08	1.16	1.13	0.97	1.09	1.09
Evolutionary Biology	0.87	0.90	1.35	1.24	1.16	0.95	1.09	1.08
Agriculture, Multidisciplinary	1.26	1.01	0.87	1.24	0.94	0.90	1.08	1.04
Rehabilitation	0.96	1.25	1.22	0.88	1.10	1.08	1.08	1.08
Developmental Biology	0.82	1.16	1.23	1.10	1.05	1.12	1.07	1.08
Psychology, Experimental	0.91	1.11	0.85	1.68	0.96	0.92	1.07	1.07
Veterinary Sciences	1.05	0.92	1.05	1.10	1.12	1.19	1.07	1.07
Plant Sciences	1.14	0.91	1.14	1.18	1.01	1.03	1.06	1.07
Medical Informatics	1.05	1.50	1.04	0.95	0.72	0.88	1.06	1.02
Forestry	1.09	0.99	1.01	1.21	0.91	1.12	1.04	1.05
Environmental Studies	0.91	0.79	1.05	1.20	1.13	1.00	1.04	1.01
Agriculture, Dairy & Animal Science	0.99	0.96	1.05	0.94	1.24	1.14	1.04	1.05
Agronomy	1.13	0.94	0.92	0.97	1.06	1.17	1.04	1.03

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Endocrinology & Metabolism	1.37	0.92	0.98	1.07	0.98	0.96	1.03	1.05
Neurosciences	0.95	0.93	0.93	1.27	1.00	1.13	1.03	1.03
Sport Sciences	1.13	0.91	1.04	0.84	1.13	1.10	1.03	1.03
Substance Abuse	0.85	1.22	1.06	0.88	1.09	1.03	1.03	1.02
Nursing	1.00	1.06	1.16	0.83	1.07	1.08	1.03	1.03
Mycology	1.09	0.93	0.67	1.27	0.73	1.63	1.02	1.05
Transplantation	1.39	1.24	0.95	0.60	1.10	0.83	1.02	1.02
Medicine, Research & Experimental	1.01	0.97	1.10	1.25	0.86	0.94	1.02	1.02
Marine & Freshwater Biology	0.96	1.02	0.98	1.04	1.00	1.12	1.02	1.02
Cell Biology	0.93	0.95	1.05	1.17	1.02	0.98	1.02	1.02
Ecology	0.99	0.98	1.01	1.14	1.00	0.97	1.01	1.02
Pathology	0.93	1.04	1.01	0.97	0.99	1.13	1.01	1.01
Biochemistry & Molecular Biology	0.85	0.94	1.07	1.13	1.09	1.02	1.01	1.02
Environmental Sciences	1.04	0.96	0.99	1.10	0.99	0.93	1.00	1.00
Physiology	0.82	1.16	0.82	1.18	0.82	1.25	0.99	1.01
Psychology, Applied	1.06	1.22	0.72	0.98	1.23	0.64	0.99	0.97
Horticulture	1.43	1.16	0.94	0.89	1.05	0.45	0.99	0.99

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Water Resources	1.06	0.84	0.98	1.04	0.74	1.18	0.98	0.97
Dentistry, Oral Surgery & Medicine	1.01	0.87	0.85	0.91	1.19	1.04	0.97	0.98
Infectious Diseases	0.78	0.96	0.90	0.97	0.88	1.26	0.97	0.96
Fisheries	0.87	0.85	0.83	1.09	1.05	1.13	0.97	0.97
Soil Science	1.01	0.91	1.12	1.14	0.77	0.86	0.97	0.97
Chemistry, Medicinal	0.94	0.78	1.17	1.15	0.95	0.85	0.96	0.97
Ophthalmology	1.04	1.02	0.76	0.84	0.68	1.45	0.96	0.96
Biochemical Research Methods	0.63	1.20	1.03	0.94	1.12	0.95	0.96	0.98
Oceanography	1.11	0.88	0.94	0.85	1.08	0.94	0.96	0.97
Parasitology	0.90	0.85	0.97	0.99	0.93	1.10	0.96	0.96
Materials Science, Biomaterials	0.87	0.67	0.76	1.14	0.83	1.29	0.96	0.93
Critical Care Medicine	0.85	0.87	1.09	0.63	1.29	1.08	0.95	0.97
Emergency Medicine	0.79	1.01	1.22	0.76	1.26	0.82	0.95	0.98
Paleontology	0.77	0.70	1.25	1.11	0.82	0.89	0.94	0.92
Orthopedics	1.01	0.81	1.07	0.91	0.98	0.82	0.93	0.93
Geosciences, Multidisciplinary	0.85	1.01	0.99	1.00	0.87	0.89	0.93	0.93
Psychology, Clinical	1.06	0.92	0.98	0.90	0.90	0.84	0.93	0.93

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Tropical Medicine	0.81	0.77	0.91	0.89	0.81	1.14	0.91	0.89
Neuroimaging	0.82	0.76	0.78	1.02	1.09	1.05	0.91	0.92
Engineering, Biomedical	0.78	0.74	0.68	0.96	1.09	1.01	0.90	0.88
Engineering, Environmental	0.68	0.89	0.73	1.09	0.76	1.10	0.89	0.88
Computer Science, Cybernetics	0.55	0.90	0.93	0.99	0.91	0.58	0.88	0.81
Anthropology	0.55	0.69	0.84	0.94	0.91	1.33	0.88	0.88
Psychology, Developmental	0.90	0.97	0.70	0.89	0.79	0.97	0.87	0.87
Imaging Science & Photographic Technology	0.56	1.26	0.67	0.70	0.88	1.03	0.84	0.85
Integrative & Complementary Medicine	0.66	1.00	0.90	0.63	1.15	0.60	0.83	0.82
Robotics	0.51	0.92	0.82	0.91	1.05	0.81	0.82	0.84
Microscopy	0.72	0.87	0.86	0.33	0.73	1.24	0.80	0.79
Ornithology	0.58	0.83	0.85	0.88	0.62	0.91	0.78	0.78
Otorhinolaryngology	0.95	0.63	0.85	0.51	0.69	0.87	0.77	0.75
Biophysics	0.54	0.59	1.07	0.93	1.00	0.80	0.77	0.82
Agricultural Engineering	0.39	0.19	0.78	1.02	1.07	0.99	0.75	0.74

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Radiology, Nuclear Medicine & Medical Imaging	0.81	0.65	0.71	0.78	0.92	0.66	0.75	0.75
Nanoscience & Nanotechnology	0.77	0.59	0.82	0.73	0.59	0.73	0.70	0.71
Anatomy & Morphology	0.73	0.58	0.62	0.86	0.68	0.67	0.69	0.69
Crystallography	0.19	0.26	0.62	0.97	0.63	0.79	0.42	0.58
Psychology, Psychoanalysis	0.28	0.00	0.14	0.00	0.00	1.60	0.29	0.34

Table 3.2.4 Life sciences ratio of NCI of Scottish publications relative to EU-28

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Medicine, General & Internal	3.29	3.99	3.43	0.95	2.13	1.45	2.62	2.54
Psychology, Mathematical	1.23	5.62	0.80	1.39	2.27	0.73	2.47	2.01
Public, Environmental & Occupational Health	1.19	1.13	3.47	1.59	2.05	2.59	2.09	2.00
Allergy	1.47	2.01	2.22	1.51	2.82	1.35	2.02	1.90
Cardiac & Cardiovascular Systems	1.94	2.00	2.20	1.89	1.98	1.91	1.98	1.99
Genetics & Heredity	1.94	1.60	2.09	1.88	1.79	1.74	1.84	1.84
Rheumatology	1.65	1.92	2.48	1.79	1.78	0.63	1.82	1.71
Gastroenterology & Hepatology	1.35	1.75	1.62	1.89	1.93	1.99	1.77	1.76
Respiratory System	2.13	1.47	1.74	1.57	1.58	2.02	1.75	1.75
Peripheral Vascular Disease	1.80	1.38	1.41	2.35	1.78	1.50	1.71	1.70
Clinical Neurology	2.10	1.23	1.74	1.54	1.88	1.57	1.68	1.68
Urology & Nephrology	1.60	1.33	1.37	1.98	1.64	1.98	1.68	1.65
Oncology	1.73	1.69	1.50	1.58	1.69	1.60	1.63	1.63
Entomology	1.31	1.50	2.38	1.55	1.25	1.04	1.60	1.51
Anesthesiology	1.28	1.44	1.16	1.53	2.16	1.98	1.59	1.59
Psychology, Biological	1.26	1.24	1.03	4.26	0.74	0.95	1.59	1.58

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Physics, Multidisciplinary	1.54	1.31	1.63	1.54	1.68	1.53	1.55	1.54
Immunology	1.31	1.46	1.41	1.69	2.00	1.30	1.54	1.53
Obstetrics & Gynecology	1.55	1.57	1.69	1.44	1.57	1.30	1.52	1.52
Hematology	1.31	1.53	1.51	2.11	1.19	1.39	1.51	1.51
Pharmacology & Pharmacy	1.42	1.21	1.17	1.89	1.50	1.89	1.51	1.51
Reproductive Biology	1.22	1.33	1.51	1.39	2.17	1.33	1.48	1.49
Psychology, Multidisciplinary	1.43	1.44	1.16	1.81	1.15	1.76	1.46	1.46
Biotechnology & Applied Microbiology	1.19	2.03	1.06	1.49	1.41	1.56	1.45	1.46
Critical Care Medicine	1.33	1.18	1.58	1.08	1.84	1.52	1.43	1.42
Biology	1.50	1.41	1.43	1.49	1.52	1.23	1.43	1.43
Virology	1.29	1.36	1.48	1.29	1.79	1.33	1.43	1.42
Medical Laboratory Technology	1.58	1.70	1.05	1.85	0.79	1.32	1.43	1.38
Dermatology	1.85	1.50	1.54	1.38	1.93	0.78	1.42	1.50
Andrology	3.19	2.05	1.89	0.00	1.03	0.28	1.41	1.41
Psychiatry	1.17	1.28	1.48	1.24	1.38	1.79	1.40	1.39
Multidisciplinary Sciences	0.97	0.76	1.75	1.79	1.70	1.07	1.40	1.34
Biochemistry & Molecular Biology	1.17	1.29	1.50	1.47	1.52	1.42	1.39	1.39

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Ergonomics	1.42	1.75	0.69	1.95	0.69	0.99	1.39	1.25
Pediatrics	1.73	1.17	1.37	1.35	1.43	1.17	1.38	1.37
Limnology	1.21	1.41	1.36	0.95	2.07	1.18	1.37	1.36
Endocrinology & Metabolism	1.77	1.19	1.37	1.31	1.25	1.34	1.36	1.37
Zoology	1.48	1.30	1.29	1.49	1.33	1.27	1.35	1.36
Plant Sciences	1.42	1.20	1.60	1.44	1.23	1.27	1.35	1.36
Microbiology	1.38	1.37	1.27	1.25	1.41	1.40	1.35	1.35
Geriatrics & Gerontology	0.81	1.51	0.91	1.47	1.35	1.72	1.34	1.29
Health Care Sciences & Services	1.28	1.06	1.68	1.66	1.10	1.29	1.33	1.34
Psychology	1.07	1.03	1.04	2.42	1.11	1.14	1.33	1.30
Developmental Biology	0.99	1.36	1.37	1.35	1.40	1.50	1.32	1.33
Medicine, Research & Experimental	1.30	1.19	1.33	1.60	1.17	1.30	1.32	1.31
Toxicology	1.53	1.13	1.44	1.24	1.30	1.16	1.31	1.30
Agriculture, Dairy & Animal Science	1.33	1.33	1.07	1.22	1.62	1.43	1.31	1.33
Nutrition & Dietetics	1.30	1.28	1.38	1.02	1.51	1.35	1.30	1.31
Environmental Sciences	1.34	1.25	1.25	1.44	1.37	1.21	1.30	1.31
Social Sciences, Biomedical	1.10	1.41	1.26	1.58	1.14	1.33	1.29	1.30

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Agriculture, Multidisciplinary	1.59	1.32	1.05	1.42	1.04	0.93	1.29	1.23
Neurosciences	1.21	1.14	1.17	1.59	1.22	1.36	1.28	1.28
Mathematical & Computational Biology	1.13	2.48	0.91	1.10	1.19	0.87	1.28	1.28
Biodiversity Conservation	1.48	1.34	1.15	1.38	1.04	1.38	1.27	1.30
Medical Informatics	1.21	2.19	1.41	1.32	0.76	0.78	1.27	1.28
Transplantation	1.73	1.61	1.16	0.79	1.35	0.97	1.27	1.27
Evolutionary Biology	1.12	1.07	1.63	1.37	1.33	1.06	1.27	1.26
Surgery	1.28	1.22	1.30	1.32	1.43	1.04	1.27	1.27
Veterinary Sciences	1.34	1.11	1.26	1.26	1.32	1.33	1.27	1.27
Mycology	1.37	1.07	0.78	1.72	0.86	2.11	1.27	1.32
Cell Biology	1.15	1.11	1.34	1.40	1.25	1.27	1.25	1.25
Pathology	1.16	1.32	1.19	1.19	1.22	1.42	1.25	1.25
Forestry	1.05	1.22	1.12	1.75	1.19	1.22	1.25	1.26
Ecology	1.29	1.21	1.22	1.36	1.21	1.18	1.24	1.25
Emergency Medicine	1.34	1.29	1.19	0.87	1.58	1.11	1.24	1.23
Primary Health Care	1.17	1.06	1.46	0.97	1.37	1.42	1.24	1.24
Cell & Tissue Engineering	1.17	0.56	1.24	1.47	1.39	1.21	1.24	1.17
Marine & Freshwater Biology	1.22	1.25	1.18	1.32	1.14	1.29	1.23	1.23

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Infectious Diseases	0.99	1.17	1.09	1.25	1.16	1.61	1.23	1.21
Agronomy	1.32	0.94	1.13	1.19	1.30	1.55	1.23	1.24
Fisheries	1.17	1.02	1.04	1.32	1.26	1.59	1.22	1.23
Environmental Studies	1.05	0.90	1.24	1.33	1.48	1.08	1.21	1.18
Biochemical Research Methods	0.94	1.70	1.10	1.12	1.21	1.17	1.21	1.21
Soil Science	1.42	1.33	1.58	1.10	0.80	1.09	1.20	1.22
Geosciences, Multidisciplinary	1.02	1.24	1.28	1.36	1.17	1.13	1.20	1.20
Sport Sciences	1.27	1.07	1.08	1.00	1.29	1.42	1.20	1.19
Substance Abuse	0.84	1.33	1.21	0.99	1.34	1.30	1.18	1.17
Paleontology	0.93	0.78	1.45	1.52	1.02	1.13	1.16	1.14
Gerontology	0.80	1.00	0.88	1.35	1.05	1.89	1.16	1.16
Food Science & Technology	1.08	1.41	1.23	0.93	1.04	1.22	1.15	1.15
Water Resources	1.15	0.94	1.11	1.23	0.86	1.52	1.15	1.13
Neuroimaging	1.07	1.01	1.01	1.26	1.30	1.23	1.15	1.15
Chemistry, Medicinal	1.02	0.89	1.44	1.41	1.07	0.96	1.11	1.13
Physiology	0.94	1.36	0.98	1.26	0.89	1.31	1.11	1.12
Anthropology	0.77	0.85	1.09	1.22	1.13	1.45	1.11	1.09
Rehabilitation	0.93	1.28	1.22	0.85	1.16	1.17	1.10	1.10

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Oceanography	1.25	1.03	1.15	0.96	1.30	0.95	1.09	1.11
Psychology, Experimental	0.93	1.04	0.86	1.85	0.93	0.98	1.09	1.10
Ophthalmology	1.16	1.09	0.90	0.92	0.79	1.61	1.08	1.08
Parasitology	1.00	0.99	1.09	1.05	1.12	1.17	1.07	1.07
Tropical Medicine	0.93	0.87	1.15	0.96	0.94	1.33	1.06	1.03
Computer Science, Cybernetics	0.73	1.05	1.52	1.11	1.12	0.48	1.05	1.00
Biophysics	0.90	0.96	1.30	1.10	1.05	0.97	1.04	1.05
Horticulture	1.25	1.23	1.11	0.83	1.25	0.50	1.04	1.03
Nursing	1.06	1.02	1.12	0.83	1.05	1.17	1.04	1.04
Microscopy	0.96	1.18	1.00	0.42	1.05	1.45	1.03	1.01
Orthopedics	1.06	0.95	1.12	1.00	0.99	0.92	1.01	1.01
Psychology, Clinical	1.16	1.00	1.02	0.96	0.94	0.92	1.00	1.00
Psychology, Developmental	1.04	1.00	0.77	1.04	0.87	1.04	0.96	0.96
Psychology, Applied	0.91	0.90	0.66	0.94	1.31	0.80	0.96	0.92
Engineering, Environmental	0.67	1.12	0.75	1.24	0.79	1.11	0.94	0.95
Radiology, Nuclear Medicine & Medical Imaging	0.96	0.84	0.87	1.06	1.08	0.85	0.94	0.94
Engineering, Biomedical	0.73	0.73	0.62	1.02	1.17	1.20	0.94	0.91

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Agricultural Engineering	0.38	0.30	0.78	1.20	1.49	0.96	0.90	0.85
Dentistry, Oral Surgery & Medicine	0.86	0.78	0.77	0.84	1.16	0.91	0.88	0.89
Materials Science, Biomaterials	0.68	0.46	0.73	1.11	0.81	1.25	0.85	0.84
Ornithology	0.65	1.00	1.13	0.85	0.60	0.88	0.85	0.85
Imaging Science & Photographic Technology	0.70	1.16	0.57	0.67	0.88	0.94	0.83	0.82
Anatomy & Morphology	0.83	0.79	0.88	1.03	0.80	0.69	0.83	0.84
Nanoscience & Nanotechnology	0.80	0.69	0.87	0.92	0.80	0.86	0.83	0.82
Otorhinolaryngology	1.00	0.67	0.93	0.52	0.65	0.84	0.79	0.77
Integrative & Complementary Medicine	0.69	0.84	0.83	0.58	1.12	0.63	0.78	0.78
Robotics	0.57	0.98	0.73	0.91	0.79	0.75	0.76	0.79
Crystallography	0.43	0.61	0.76	1.22	0.67	0.70	0.68	0.73
Psychology, Psychoanalysis	0.32	0.00	0.22	0.00	0.00	1.08	0.32	0.27

The figure below shows a scatter plot of individual life science fields by their NCI and the total number of publications. The vertical axis crosses at the median publication count. Research fields in the top right corner are considered strong, while fields in the bottom left corner are considered weak. Scottish publications had a NCI (>1) which is higher than the global average in the vast majority of life sciences fields. Out of 115 fields selected, 106 fields were in this group (above the horizontal axis). Particularly high in NCI were the fields Of General & Internal Medicine (3.68), Mathematical Psychology (3.00), and Cardiac & Cardiovascular Systems (2.42).

When considered with the number of publications, the following fields were particular strong: Biochemistry & Molecular Biology, and General & Internal Medicine. Biochemistry & Molecular Biology had high volume (4,385 publications) and good NCI (1.66) which made it a field of strength. General & Internal Medicine, on the other hand had a high NCI (3.68) but only a moderate publication volume (345 publications) marking it an opportunity field to grow.

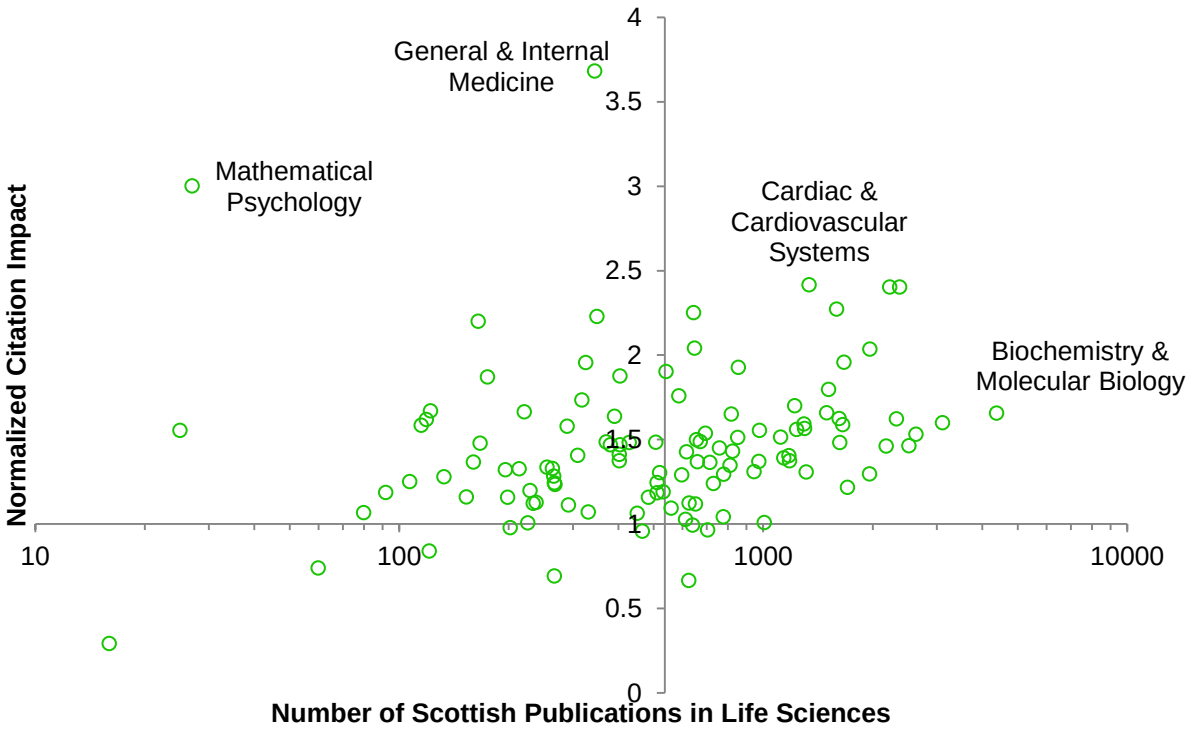


Figure 3.2.1 Life sciences fields – Scottish NCI versus number of publications

3.2.2 Patent strengths and weaknesses

In the life sciences area, a total of 617 patents in Scotland were identified and analyzed based on the technical categories and restricted to the assignee, inventor or attorney address field containing either Scotland (or its cities or towns), and having earliest priority country[10] as UK, Patent Cooperation Treaty (PCT) or European Patent Convention during the time period of 2010 to 2015.

3.2.2.1 Scotland Life Sciences Patent Research Output based on Tier 1 Entities

The Table below shows the Tier 1 entities (top 12 entities) portfolio. Entities having more than 10 patent publications are considered as Tier 1 entities. The Clarivate strength score assigned to each patent family measures the various characteristics that act as proxies for the commercial behavior behind and the utility of an individual piece of intellectual property. The Clarivate strength score index is based on the various parameters including market protection time, novelty, geographic market protection, technical coverage, frequency and patent citation impact (see Section 2 for definitions and Appendix B for analysis details).

Table 3.2.5 Life sciences patent strength of Scottish research based on Tier 1 entities

Tier 1 - Entities	Total Inventions	Market Protection Time	Novelty	Geographic Market Protection	Technical Coverage	Citations Per Patent	Average Clarivate Patent Strength Score
University of Dundee	53	13.36	12.13	2.2	2.7	8.8	32
University of Edinburgh	50	14.1	4.42	2.3	3.6	4.5	33
University of St Andrews	40	13.43	10.23	3	3.6	6.6	37
University of Glasgow	26	14	7.24	3.3	2.9	9.4	39
University of Strathclyde	24	13.29	10.82	2.8	4.3	11.9	42
University of Aberdeen	23	13.96	7.06	2.5	3	3.5	34
ITI Scotland Ltd	17	12.35	3.82	2.9	3.4	7.2	27

[10] A priority country is a country where the patent is first filed before being (possibly) extended to other countries.

Tier 1 - Entities	Total Inventions	Market Protection Time	Novelty	Geographic Market Protection	Technical Coverage	Citations Per Patent	Average Clarivate Patent Strength Score
Optos Plc	14	14.14	15.77	7.9	3.3	11.6	59
Terumo	14	14.93	7.42	1.7	2.3	1.5	28
Aircraft Medical	13	12.69	17.98	4.3	2.2	25	50
Johnson & Johnson	12	15.75	3.79	6.3	4.8	1.7	56
Touch Bionics	11	13.82	24.79	2.5	2.4	14.8	48

Among the Tier 1 entities, the University of Dundee is the largest entity in terms of portfolio size, closely followed by the University of Edinburgh. The University of Strathclyde has a relatively small portfolio compared to the other Universities, however has the highest strength score and also the greatest impact in terms of citations received across its portfolio. Of the Tier 1 entities 50% are academic institutes, indicating a high level of research activity within the life sciences area.

Based on the Clarivate Strength Index, Optos Plc has the strongest portfolio due to high geographical market protection, closely followed by Johnson & Johnson who additionally have a technically broad portfolio. Frequency of citation by downstream patent applications shows Aircraft Medical and Touch Bionics have very high impact portfolios based on patent citation frequency (“Citation Impact”).

Johnson & Johnson is active through its subsidiary Lifescan Scotland Ltd, formerly known as Iverness Medical Ltd. Optos Plc, Touch Bionics and Aircraft Medical are all companies that originate from Scotland. Vascutek, a subsidiary of Japanese medical device company Terumo, is based in Inchinnan, Scotland. The company reported an overall increase in sales for 2016, despite substantial losses in previous years.

Additional insight into these Strength rankings can be revealed when they are plotted against market protection time. The bubble chart below visually represents the strength score vs. market protection time of the portfolios. In this chart, the bubble size reflects portfolio size. This analysis summarizes the results for Tier 1 portfolios.

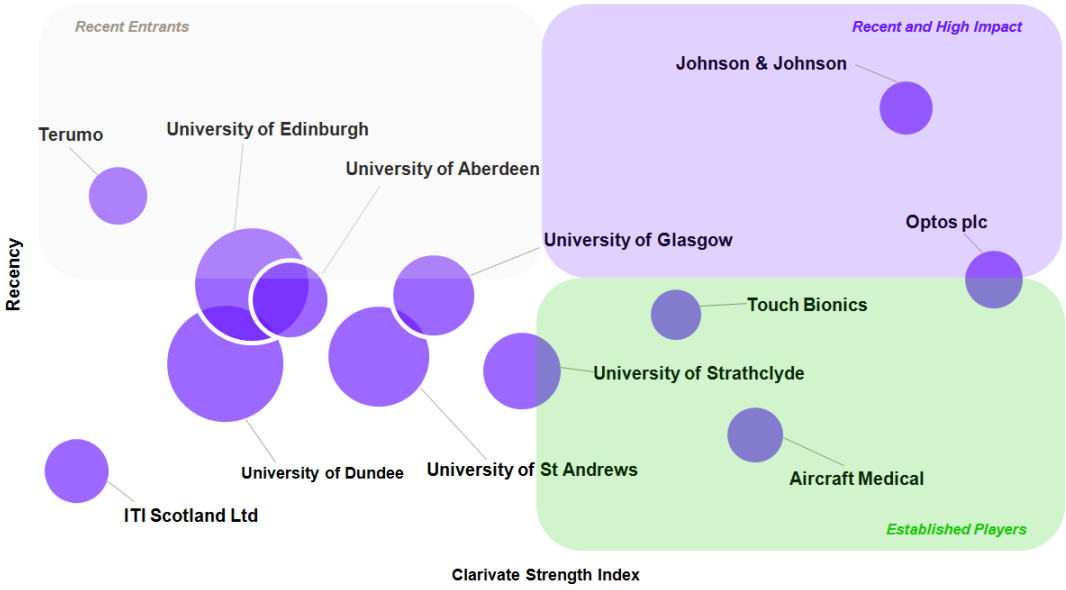


Figure 3.2.2 Life sciences Tier 1 entities – patent strength versus market protection time

In the above chart, the most attractive portfolios are those closest to the upper right-hand quadrant, i.e., those that are both higher strength and have a longer life remaining (i.e., more recent filing). When viewed from this perspective, Johnson & Johnson stands out as having a particularly strong portfolio which is still relatively young. Optos Plc is slightly older in terms of its recency but has the highest scoring portfolio. Aircraft Medical is old but has a stronger portfolio in comparison with Touch Bionics.

3.2.2.2 Scotland Life Sciences Patent Research Output based on Sub-technical Categories

This section focuses on the technical make-up of the patents and patent applications within the life sciences.

The table below provides the analysis for the technology segments and categories by patent volume, market protection time, novelty, geographic market protection, technical coverage, impact on the field and Clarivate patent strength score.

It is observed that Food, Diagnostics in General and Biopharmaceuticals categories rank the highest in terms of patent volume. Sowing / Planting / Harvesting category has the highest patent strength.

Table 3.2.6 Life sciences sub technical categories patent portfolio

Level 1 Category	Level 2 Sub-category	Inventions per Category	Market Protection Time	Novelty	Geographic Market Protection	Technical Coverage	Citations Per Patent	Average Clarivate Patent Strength Score
Agricultural	Sowing / Planting / Harvesting	3	15.67	6.49	2.67	3.33	13.57	53.82
	Transgenic Plants / Tissue Culture	5	15.00	3.90	3.40	4.20	8.14	44.21
	Fertilizers / Pesticides	5	14.40	0.00	1.60	2.80	0.00	26.75
	Horticulture / Cultivation	14	14.21	6.03	1.79	3.36	8.72	35.22
Food	Food	223	13.81	6.58	3.17	3.51	6.75	36.38
	Beverages	13	13.38	9.49	5.00	3.38	4.70	39.73
Medicine	Biologics/ Biopharmaceutical	169	13.78	6.76	3.08	3.43	5.90	35.79
	Vaccines	26	13.73	8.49	3.15	3.19	0.00	32.55
	Regenerative Medicines	19	13.42	0.34	2.00	3.37	3.21	25.84
	Pharmaceutical Drug	96	13.59	11.57	3.11	3.25	11.87	39.51
Diagnostics	Micro Diagnostics	16	12.81	6.09	2.81	4.38	19.08	43.27
	Imaging	12	12.75	12.45	3.25	4.00	8.48	38.12
	Immunoassay	55	13.53	6.61	2.95	3.60	5.18	34.74
	Nucleic Acid Based Diagnostics	78	13.56	7.49	3.37	3.13	6.00	35.38
	Diagnostics In General	181	13.86	10.19	3.56	3.54	10.23	42.47
Medicinal Device	Electromedical Devices	124	13.69	10.00	3.42	3.69	9.68	39.80
	Stents	18	14.22	9.02	1.89	2.89	2.26	28.64
	Ophthalmic	17	12.76	18.72	5.12	4.71	16.76	50.38
	Implants / Prosthesis	62	13.53	14.35	2.76	3.44	7.22	37.42
	Surgical Instruments	58	13.33	12.54	3.00	2.69	6.32	33.26
	Other Medical Devices	17	13.94	6.11	2.06	2.41	7.18	28.89

Level 1 Category	Level 2 Sub-category	Inventions per Category	Market Protection Time	Novelty	Geographic Market Protection	Technical Coverage	Citations Per Patent	Average Clarivate Patent Strength Score
Disease	Cancer	60	13.48	10.82	3.42	2.98	11.19	39.65
	Cardiovascular Disease	45	13.24	9.52	3.18	3.09	10.85	34.29
	Respiratory Disease	20	13.45	13.96	5.40	2.95	14.24	45.08
	Neurodegenerative & Muscular Disease	46	13.26	10.73	3.17	2.57	12.83	36.56
	Gastrointestinal Disease	33	13.12	9.05	3.58	2.91	11.72	34.74
	Metabolic Disease	25	13.48	10.39	2.28	2.56	13.84	37.67
	Infectious Disease	63	13.63	9.79	3.19	3.14	8.72	37.18
	Immune Disorder	40	13.33	7.95	2.83	2.98	8.65	34.03
	Other Diseases	127	13.15	10.23	3.33	3.17	8.65	33.89
Animal / Veterinary Science		44	13.02	8.41	2.57	2.52	5.55	26.12

Additional insight into these Patent Strength rankings can be revealed when the technical categories patent strength is plotted against recency of patents (market protection time). In the chart below, bubble sizes are representative of the relative individual category dataset size. The most attractive technologies are those closest to the upper right-hand quadrant, i.e., those that are both higher Strength and have a higher life remaining. Inventions closest to the upper-right hand quadrant are recent and have a high average strength score. This plot of Strength versus market protection time provides an understanding of categories that stand out with respect to being both high strength and high recency (longer protection time).

Based on this, the technical categories Sowing / Planting / Harvesting and Transgenic Plant / Tissue Culture are relatively small in size, but rank high in terms of strength and are still very recent innovations. Technology sub-categories such as Micro-Diagnostics, Respiratory Disease and Ophthalmic are all relatively mature categories however score high in terms of strength ranking. These technology areas are most likely occupied by the more established players in the landscape.

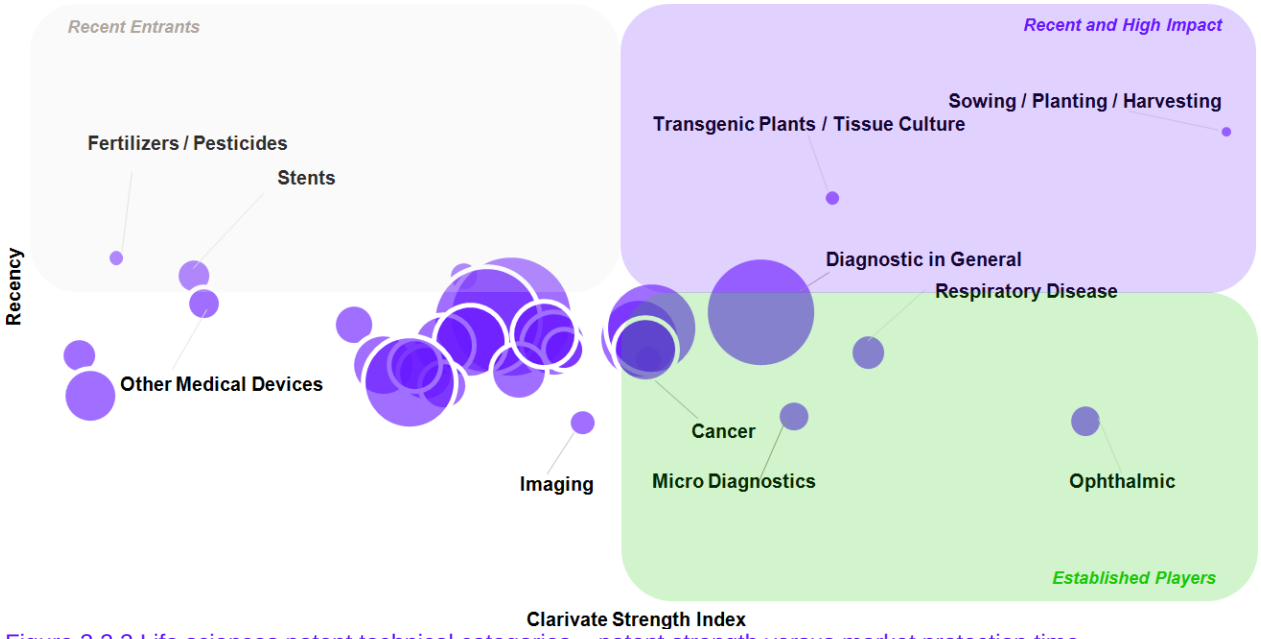


Figure 3.2.3 Life sciences patent technical categories – patent strength versus market protection time

3.3 Life Sciences Research Collaboration

The level of collaboration in life sciences research in Scotland was evaluated by assessing the number of co-authorships in publications. Overall, an upward trend is observed in the number of Scottish publications that have international co-authors. When compared to Scottish publications in general, these internationally-collaborated publications had a positive impact as well – these publications had a higher citation impact (20.14 compared to16.14) and NCI (2.03 compared to 1.61) than those that were not internationally collaborative.

Table 3.3.1 Life sciences publication collaboration and impact

	2010	2011	2012	2013	2014	2015	Grand Total	
Number of Publications w/ International Co-authorship	4,691	4,873	5,077	5,567	6,111	6,368	32,687	
							Weighted Average	**Unweighted Average**
Average Citation Impact of pubs w/ International Co-authorship	36.8	28.94	26.52	19.12	12.00	5.17	20.14	21.43
Average NCI of pubs w/ International Co-authorship	1.92	1.86	2.18	2.10	2.08	2.08	2.03	2.04

Scottish researchers have been collaborating with researchers from across the globe. The following map and table shows the top 25 countries with the most publications collaborated with Scotland. Of all Scottish publications, 30% have collaborating authors from the USA. Not surprisingly, most of the countries on the list are in Europe with the exceptions of the USA, Australia, Canada, China, Japan, Brazil and New Zealand.

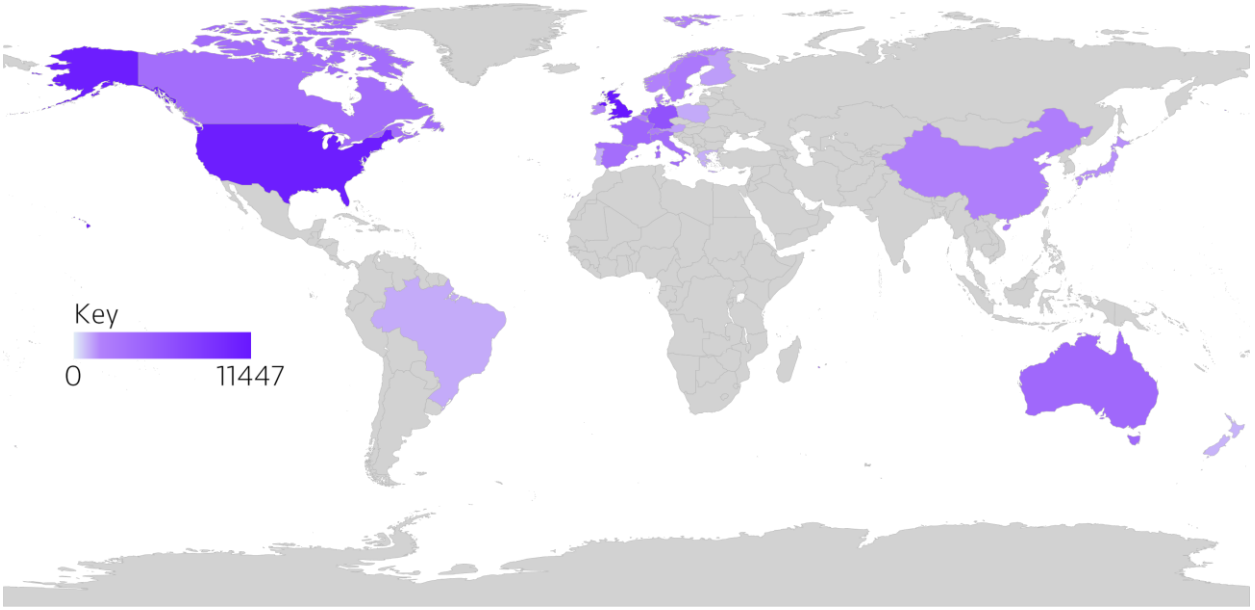


Figure 3.3.1 Life sciences top 25 countries which collaborate most frequently with Scotland

Table 3.3.2 Life sciences top 25 countries which collaborate most frequently with Scotland ranked by percent of Scottish publications

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
USA	30.48%	31.25%	32.74%	33.55%	33.51%	34.45%	32.81%	32.67%
England	29.44%	29.84%	32.68%	33.90%	33.94%	33.32%	32.36%	32.19%
Germany	17.61%	17.01%	18.93%	18.23%	19.21%	19.41%	18.48%	18.40%
France	11.94%	12.17%	13.53%	12.83%	13.32%	12.89%	12.82%	12.78%
Australia	10.17%	11.12%	11.88%	12.16%	14.07%	14.34%	12.46%	12.29%
The Netherlands	11.34%	11.43%	13.10%	12.36%	12.86%	12.61%	12.33%	12.28%
Italy	9.93%	11.00%	12.43%	11.57%	11.16%	11.65%	11.32%	11.29%
Canada	10.27%	11.80%	11.15%	10.10%	11.45%	11.26%	11.02%	11.01%
Spain	9.27%	9.64%	11.35%	10.36%	11.18%	11.17%	10.56%	10.49%
Sweden	7.87%	6.98%	8.25%	8.19%	7.85%	8.73%	8.02%	7.98%
Switzerland	6.71%	7.08%	7.70%	6.92%	7.97%	7.29%	7.30%	7.28%
China	4.20%	4.82%	5.67%	6.20%	6.69%	8.37%	6.14%	5.99%
Denmark	4.37%	4.97%	5.53%	5.48%	5.71%	6.96%	5.58%	5.50%
Norway	4.92%	5.21%	6.03%	5.42%	5.35%	5.97%	5.51%	5.48%
Belgium	5.09%	4.66%	5.46%	5.41%	5.48%	5.94%	5.38%	5.34%
Republic of Ireland	4.78%	4.45%	5.14%	5.01%	5.42%	4.93%	4.97%	4.95%
Japan	3.41%	4.51%	5.46%	4.65%	4.48%	4.99%	4.61%	4.59%
Finland	3.75%	3.88%	3.82%	3.66%	4.09%	4.24%	3.93%	3.91%
Austria	3.33%	2.96%	4.51%	3.99%	3.73%	3.56%	3.69%	3.68%

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Poland	2.60%	2.83%	3.43%	3.65%	3.70%	3.33%	3.29%	3.26%
Brazil	2.73%	2.98%	2.99%	3.14%	3.27%	3.96%	3.22%	3.18%
Greece	2.56%	2.81%	3.27%	2.86%	3.26%	3.22%	3.02%	3.00%
Portugal	2.30%	2.65%	2.74%	3.07%	3.03%	3.42%	2.91%	2.87%
New Zealand	2.39%	2.63%	2.76%	3.00%	2.93%	2.81%	2.77%	2.75%
Wales	2.20%	2.81%	2.84%	2.80%	2.86%	2.43%	2.66%	2.66%

Despite the fact that New Zealand is only the 24th country in terms of the number of publications collaborated with Scotland, these co-authored publications had a relatively high citation impact (47.06). When looking at the NCI alone, New Zealand again has a high weighted average of 5.53, followed by Greece (5.26), Japan (4.96), Austria (4.87), and Denmark (4.86). Surprisingly, Germany (3.44), the USA (3.16), and England (3.02) are in the 23rd, 24th and 25th place, respectively.

Table 3.3.3 Life sciences top 25 countries which collaborate most frequently with Scotland ranked by average citation impact

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
USA	59.1	46.14	45.94	28.35	19.39	8.36	31.9	34.55
England	57.41	40.9	40.73	27.79	18.06	8.03	29.62	32.15
Germany	62.86	48.08	48.2	34.3	20.4	9.35	34.5	37.20
France	69.97	49.08	55.27	39.5	22.31	11.21	38.63	41.22
Australia	66.22	58.06	57.45	30.37	19.4	9.83	35.34	40.22
The Netherlands	77.14	50.36	61.76	38.03	20.3	10.83	39.93	43.07
Italy	82.62	47.69	58.6	37.56	23.4	11.18	40.39	43.51
Canada	71.01	49.9	58.44	32.86	19.72	11.7	37.94	40.61
Spain	70.97	44.4	56.72	32.21	18.4	9.59	35.45	38.72
Sweden	84.4	59.62	72.67	42.7	28.63	12.2	46.51	50.04

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Switzerland	77.1	45.3	67.49	43.25	20.03	13.37	41.44	44.42
China	42.64	38.02	63.7	27.12	19.7	9.78	29.05	33.49
Denmark	82.23	58.27	79.23	34.93	28.25	13.62	43.71	49.42
Norway	74.36	65.98	62.15	40.32	22.82	13.57	43.2	46.53
Belgium	71.22	48.72	70.09	40.86	23.61	12.11	41.14	44.44
Republic of Ireland	54.05	40.04	61.11	26.51	17.26	11.95	32.97	35.15
Japan	61.62	52.95	74.69	41.49	31.92	13.41	43.74	46.01
Finland	97.84	53.99	57.99	36.22	29.87	15.42	44.97	48.56
Austria	97.15	36.98	72.81	44.33	23.81	17.23	46.71	48.72
Poland	80.14	52.17	47.84	40.35	20.21	8.73	37.13	41.57
Brazil	36.68	43.23	72.01	26.77	23.17	14.1	33.06	35.99
Greece	61.46	45.15	88.55	44.97	28.08	16.76	45.06	47.50
Portugal	39.86	31.6	40.5	22.67	25.46	13.05	26.78	28.86
New Zealand	65.51	50.45	119.15	30.11	25.93	13.65	47.06	50.80
Wales	61.15	56.61	74.68	28.71	23.45	14.99	41.05	43.27

Table 3.3.4 Life sciences top 25 countries which collaborate most frequently with Scotland ranked by NCI

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
USA	2.93	2.82	3.62	3.03	3.26	3.19	3.16	3.14
England	2.9	2.51	3.33	2.97	3.11	3.19	3.02	3.00
Germany	3.08	2.97	3.81	3.5	3.46	3.65	3.44	3.41
France	3.51	3.02	4.59	3.99	3.63	4.3	3.88	3.84

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Australia	3.32	3.61	4.83	3.08	3.42	3.88	3.69	3.69
The Netherlands	3.77	3.09	5.11	3.74	3.45	4.3	3.94	3.91
Italy	3.96	2.84	4.59	3.76	4	4.4	3.97	3.93
Canada	3.5	3.07	5.06	3.42	3.34	4.61	3.85	3.83
Spain	3.5	2.79	4.78	3.31	3.07	3.93	3.59	3.56
Sweden	4.04	3.54	6.21	4.38	4.89	5	4.74	4.68
Switzerland	3.68	2.81	5.71	4.41	3.35	5.49	4.29	4.24
China	2.2	2.57	5.79	2.99	3.78	3.98	3.69	3.55
Denmark	4.04	3.48	6.68	3.92	4.78	5.56	4.86	4.74
Norway	3.54	4.01	5.39	4.03	4.27	5.64	4.58	4.48
Belgium	3.61	2.92	5.28	4.12	3.73	4.94	4.18	4.10
Republic of Ireland	2.86	2.43	5.35	2.76	3.03	4.79	3.59	3.54
Japan	2.98	3.34	6.63	4.17	5.86	5.48	4.96	4.74
Finland	4.54	3.14	3.97	3.45	5.56	6.58	4.7	4.54
Austria	4.45	2.37	5.57	4.5	4.01	7.26	4.87	4.69
Poland	3.86	3.06	3.36	3.93	3.35	3.26	3.46	3.47
Brazil	2.05	2.87	6.04	3.03	4.84	6.06	4.39	4.15
Greece	2.94	2.72	7.56	4.4	5.45	6.95	5.26	5.00
Portugal	2.05	1.87	2.77	2.46	4.6	6.03	3.62	3.30
New Zealand	3.37	2.83	10.93	3.64	5.39	6.51	5.53	5.45
Wales	2.97	3.22	6.2	3.22	4.03	7.1	4.54	4.46

3.4 Life Sciences Research Productivity and Efficiency

Levels of research publications are, of course, related to the size of the countries within which that research is taking place. In order to enable these factors to be understood, we divided the number of patents, the numbers of papers and counts of citations to those papers relative to the following factors[11]:

- Gross Domestic Product (GDP) in 2015 Q4 value[12]
- Gross Domestic Expenditure on R&D (GERD) excluding Private Non-Profit (PNP)[13]
- Business Enterprise Expenditure on R&D (BERD)[13]
- Government Expenditure on R&D (GovERD) [13]
- Higher Education Expenditure on R&D (HERD) [13]
- R&D personnel (full-time equivalent) [13,14]

The following tables show the value of the ratios, and include Scotland's ranking in parenthesis (rank / number of comparator countries with available data)[15]. Data for GDP, R&D expenditure and researcher numbers cannot be desegregated to the level of life sciences. However, the analysis will still have indicative value and will be in line with similar work that Scottish Enterprise has previously commissioned. As seen below, Scotland consistently ranks highly for publication volume and publication citation metrics, and ranks in the middle for patent volume metrics.

Table 3.4.1 Life sciences patents divided by national productivity or R&D expenditure factors

Patents divided by	2010	2011	2012	2013	2014	2015
GDP in 2015 Q4 values						
ratio per billion GBP (rank/number of comparators)	1.09 (17/28)	0.85 (17/28)	0.99 (17/28)	0.49 (23/28)	0.52 (22/28)	0.77 (17/24)
Gross Domestic Expenditure on R&D excluding PNP						
ratio per billion GBP (rank/number of comparators)	71.7 (10/23)	56.02 (13/24)	67.05 (10/23)	30.08 (17/24)	32.52 (15/21)	NA[16]
Business Enterprise Expenditure						
ratio per billion GBP (rank/number of comparators)	214.93 (6/23)	155.02 (8/24)	180.62 (7/23)	82.39 (14/24)	82.38 (11/21)	126.31 (-)[17]
Government Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	455.48 (16/24)	385.71 (17/24)	540.08 (12/24)	257.81 (19/24)	285.71 (19/23)	NA[16]

[11] Please refer to Section 2.2 for a description and links for data sources. Specifically for Scotland, economic data were obtained from Scottish Government's reports with the exception of R&D personnel and Researchers, which was obtained from European Commission's Eurostat database.
[12] Taiwan's GDP data were obtained from the government's website (https://eng.stat.gov.tw). For India, Iran and Singapore, GDP data were obtained from World Bank's World Development Indicator database.
[13] Brazil, India and Iran were excluded from GERD, BERD, GovERD, HERD, and R&D personnel and Researchers analysis as these data were not available at OECD's data portal.
[14] The United States does not report total R&D Personnel so only Researchers used in the analysis.
[15] Not all economic factor data are available for all comparator countries. The yearly ranking ignores the comparator countries whose data are not available for that year.
[16] At the time of analysis, 2015 data were not yet available on GERD, BERD, GovERD, HERD, R&D Personnel and Researchers for Scotland.
[17] At the time of analysis, 2015 GERD, BERD, GovERD, HERD, R&D Personnel and Researchers data were not available for comparator countries,

Patents divided by	2010	2011	2012	2013	2014	2015
Higher Education Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	137.4 (18/24)	113.33 (19/24)	131.55 (15/24)	63.4 (22/24)	68.12 (19/23)	NA[16]
R&D Personnel and Researchers						
ratio per Full-Time-Equivalent (rank/number of comparators)	0.0044 (9/22)	0.0035 (10/23)	0.0042 (8/23)	0.0020 (15/22)	0.0021 (15/19)	NA[16]

Table 3.4.2 Life sciences publications divided by national productivity or R&D expenditure factors

Publications divided by	2010	2011	2012	2013	2014	2015
GDP in 2015 Q4 values						
ratio per billion GBP (rank/number of comparators)	0.08 (1/28)	0.08 (1/28)	0.08 (1/28)	0.08 (1/28)	0.08 (2/28)	0.08 (2/24)
Gross Domestic Expenditure on R&D excluding PNP						
ratio per billion GBP (rank/number of comparators)	5.08 (1/23)	5.07 (2/24)	5.2 (1/23)	4.65 (2/24)	4.76 (1/21)	NA[16]
Business Enterprise Expenditure						
ratio per billion GBP (rank/number of comparators)	15.23 (1/23)	14.03 (1/24)	14 (1/23)	12.75 (2/24)	12.06 (1/21)	12.26 (-)[17]
Government Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	32.27 (6/24)	34.9 (5/24)	41.85 (5/24)	39.89 (5/24)	41.81 (6/23)	NA[16]
Higher Education Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	9.73 (1/24)	10.25 (2/24)	10.19 (1/24)	9.81 (3/24)	9.97 (1/23)	NA[16]
R&D Personnel and Researchers						
ratio per Full-Time-Equivalent (rank/number of comparators)	0.322 (1/22)	0.32 (1/23)	0.32 (1/23)	0.31 (1/22)	0.31 (1/19)	NA[16]

Table 3.4.3 Life sciences publication citations divided by national productivity or R&D expenditure factors

Total citations divided by	2010	2011	2012	2013	2014	2015
GDP in 2015 Q4 values						
ratio per billion GBP	2.17	0.35	0.77	1.12	1.43	1.53
(rank/number of comparators)	(1/28)	(1/28)	(1/28)	(1/28)	(2/28)	(2/24)
Gross Domestic Expenditure on R&D excluding PNP						
ratio per billion GBP	143.36	22.97	52.19	68.87	89.85	
(rank/number of comparators)	(1/23)	(1/24)	(1/23)	(1/24)	(1/21)	NA[16]
Business Enterprise Expenditure						
ratio per billion GBP	429.73	63.56	140.61	188.64	227.61	249.25
(rank/number of comparators)	(1/23)	(1/24)	(1/23)	(1/24)	(1/21)	(-)[17]
Government Expenditure on R&D						
ratio per billion GBP	910.71	158.15	420.43	590.27	789.41	
(rank/number of comparators)	(6/24)	(5/24)	(5/24)	(5/24)	(5/23)	NA[16]
Higher Education Expenditure on R&D						
ratio per billion GBP	274.72	46.47	102.41	145.16	188.2	
(rank/number of comparators)	(1/24)	(2/24)	(1/24)	(2/24)	(1/23)	NA[16]
R&D Personnel and Researchers						
ratio per Full-Time-Equivalent	9.15	7.20	6.70	4.81	3.18	
(rank/number of comparators)	(1/22)	(1/23)	(1/23)	(1/22)	(1/19)	NA[16]

4 BENCHMARKING SCOTTISH RESEARCH IN CHEMICAL SCIENCES

4.1 Chemical Sciences Research Output and Impact

We analyzed the volume of publications in chemical sciences and citation indicators in Scotland and selected countries or aggregates. The results, ranked by total number of research publications are listed in Table 4.1.1. Chemical sciences were defined as a set of research fields based on JSC's (see Table 4.2.1). Globally, 4.3 million publications were produced over the period of 2010 to 2015. During this time Scotland produced 35,846 publications in chemical sciences. The strongest producer of chemical science research based on publication volume was the USA at 969,897 publications, closely followed by China at 882,863. The G8 and China together accounted for 68% of all chemical sciences publications during this period.

Scotland's contribution to the UK publications was 14% based on publication volume. Among the European countries in the comparator list, Scotland was more active than Finland and the Republic of Ireland.

While Scotland's research output volume was small, its impact was high. Scotland ranked fourth in terms of the Citation Impact (total citation per publication) following Singapore, Switzerland, and the Netherlands. The Scottish Citation Impact was 16.55; this was higher than UK (15.48) and USA (15.61). When looking at the NCI which takes both field and publication year into account, Scotland dropped slightly to fifth place following Switzerland, Singapore, the Netherlands and Denmark.

In the chemical sciences sector, a total of 1,041 patents were identified for Scotland and analyzed based on technical categories and restricted to the assignee, inventor or attorney address field containing either Scotland (or its cities or towns), and having earliest priority country as the UK, PCT or European Patent Convention. A more detailed methodology is described in Section 2 and Appendix B.

The volume of patents for these countries of interest is defined by the number of patents claiming priority from the respective countries. Total citations to patents originating from the countries of interest are reported and presented to provide a comparative picture.

The analysis shows a broad distribution of patents in this space. The top geographical regions include China, the G8, Japan, the USA and South Korea. In terms of patent volume, Scotland is on the lower end of the scale with 1,041 patents. Total citations and average citations were calculated from the citing patents. Based on the citations per patent Scotland is the second country behind the USA.

Scotland's contribution to the UK portfolio is around 5% based on the patent volume. Among the European countries, Scotland's total number of patents is greater than that of Belgium and the Republic of Ireland.

Based on the total patent citations, Scotland's patents receive relatively higher citation counts as compared to Switzerland, Brazil, Belgium, Singapore, South Africa, Israel, New Zealand, the Republic of Ireland, and Iran indicating a strong portfolio for a country of its size.

Table 4.1.1 Chemical sciences research output, patents and impact

Country / Aggregate	Number of Publications	Total Citations	Citation Impact	NCI	Number of Patents	Citations Per Patent
Scotland	35,846	593,117	16.55	1.49	1,041	2.21
G8	2,157,784	27,106,647	12.56	1.18	834,803	1.86
EU-28	1,397,176	16,160,185	11.57	1.15	167,681	1.27
USA	969,897	15,139,388	15.61	1.38	304,864	3.05
China	882,863	7,253,327	8.22	0.92	1,518,026	0.63
Germany	320,816	4,428,880	13.81	1.33	73,214	1.37
Japan	267,854	2,662,074	9.94	0.96	338,626	1.22
United Kingdom	257,120	3,980,240	15.48	1.43	20,578	1.85
France	211,780	2,721,008	12.85	1.25	25,061	1.48
India	211,297	1,529,481	7.24	0.8	16,451	0.69
Italy	173,523	2,021,521	11.65	1.25	10,432	1.02
South Korea	165,026	1,609,968	9.76	0.93	195,069	0.78
Canada	158,904	2,107,449	13.26	1.25	3,263	1.05
Russia	127,251	654,318	5.14	0.63	57,942	0.31
Australia	121,132	1,634,010	13.49	1.37	6,320	1.04
Brazil	99,217	709,633	7.15	0.78	12,211	0.11
The Netherlands	82,661	1,389,194	16.81	1.54	3,106	0.88
Iran	81,305	572,145	7.04	0.83	9	0.78
Switzerland	80,236	1,416,764	17.66	1.65	1,901	1.01
Taiwan	76,824	707,894	9.21	0.91	25,511	0.72
Sweden	63,303	926,270	14.63	1.4	2,828	1.67
Belgium	53,161	758,847	14.27	1.39	1,039	1.05

Country / Aggregate	Number of Publications	Total Citations	Citation Impact	NCI	Number of Patents	Citations Per Patent
Denmark	40,546	625,216	15.42	1.54	1,970	2.15
Singapore	34,406	636,377	18.5	1.61	894	0.93
Israel	32,379	482,419	14.9	1.29	672	1.15
Finland	31,803	440,732	13.86	1.34	2,175	1.46
South Africa	24,795	233,400	9.41	1.05	1,161	0.69
Republic of Ireland	20,974	325,379	15.51	1.41	356	1.41
New Zealand	20,266	256,513	12.66	1.33	933	0.78

4.2 Chemical Sciences Research Strengths and Weaknesses by Sub-Category

4.2.1 Research publication strengths and weaknesses

The following tables display the research field included in the chemical sciences analysis and their respective trend over the 2010 to 2015 period.

The first table shows the relative portion of UK chemical sciences publications that were Scottish in each year. Since there was a different publication volume in each year, a weighted average was calculated to take this fact into account for each field. As the weighted average is a better overall estimate than the unweighted average, we used it to assess our rankings. Unless otherwise stated, the research fields are ranked by the weighted average column.

4.2.1.1 Publication volume: comparing with UK, EU-28

It was observed that in diverse fields such as Petroleum Engineering, Soil Science, Crystallography, Oceanography, and Particles & Fields Physics, Scotland was a significant contributor to UK research output in terms of publication volume. The proportion of UK publications in these fields that was Scottish ranged from 21% to 36%. On the opposite end in the fields of Metallurgy & Metallurgical Engineering, Ceramics Materials Science, Characterization & Testing Materials Science, Composites Materials Science, and Neuroimaging, Scotland was a lesser contributor to UK publication volume, accounting for 4 to 7% each.

Similarly, Scotland was a significant contributor to EU-28 research output in the fields of Petroleum Engineering. However, the other top fields were Biodiversity Conservation, Geology, Biology and Oceanography. It was observed that, with the exception of Paper & Wood, Scotland played a relatively minor role in EU-28's research output in various Materials Sciences. This is potentially due to a difference of research volume in different fields in the UK and in the EU-28 as a whole.

Table 4.2.1 Chemical sciences proportion of Scottish publications out of UK publications

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Engineering, Petroleum	32.52%	32.35%	34.94%	32.86%	33.70%	48.48%	36.07%	35.81%
Soil Science	28.27%	28.94%	25.24%	30.15%	29.09%	30.81%	28.81%	28.75%
Crystallography	30.48%	27.29%	21.85%	22.79%	21.58%	17.79%	24.13%	23.63%
Oceanography	19.56%	23.36%	21.52%	21.25%	19.91%	22.21%	21.35%	21.30%
Physics, Particles & Fields	16.47%	20.18%	23.89%	21.72%	20.92%	19.90%	20.65%	20.51%
Geology	26.89%	16.67%	17.32%	21.72%	20.65%	20.37%	20.50%	20.60%
Physics, Nuclear	17.18%	18.75%	24.54%	21.10%	18.85%	20.40%	20.21%	20.14%
Biodiversity Conservation	16.84%	19.93%	19.42%	17.80%	22.29%	18.41%	19.23%	19.11%
Chemistry, Inorganic & Nuclear	20.95%	16.23%	17.77%	19.38%	19.24%	18.43%	18.67%	18.66%
Materials Science, Paper & Wood	30.77%	17.39%	4.55%	15.00%	20.51%	19.05%	18.54%	17.88%
Biology	17.64%	17.29%	18.58%	20.61%	16.91%	16.91%	17.93%	17.99%
Geochemistry & Geophysics	17.61%	16.43%	19.89%	17.85%	16.87%	15.35%	17.28%	17.33%
Geosciences, Multidisciplinary	16.02%	15.00%	16.89%	15.64%	16.53%	17.67%	16.36%	16.29%
Physics, Multidisciplinary	14.24%	16.40%	15.99%	15.83%	18.59%	15.98%	16.22%	16.17%
Cell Biology	16.52%	15.87%	16.50%	15.79%	15.89%	15.47%	15.99%	16.01%
Microbiology	14.88%	17.15%	14.46%	16.31%	17.36%	15.35%	15.92%	15.92%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Biochemistry & Molecular Biology	16.66%	15.27%	16.22%	15.22%	15.42%	15.02%	15.65%	15.64%
Green & Sustainable Science & Technology	16.28%	17.65%	13.40%	14.78%	13.03%	15.71%	14.92%	15.14%
Chemistry, Organic	13.54%	14.91%	12.95%	14.48%	15.81%	15.95%	14.53%	14.61%
Mineralogy	14.38%	11.92%	11.82%	17.46%	17.75%	13.51%	14.40%	14.47%
Multidisciplinary Sciences	16.31%	16.37%	17.01%	14.36%	14.16%	10.65%	14.34%	14.81%
Biochemical Research Methods	14.70%	14.25%	16.19%	14.01%	13.45%	13.16%	14.33%	14.29%
Limnology	16.67%	10.07%	18.32%	13.84%	13.70%	12.61%	14.09%	14.20%
Biotechnology & Applied Microbiology	13.60%	11.73%	14.46%	14.37%	14.67%	15.53%	14.06%	14.06%
Chemistry, Physical	11.11%	12.50%	11.13%	10.25%	9.95%	10.97%	14.06%	10.99%
Energy & Fuels	12.88%	13.97%	13.76%	12.78%	14.79%	14.70%	13.95%	13.81%
Chemistry, Multidisciplinary	15.63%	14.03%	14.19%	13.86%	12.71%	12.51%	13.71%	13.82%
Substance Abuse	14.98%	11.31%	18.53%	11.65%	13.66%	13.25%	13.70%	13.90%
Toxicology	14.56%	12.45%	13.99%	13.63%	14.76%	11.99%	13.61%	13.56%
Chemistry, Medicinal	16.82%	15.17%	11.42%	13.72%	12.72%	10.73%	13.48%	13.43%
Spectroscopy	14.50%	14.39%	9.95%	12.02%	15.45%	11.74%	13.13%	13.01%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Engineering, Environmental	13.14%	13.40%	10.89%	11.67%	12.92%	15.11%	12.93%	12.86%
Anesthesiology	13.77%	13.90%	12.32%	11.72%	11.80%	9.82%	12.07%	12.22%
Nanoscience & Nanotechnology	12.20%	12.09%	13.63%	11.15%	10.85%	11.75%	11.92%	11.94%
Chemistry, Analytical	12.32%	13.14%	11.59%	11.50%	11.47%	10.26%	11.71%	11.71%
Physics, Atomic, Molecular & Chemical	12.92%	12.10%	12.70%	11.37%	10.80%	10.11%	11.63%	11.67%
Food Science & Technology	12.25%	11.46%	10.89%	11.02%	12.07%	10.33%	11.33%	11.34%
Clinical Neurology	11.57%	11.08%	11.14%	11.81%	11.36%	10.63%	11.26%	11.26%
Cell & Tissue Engineering	11.38%	6.99%	13.55%	10.07%	10.81%	12.81%	11.16%	10.94%
Chemistry, Applied	9.68%	10.47%	11.00%	8.99%	15.08%	10.11%	11.10%	10.89%
Neurosciences	11.10%	11.92%	11.56%	10.68%	10.53%	10.72%	11.07%	11.09%
Materials Science, Multidisciplinary	8.47%	10.48%	10.17%	9.78%	8.34%	9.45%	9.44%	9.45%
Physics, Condensed Matter	7.72%	8.77%	8.65%	9.67%	9.72%	10.88%	9.19%	9.23%
Engineering, Chemical	7.44%	8.73%	8.42%	8.05%	10.16%	11.24%	9.13%	9.01%
Meteorology & Atmospheric Sciences	10.26%	9.46%	7.29%	8.47%	8.57%	9.71%	8.96%	8.96%

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Thermodynamics	8.12%	9.42%	7.89%	6.21%	11.74%	8.06%	8.60%	8.57%
Electrochemistry	8.29%	7.84%	11.22%	7.89%	8.72%	7.41%	8.50%	8.56%
Materials Science, Biomaterials	7.79%	9.31%	7.45%	9.48%	8.35%	7.19%	8.28%	8.26%
Polymer Science	8.39%	7.50%	8.75%	8.44%	9.54%	6.43%	8.16%	8.17%
Nuclear Science & Technology	7.27%	10.11%	7.41%	8.10%	9.39%	6.00%	8.09%	8.05%
Materials Science, Coatings & Films	6.34%	7.32%	11.06%	6.05%	7.45%	9.20%	7.78%	7.90%
Mining & Mineral Processing	5.48%	6.30%	12.73%	5.53%	9.35%	6.36%	6.95%	7.62%
Neuroimaging	4.87%	6.77%	8.33%	5.90%	7.80%	6.67%	6.81%	6.72%
Materials Science, Composites	7.79%	7.32%	4.98%	4.70%	8.39%	7.34%	6.81%	6.75%
Materials Science, Characterization & Testing	7.94%	4.73%	6.44%	8.02%	3.26%	3.82%	5.84%	5.70%
Materials Science, Ceramics	2.23%	9.34%	5.88%	7.10%	6.79%	4.32%	5.82%	5.94%
Metallurgy & Metallurgical Engineering	2.91%	3.03%	3.39%	4.98%	5.14%	4.62%	4.01%	4.01%

Table 4.2.2 Chemical sciences proportion of Scottish publications out of EU-28 publications

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Engineering, Petroleum	9.43%	7.77%	9.06%	6.87%	8.07%	14.63%	9.31%	9.31%
Biodiversity Conservation	5.32%	6.81%	5.80%	5.81%	7.53%	6.15%	6.27%	6.24%
Geology	7.57%	5.21%	4.35%	5.25%	5.77%	5.87%	5.63%	5.67%
Biology	4.80%	5.22%	5.33%	6.12%	5.17%	5.13%	5.29%	5.29%
Oceanography	4.63%	5.77%	5.18%	5.49%	4.81%	5.41%	5.23%	5.22%
Substance Abuse	5.25%	4.27%	6.34%	3.98%	4.60%	5.32%	4.91%	4.96%
Physics, Particles & Fields	3.32%	4.17%	5.33%	4.88%	5.12%	5.01%	4.66%	4.64%
Multidisciplinary Sciences	6.24%	5.50%	5.02%	4.24%	4.22%	3.31%	4.47%	4.76%
Crystallography	5.81%	4.76%	3.81%	4.10%	4.05%	3.37%	4.41%	4.32%
Soil Science	3.84%	4.70%	3.30%	4.15%	3.27%	3.70%	3.83%	3.83%
Geochemistry & Geophysics	3.83%	3.47%	4.43%	3.83%	3.59%	3.79%	3.82%	3.82%
Cell Biology	3.92%	3.72%	3.80%	3.72%	3.66%	3.61%	3.73%	3.74%
Geosciences, Multidisciplinary	3.78%	3.25%	3.52%	3.28%	3.38%	3.66%	3.48%	3.48%
Biochemistry & Molecular Biology	3.83%	3.44%	3.43%	3.25%	3.34%	3.24%	3.42%	3.42%
Physics, Nuclear	2.33%	2.72%	3.88%	3.37%	3.02%	3.70%	3.17%	3.17%
Microbiology	2.95%	3.45%	2.79%	3.10%	3.30%	3.05%	3.11%	3.11%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Green & Sustainable Science & Technology	3.40%	3.43%	2.66%	2.75%	2.59%	3.09%	2.93%	2.99%
Physics, Multidisciplinary	2.37%	2.78%	2.93%	2.69%	3.29%	2.98%	2.85%	2.84%
Limnology	2.88%	2.24%	3.63%	3.04%	2.92%	2.27%	2.84%	2.83%
Biochemical Research Methods	3.00%	2.99%	3.18%	2.66%	2.50%	2.48%	2.81%	2.80%
Cell & Tissue Engineering	2.75%	1.58%	3.68%	2.50%	2.71%	3.14%	2.77%	2.73%
Chemistry, Inorganic & Nuclear	3.34%	2.72%	2.53%	2.55%	2.74%	2.67%	2.76%	2.76%
Neurosciences	2.72%	2.90%	2.86%	2.61%	2.53%	2.55%	2.69%	2.70%
Anesthesiology	2.45%	2.64%	2.69%	2.60%	2.43%	2.51%	2.55%	2.55%
Clinical Neurology	2.46%	2.37%	2.48%	2.69%	2.72%	2.47%	2.53%	2.53%
Toxicology	2.90%	2.22%	2.54%	2.41%	2.69%	2.08%	2.47%	2.47%
Chemistry, Multidisciplinary	2.69%	2.46%	2.44%	2.30%	2.21%	2.19%	2.37%	2.38%
Biotechnology & Applied Microbiology	2.46%	2.12%	2.44%	2.30%	2.36%	2.50%	2.37%	2.36%
Meteorology & Atmospheric Sciences	2.68%	2.32%	1.89%	2.24%	2.26%	2.74%	2.36%	2.36%
Mineralogy	2.18%	1.70%	2.53%	2.57%	2.70%	2.11%	2.30%	2.30%
Energy & Fuels	2.03%	2.32%	2.09%	2.23%	2.29%	2.54%	2.29%	2.25%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Chemistry, Organic	2.38%	2.51%	2.03%	2.06%	2.26%	2.36%	2.27%	2.27%
Chemistry, Medicinal	2.91%	2.68%	1.87%	2.16%	1.92%	1.61%	2.18%	2.19%
Spectroscopy	2.66%	2.25%	1.46%	1.74%	2.41%	1.85%	2.07%	2.06%
Nanoscience & Nanotechnology	1.87%	1.77%	2.15%	1.75%	1.66%	1.83%	1.83%	1.84%
Physics, Atomic, Molecular & Chemical	2.02%	1.84%	1.88%	1.81%	1.70%	1.66%	1.82%	1.82%
Engineering, Environmental	1.83%	1.83%	1.52%	1.56%	1.80%	2.35%	1.82%	1.81%
Neuroimaging	1.30%	1.72%	2.32%	1.52%	2.01%	1.69%	1.78%	1.76%
Materials Science, Biomaterials	1.43%	2.18%	1.51%	1.84%	1.59%	1.40%	1.64%	1.66%
Chemistry, Physical	1.61%	1.82%	1.58%	1.48%	1.45%	1.66%	1.60%	1.60%
Chemistry, Analytical	1.54%	1.79%	1.52%	1.47%	1.51%	1.33%	1.53%	1.53%
Materials Science, Multidisciplinary	1.27%	1.56%	1.53%	1.43%	1.16%	1.53%	1.41%	1.41%
Physics, Condensed Matter	1.10%	1.23%	1.29%	1.37%	1.43%	1.60%	1.33%	1.34%
Chemistry, Applied	1.16%	1.21%	1.24%	0.89%	2.08%	1.01%	1.27%	1.27%
Materials Science, Composites	1.17%	1.30%	0.98%	0.75%	1.50%	1.42%	1.20%	1.19%
Engineering, Chemical	0.89%	1.22%	1.04%	0.98%	1.24%	1.54%	1.17%	1.15%

Research Area	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Thermodynamics	0.98%	1.17%	0.87%	0.87%	1.38%	1.15%	1.09%	1.07%
Food Science & Technology	1.26%	1.24%	0.99%	1.06%	1.06%	0.93%	1.09%	1.09%
Electrochemistry	1.07%	0.96%	1.35%	0.93%	1.14%	0.98%	1.07%	1.07%
Nuclear Science & Technology	0.95%	1.30%	0.86%	1.08%	1.22%	0.87%	1.06%	1.05%
Polymer Science	0.98%	0.97%	1.12%	0.95%	1.11%	0.79%	0.99%	0.99%
Materials Science, Coatings & Films	0.75%	0.92%	1.28%	0.69%	0.96%	1.14%	0.94%	0.96%
Materials Science, Characterization & Testing	1.32%	0.75%	0.86%	1.21%	0.52%	0.56%	0.88%	0.87%
Mining & Mineral Processing	0.53%	0.87%	0.67%	0.69%	0.93%	0.90%	0.77%	0.76%
Materials Science, Ceramics	0.36%	1.27%	0.81%	0.92%	0.81%	0.45%	0.76%	0.77%
Materials Science, Paper & Wood	1.54%	0.65%	0.13%	0.44%	1.01%	0.51%	0.67%	0.71%
Metallurgy & Metallurgical Engineering	0.36%	0.42%	0.47%	0.63%	0.67%	0.62%	0.53%	0.53%

4.2.1.2 NCI: comparing with UK and EU-28

When looking at the NCI, we computed a ratio between the metric of Scotland and of the UK. The top field is Paper & Wood Materials Science at a ratio value of 1.56. Interestingly, while Scottish research contributed about 30% of UK publications in Petroleum Engineering, the NCI ratio between Scotland and UK was close to 1.00 indicating that Scottish research in this field was on par with the UK research in terms of NCI.

When comparing NCI of Scotland and of EU-28 aggregate, Paper & Wood Materials Science, Nuclear Physics and Particles & Fields Physics occupy the top three places.

Table 4.2.3 Chemical sciences ratio of NCI of Scottish publications relative to the UK

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Materials Science, Paper & Wood	1.42	1.44	1.52	4.37	1.73	0.61	1.56	1.85
Physics, Nuclear	1.90	0.96	1.59	1.24	1.58	1.15	1.43	1.40
Physics, Particles & Fields	1.48	0.97	1.46	1.25	1.20	1.26	1.28	1.27
Anesthesiology	1.02	0.95	0.88	1.23	1.72	1.62	1.22	1.23
Clinical Neurology	1.43	0.85	1.24	1.17	1.31	1.16	1.20	1.19
Cell & Tissue Engineering	0.96	0.63	1.21	1.47	1.31	1.19	1.19	1.13
Toxicology	1.53	0.97	1.37	1.14	1.10	0.96	1.18	1.18
Nuclear Science & Technology	1.12	1.01	1.34	1.22	1.12	1.13	1.14	1.16
Multidisciplinary Sciences	0.70	0.74	1.24	1.52	1.48	0.90	1.14	1.10
Physics, Multidisciplinary	1.12	0.99	1.24	1.20	1.16	1.07	1.14	1.13
Food Science & Technology	1.00	1.37	1.23	0.98	0.93	1.25	1.13	1.13
Limnology	1.20	1.15	1.12	0.80	1.52	0.90	1.12	1.12
Chemistry, Applied	1.46	1.23	1.30	0.96	0.93	0.90	1.12	1.13
Chemistry, Inorganic & Nuclear	1.36	0.97	1.08	1.02	1.09	1.08	1.12	1.10

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Biotechnology & Applied Microbiology	0.95	1.54	0.76	1.21	1.09	1.19	1.11	1.12
Biodiversity Conservation	1.23	1.17	1.06	1.23	0.90	1.16	1.11	1.12
Microbiology	1.13	1.13	1.07	1.09	1.09	1.06	1.09	1.09
Biology	1.11	1.07	1.08	1.16	1.13	0.97	1.09	1.09
Geochemistry & Geophysics	1.00	0.92	0.81	1.72	0.82	1.09	1.08	1.06
Electrochemistry	0.97	1.61	1.41	0.85	0.92	0.78	1.07	1.09
Meteorology & Atmospheric Sciences	1.10	1.07	1.28	1.24	0.83	0.93	1.06	1.08
Chemistry, Organic	1.05	0.90	1.20	1.11	1.18	0.84	1.04	1.05
Neurosciences	0.95	0.93	0.93	1.27	1.00	1.13	1.03	1.03
Substance Abuse	0.85	1.22	1.06	0.88	1.09	1.03	1.03	1.02
Cell Biology	0.93	0.95	1.05	1.17	1.02	0.98	1.02	1.02
Biochemistry & Molecular Biology	0.85	0.94	1.07	1.13	1.09	1.02	1.01	1.02
Engineering, Petroleum	0.68	0.90	0.98	1.69	1.05	1.36	0.98	1.11
Geology	0.91	0.62	1.03	1.37	0.94	0.84	0.98	0.95
Green & Sustainable Science & Technology	1.23	0.62	0.88	0.80	1.08	1.09	0.97	0.95

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Soil Science	1.01	0.91	1.12	1.14	0.77	0.86	0.97	0.97
Chemistry, Medicinal	0.94	0.78	1.17	1.15	0.95	0.85	0.96	0.97
Biochemical Research Methods	0.63	1.20	1.03	0.94	1.12	0.95	0.96	0.98
Materials Science, Ceramics	1.92	0.65	0.87	1.19	1.03	0.61	0.96	1.05
Oceanography	1.11	0.88	0.94	0.85	1.08	0.94	0.96	0.97
Materials Science, Biomaterials	0.87	0.67	0.76	1.14	0.83	1.29	0.96	0.93
Chemistry, Analytical	0.86	1.12	0.93	0.90	0.98	0.93	0.96	0.95
Geosciences, Multidisciplinary	0.85	1.01	0.99	1.00	0.87	0.89	0.93	0.93
Mineralogy	0.96	1.04	0.87	1.12	0.81	0.69	0.93	0.92
Neuroimaging	0.82	0.76	0.78	1.02	1.09	1.05	0.91	0.92
Spectroscopy	0.77	1.04	1.39	0.86	0.74	0.89	0.91	0.95
Engineering, Chemical	0.99	0.83	0.85	0.83	1.00	0.87	0.90	0.90
Engineering, Environmental	0.68	0.89	0.73	1.09	0.76	1.10	0.89	0.88
Polymer Science	0.66	0.84	0.72	0.75	1.14	1.13	0.87	0.87
Physics, Atomic, Molecular & Chemical	0.88	0.86	0.99	0.79	0.92	0.82	0.87	0.88

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Materials Science, Coatings & Films	0.45	0.37	1.22	0.85	1.08	1.02	0.87	0.83
Chemistry, Multidisciplinary	0.91	0.90	0.89	0.93	0.74	0.87	0.87	0.87
Energy & Fuels	0.89	0.67	0.91	1.05	0.86	0.79	0.87	0.86
Materials Science, Multidisciplinary	0.89	0.85	0.87	0.92	0.89	0.77	0.86	0.87
Materials Science, Characterization & Testing	0.96	1.13	0.38	0.78	1.81	0.55	0.86	0.93
Chemistry, Physical	0.74	0.85	0.85	0.88	0.81	0.83	0.83	0.83
Physics, Condensed Matter	0.60	0.83	1.10	0.73	0.71	0.91	0.82	0.81
Materials Science, Composites	0.89	1.09	0.73	1.06	0.62	0.76	0.81	0.86
Thermodynamics	0.60	0.65	0.72	0.72	1.01	0.75	0.76	0.74
Nanoscience & Nanotechnology	0.77	0.59	0.82	0.73	0.59	0.73	0.70	0.71
Metallurgy & Metallurgical Engineering	0.96	0.35	0.51	0.77	0.70	0.77	0.68	0.68
Mining & Mineral Processing	2.31	0.54	0.75	0.51	0.84	0.24	0.64	0.86
Crystallography	0.19	0.26	0.62	0.97	0.63	0.79	0.42	0.58

Table 4.2.4 Chemical sciences ratio of NCI of Scottish publications relative to EU-28

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Materials Science, Paper & Wood	1.92	2.95	2.71	6.77	1.66	1.21	2.41	2.87
Physics, Nuclear	2.68	1.23	2.91	1.76	2.28	1.50	2.08	2.06
Physics, Particles & Fields	2.15	1.26	2.12	1.62	1.54	1.57	1.71	1.71
Clinical Neurology	2.10	1.23	1.74	1.54	1.88	1.57	1.68	1.68
Anesthesiology	1.28	1.44	1.16	1.53	2.16	1.98	1.59	1.59
Physics, Multidisciplinary	1.54	1.31	1.63	1.54	1.68	1.53	1.55	1.54
Biotechnology & Applied Microbiology	1.19	2.03	1.06	1.49	1.41	1.56	1.45	1.46
Biology	1.50	1.41	1.43	1.49	1.52	1.23	1.43	1.43
Meteorology & Atmospheric Sciences	1.36	1.41	1.60	1.72	1.14	1.26	1.40	1.42
Multidisciplinary Sciences	0.97	0.76	1.75	1.79	1.70	1.07	1.40	1.34
Biochemistry & Molecular Biology	1.17	1.29	1.50	1.47	1.52	1.42	1.39	1.39
Limnology	1.21	1.41	1.36	0.95	2.07	1.18	1.37	1.36
Microbiology	1.38	1.37	1.27	1.25	1.41	1.40	1.35	1.35
Nuclear Science & Technology	1.18	1.13	1.60	1.41	1.35	1.53	1.34	1.37
Toxicology	1.53	1.13	1.44	1.24	1.30	1.16	1.31	1.30

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Chemistry, Inorganic & Nuclear	1.71	1.13	1.23	1.19	1.25	1.21	1.31	1.29
Neurosciences	1.21	1.14	1.17	1.59	1.22	1.36	1.28	1.28
Biodiversity Conservation	1.48	1.34	1.15	1.38	1.04	1.38	1.27	1.30
Cell Biology	1.15	1.11	1.34	1.40	1.25	1.27	1.25	1.25
Geology	1.17	0.71	1.19	2.04	1.15	1.16	1.25	1.24
Geochemistry & Geophysics	1.13	1.01	0.90	2.18	0.94	1.29	1.25	1.24
Cell & Tissue Engineering	1.17	0.56	1.24	1.47	1.39	1.21	1.24	1.17
Biochemical Research Methods	0.94	1.70	1.10	1.12	1.21	1.17	1.21	1.21
Soil Science	1.42	1.33	1.58	1.10	0.80	1.09	1.20	1.22
Geosciences, Multidisciplinary	1.02	1.24	1.28	1.36	1.17	1.13	1.20	1.20
Substance Abuse	0.84	1.33	1.21	0.99	1.34	1.30	1.18	1.17
Food Science & Technology	1.08	1.41	1.23	0.93	1.04	1.22	1.15	1.15
Neuroimaging	1.07	1.01	1.01	1.26	1.30	1.23	1.15	1.15
Chemistry, Organic	1.17	0.97	1.28	1.26	1.34	0.88	1.14	1.15
Chemistry, Multidisciplinary	1.13	1.17	1.15	1.23	1.03	1.12	1.14	1.14
Chemistry, Medicinal	1.02	0.89	1.44	1.41	1.07	0.96	1.11	1.13

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Oceanography	1.25	1.03	1.15	0.96	1.30	0.95	1.09	1.11
Chemistry, Analytical	0.97	1.23	1.03	0.99	1.10	1.06	1.07	1.06
Engineering, Petroleum	0.92	0.84	0.85	3.25	0.68	1.24	1.06	1.30
Mineralogy	1.16	1.21	0.98	1.35	0.89	0.74	1.05	1.05
Chemistry, Applied	1.40	1.17	1.04	0.87	0.97	0.79	1.04	1.04
Physics, Condensed Matter	0.65	1.04	1.38	0.99	1.01	1.07	1.03	1.02
Spectroscopy	0.92	1.15	1.46	1.13	0.78	0.92	1.03	1.06
Electrochemistry	1.05	1.49	1.12	0.85	0.89	0.78	1.03	1.03
Physics, Atomic, Molecular & Chemical	0.94	1.02	1.14	0.94	1.15	0.97	1.02	1.03
Chemistry, Physical	0.84	0.98	1.06	1.10	1.05	0.99	1.00	1.00
Materials Science, Characterization & Testing	1.40	1.24	0.59	0.71	1.58	0.71	1.00	1.04
Green & Sustainable Science & Technology	1.23	0.70	0.88	0.80	1.13	1.09	0.99	0.97
Engineering, Chemical	1.04	0.87	0.86	0.92	1.23	1.01	0.99	0.99
Materials Science, Ceramics	1.81	0.62	0.85	1.27	1.12	0.69	0.98	1.06
Polymer Science	0.71	0.97	0.79	0.77	1.31	1.30	0.97	0.97

Research Field	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Mining & Mineral Processing	2.60	0.70	1.19	0.80	1.14	0.43	0.96	1.14
Materials Science, Multidisciplinary	0.91	0.97	0.88	1.02	1.02	0.95	0.96	0.95
Engineering, Environmental	0.67	1.12	0.75	1.24	0.79	1.11	0.94	0.95
Materials Science, Composites	0.90	1.01	0.82	1.24	0.73	0.93	0.90	0.94
Materials Science, Biomaterials	0.68	0.46	0.73	1.11	0.81	1.25	0.85	0.84
Nanoscience & Nanotechnology	0.80	0.69	0.87	0.92	0.80	0.86	0.83	0.82
Energy & Fuels	0.91	0.67	0.84	1.05	0.81	0.66	0.81	0.82
Metallurgy & Metallurgical Engineering	1.17	0.39	0.65	0.90	0.70	0.97	0.80	0.80
Materials Science, Coatings & Films	0.36	0.32	1.08	0.74	0.94	1.14	0.77	0.76
Thermodynamics	0.58	0.67	0.75	0.85	0.79	0.70	0.74	0.72
Crystallography	0.43	0.61	0.76	1.22	0.67	0.70	0.68	0.73

The figure below shows a scatter plot of individual chemical science fields by their NCI and the total number of publications. The vertical axis crosses at the median publication count. Research fields in the top right corner are considered strong, while fields in the bottom left corner are considered weak. Scottish publications had a NCI that was higher than the global average (>1) in the vast majority of chemical sciences fields. Out of 57 fields selected, 49 fields were in this group. Particularly strong were the fields of Nuclear Physics (2.58, twice of that of EU-28 average in this field) and Paper & Wood Materials Science (2.48, or 2.4 times that of EU-28 average in this field). Other physics related fields also ranked fairly high in the list of NCI.

When considered with the number of publications, the following fields were particular strong: Biochemistry & Molecular Biology (which overlaps with life sciences), Multidisciplinary Physics, Particles & Fields Physics, Clinical Neurology, and Cell Biology. Biochemistry & Molecular Biology had a high volume (4,385 publications) and good NCI (1.66) which made it a field of strength. The various fields of physics had also similar strong characteristics, albeit at a significant less level in terms of publication volume (674 publications in Nuclear Physics, for example) and higher NCI (2.58 for Nuclear Physics). Paper & Wood Materials Science, on the other hand had a relatively high NCI (2.70) but a small publication volume (28 publications) marking it and similar fields opportunities to grow.

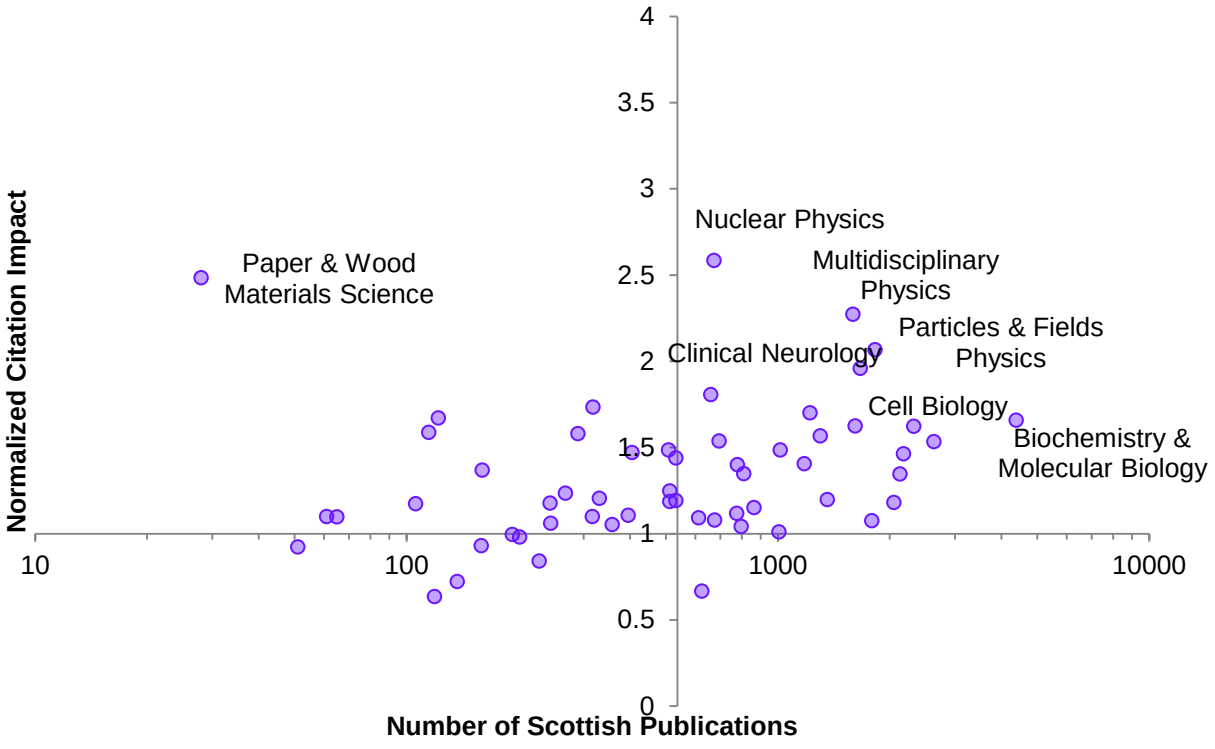


Figure 4.2.1 Chemical sciences fields – Scottish NCI versus number of publications

4.2.2 Patent strengths and weaknesses

4.2.2.1 Scotland Chemical Sciences Patent Research Output based on Tier 1 Entities

The table below shows the Tier 1 entities (top 16 entities) portfolios. Entities having more than 10 patent publications are considered in the Tier 1 entity analysis. The Clarivate strength score assigned to each patent family measure the various characteristics that act as proxies for the commercial behaviour behind and the utility of an individual piece of intellectual property. The Clarivate strength score index is based on the various parameters including market protection time, novelty, geographic market protection, technical coverage, frequency citation impact.

Among the Tier 1 entities, Schlumberger has the largest patent portfolio, closely followed by the University of St. Andrews and the University of Edinburgh. Based on the Clarivate strength index score, Johnson & Johnson, Welltec and Weatherford Int., have the highest scoring portfolios due to their high geographical market protection. Frequency of citation by downstream patent applications shows Welltec has the highest weightage, followed by the University of Strathclyde and Schlumberger.

Major companies present in Tier 1 either have a subsidiary in Scotland or have acquired a Scotland based entity. Some of the top companies are retrieved due to their offices or plants being based in Scotland, or alternatively the inventor is from Scotland. Some of these are described below.

The majority of Johnson & Johnson's filing activity is through its subsidiary Life scan Scotland Ltd. Welltec UK is located in Aberdeen and most of their inventor addresses are listed as being located in Scotland. Weatherford also has its subsidiary Petro Well Ltd located in Aberdeen, Scotland. Schlumberger has its subsidiaries, M-I Drilling Fluid UK Ltd, United Wire Ltd, and Meta Downhole Limited based in Scotland.

Table 4.2.5 Chemical sciences patent strength of Scottish research based on Tier 1 entities

Tier 1	Total Inventions	Market Protection Time	Novelty	Geographic Market Protection	Technical Coverage	Citations Per Patent	Average Clarivate Patent Strength Score
Schlumberger	44	13.34	10.77	3.61	2.80	15.26	43.04
University of St Andrews	40	13.13	16.40	3.10	3.70	9.67	41.71
University of Edinburgh	39	14.18	4.16	2.44	3.67	5.22	34.66
University of Dundee	35	13.23	12.80	2.40	2.80	10.47	33.47
ITI Scotland Ltd	34	12.26	7.45	3.32	4.32	14.96	35.52
Weatherford Int	30	14.33	13.64	4.53	2.33	14.24	51.61
University of Strathclyde	23	13.00	9.60	2.83	4.83	15.04	43.05
University of Glasgow	21	13.62	6.80	3.62	2.95	11.63	40.55

Tier 1	Total Inventions	Market Protection Time	Novelty	Geographic Market Protection	Technical Coverage	Citations Per Patent	Average Clarivate Patent Strength Score
University of Aberdeen	21	14.19	8.66	2.43	2.81	1.94	33.64
Welltec	19	14.32	17.09	6.42	2.11	19.28	54.47
National Oilwell Varco UK Ltd	18	13.67	16.60	3.72	2.06	12.44	40.96
Tendeka AS	13	14.92	4.00	4.08	2.62	7.83	42.48
Halliburton Energy	13	13.08	17.48	2.85	2.46	6.26	32.62
Expro	13	14.08	4.00	3.31	2.23	3.13	28.98
Johnson & Johnson	12	15.75	3.79	6.33	4.75	1.70	55.70
Paradigm	11	15.82	1.18	2.73	2.82	7.40	45.07

Additional insight into these Strength rankings can be revealed when they are plotted against market protection time. The bubble chart below visually represents the strength score vs. remaining life of the portfolios. In this chart, the bubble size reflects portfolio size. This analysis summarizes the results for Tier 1 portfolios.

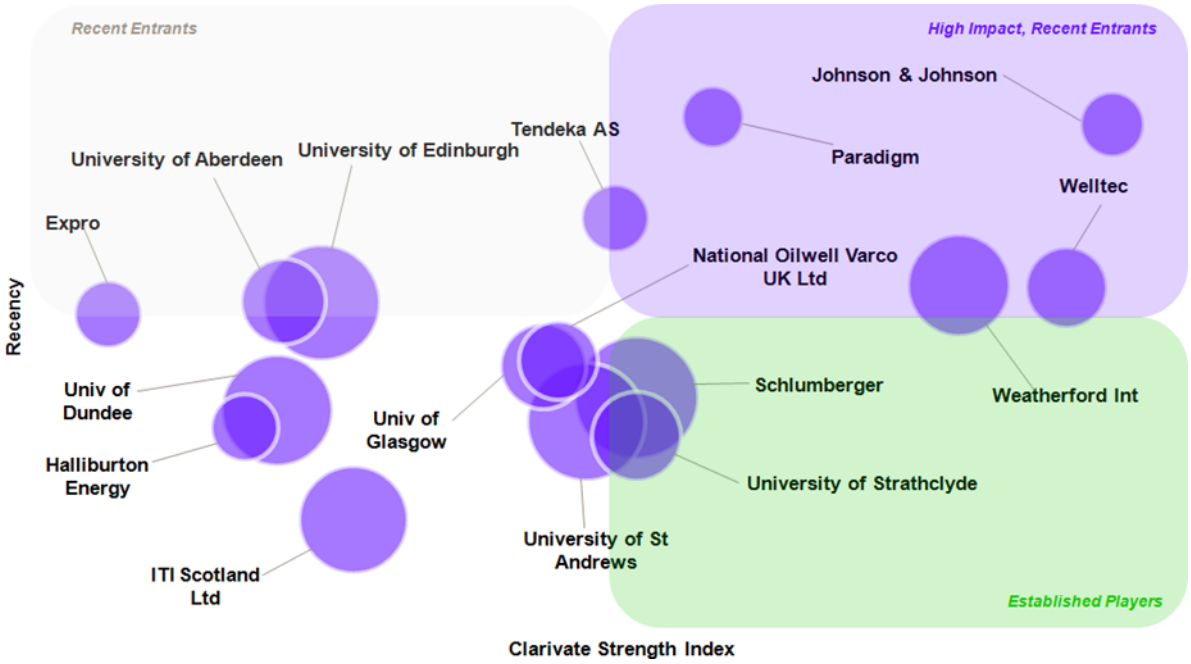


Figure 4.2.2 Chemical sciences Tier 1 entities – patent strength versus market protection time

In the above bubble chart, the most attractive portfolios are those closest to the upper right-hand quadrant, i.e., those that are both higher strength and have a longer life remaining (more recent filings). When viewed from this perspective, Johnson & Johnson and Paradigm are noteworthy, having recent & high strength inventions. Welltec and Weatherford Int. are relatively old but have high strength inventions in their portfolio.

4.2.2.2 Scotland Chemical Sciences Patent Research Output based on Sub-technical Categories

This section of the study focuses on the technical make-up of the patents and patent applications within chemical sciences.

The table below provides the analysis for the technology segments and categories by patent volume, market protection time, novelty, geographic market protection, technical coverage, impact on the field and Clarivate patent strength score.

It is observed that the Petroleum and Polymer categories are the largest in terms of patent volume. Alicyclic and Aromatic Compounds have the highest patent strength in the Organic Chemistry domain. In the Chemical Engineering field, Electrochemical Processes and Electrophoresis are the highest ranking sub-categories in the landscape.

Table 4.2.6 Chemical sciences sub technical categories patent portfolio

Level 1 Category	*Level 2 Sub-category*	*Inventions per Category*	*Market Protection Time*	*Novelty*	*Geographic Market Protection*	*Technical Coverage*	*Citations Per Patent*	*Average Clarivate Patent Strength Score*
Organic Chemistry	**Heterocyclic**	**73**	**13.4**	**11.5**	**2.9**	**3.0**	**9.2**	**35.89**
	Aromatic	**9**	**13.0**	**16.6**	**3.2**	**3.9**	**24.9**	**49.73**
	Alicyclic	**26**	**13.7**	**20.2**	**4.3**	**2.8**	**15.7**	**52.23**
	Aliphatic	**75**	**13.3**	**13.9**	**3.7**	**3.7**	**13.0**	**45.11**
	Other Organic Compound	**17**	**13.0**	**12.6**	**3.1**	**4.2**	**12.0**	**38.23**
Chemical Engineering	**Separation Techniques**	**30**	**13.6**	**11.0**	**3.4**	**3.8**	**8.1**	**39.39**
	Electrochemical Processes And Electrophoresis	**8**	**13.0**	**14.6**	**4.8**	**4.0**	**15.3**	**49.69**
	Chemical / Physical Processes / Apparatus	**86**	**13.5**	**12.7**	**3.7**	**4.0**	**12.8**	**45.69**
	Heat Transfer & Refrigeration	**5**	**14.8**	**6.5**	**4.2**	**2.8**	**8.1**	**44.71**
	Waste Water Treatment	**39**	**13.5**	**12.0**	**3.2**	**3.2**	**13.6**	**39.62**
	Chemical Engineering In General	**4**	**13.8**	**8.1**	**2.3**	**2.0**	**5.1**	**25.39**
Material Science / Applied	**Coatings & Films**	**57**	**13.4**	**10.3**	**2.9**	**3.9**	**15.4**	**41.44**
	Textiles & Paper	**14**	**14.6**	**7.4**	**3.2**	**4.1**	**13.1**	**44.82**

Level 1 Category	*Level 2 Sub-category*	*Inventions per Category*	*Market Protection Time*	*Novelty*	*Geographic Market Protection*	*Technical Coverage*	*Citations Per Patent*	*Average Clarivate Patent Strength Score*
Chemistry	**Glass / Ceramics / Cements**	**54**	**13.1**	**11.8**	**2.6**	**4.5**	**12.1**	**38.84**
	Medicinal Chemistry	**171**	**13.8**	**8.4**	**3.1**	**3.2**	**7.5**	**36.78**
	Dyes / Paints / Printing	**4**	**14.0**	**1.6**	**2.5**	**4.5**	**5.1**	**35.65**
	Catalysts	**14**	**13.6**	**14.4**	**3.5**	**2.6**	**20.3**	**48.73**
Petroleum	**Crude Oil and Natural Gas**	**378**	**13.9**	**10.1**	**3.3**	**2.6**	**10.8**	**39.76**
	Gaseous And Liquid Fuels	**8**	**14.9**	**8.1**	**4.6**	**3.9**	**7.6**	**49.98**
	Other Petroleum Products	**9**	**14.1**	**14.4**	**3.1**	**2.8**	**18.1**	**48.85**
Polymer	**Natural Polymers**	**16**	**14.1**	**7.7**	**4.0**	**3.8**	**20.3**	**49.20**
	Inorganic Polymers	**20**	**13.6**	**12.3**	**3.2**	**3.9**	**12.2**	**42.63**
	Additives	**23**	**13.7**	**4.0**	**2.8**	**4.2**	**18.6**	**42.79**
	Polymer in General	**402**	**13.8**	**8.5**	**2.7**	**3.5**	**7.3**	**36.26**
Inorganic Chemistry		**53**	**13.1**	**12.5**	**3.5**	**3.7**	**11.5**	**40.07**
Nanoscience & Nanotechnology		**12**	**12.5**	**16.2**	**4.0**	**4.2**	**17.0**	**44.22**

Additional insight into these Strength rankings can be revealed when the technical categories patent strength is plotted against market protection time.

In the chart below, the most attractive inventions are those closest to the upper right-hand quadrant, i.e., those that are both higher Strength and have a higher market life remaining. Inventions closest to the upper-right hand quadrant are recent and have a high average strength score. This plot provides an overview of categories that stand out with respect to being both high strength and recency.

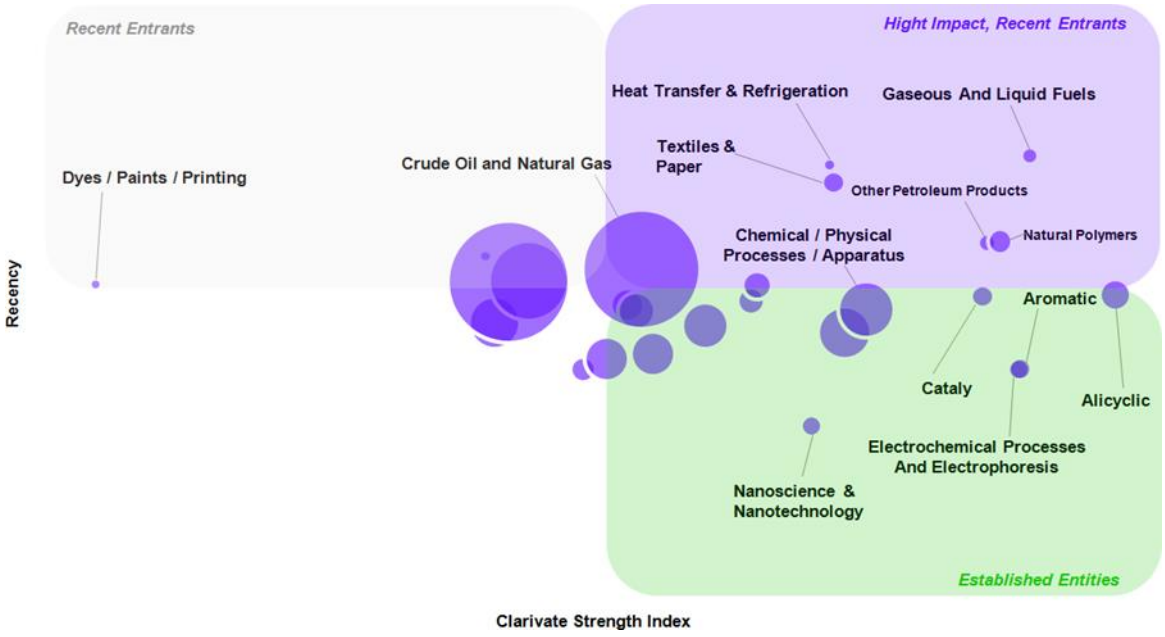


Figure 4.2.3 Chemical sciences patent technical categories – patent strength versus market protection time

Based on this, inventions on Gaseous & Liquid Fuels, Heat transfer & Refrigeration, Textiles & Refrigeration are high strength and recent inventions. In this plot, technical categories that are apparent as having the optimal combination of high strength but low recency are Aromatic Compounds and Nanoscience & Nanotechnology.

4.3 Chemical Sciences Research Collaboration

The level of collaboration in chemical sciences research in Scotland was evaluated by assessing the number of co-authorships in publications. A consistently upward trend was observed in the number of Scottish publications that had international co-authors. When compared to Scottish publications in general, these internationally-collaborated publications had a positive impact as well – these publications had a higher citation impact (18.93 compared to 16.55) and NCI (1.73 compared to1.49).

Table 4.3.1 Chemical sciences publication collaboration and impact

	2010	2011	2012	2013	2014	2015	Grand Total	
Number of Publications w/ International Co-authorship	3,031	3,200	3,403	3,631	3,915	4,182	21,362	
							Weighted Average	**Unweighted Average**
Average Citation Impact of pubs w/ International Co-authorship	33.58	25.91	26.66	17.34	11.62	4.90	18.93	20.00
Average NCI of pubs w/ International Co-authorship	1.67	1.62	1.84	1.81	1.76	1.68	1.73	1.73

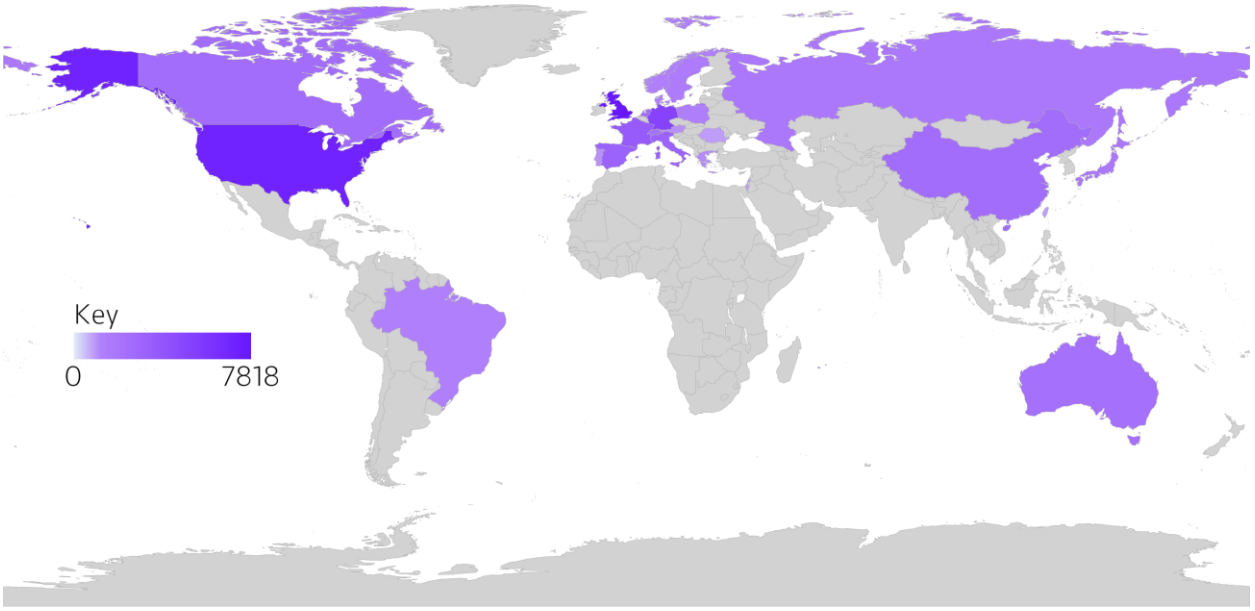


Figure 4.3.1 Chemical sciences top 25 countries which collaborate most frequently with Scotland

Table 4.3.2 Chemical sciences top 25 countries which collaborate most frequently with Scotland ranked by percent of Scottish publications

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
USA	30.98%	30.72%	35.79%	34.15%	32.52%	33.00%	32.92%	32.86%
England	28.67%	30.25%	34.18%	33.13%	31.98%	31.66%	31.73%	31.64%
Germany	21.02%	22.31%	25.80%	24.68%	24.65%	24.68%	23.98%	23.86%
France	15.77%	16.94%	17.98%	17.49%	15.91%	16.76%	16.81%	16.81%

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Italy	12.47%	13.97%	17.60%	15.64%	14.13%	14.63%	14.78%	14.74%
Spain	12.74%	13.25%	17.16%	15.23%	14.38%	13.94%	14.48%	14.45%
The Netherlands	10.59%	10.41%	14.05%	13.00%	12.57%	12.60%	12.28%	12.20%
Canada	10.72%	12.03%	13.22%	11.76%	11.37%	10.57%	11.58%	11.61%
China	6.50%	8.44%	12.72%	12.48%	12.67%	14.71%	11.53%	11.25%
Australia	7.56%	9.38%	12.40%	10.47%	11.19%	11.84%	10.60%	10.47%
Switzerland	7.09%	9.25%	12.02%	11.76%	10.68%	10.33%	10.28%	10.19%
Japan	6.57%	8.53%	10.34%	8.26%	7.56%	8.39%	8.29%	8.28%
Russia	6.70%	7.31%	10.67%	9.06%	7.89%	7.68%	8.23%	8.22%
Sweden	6.27%	6.69%	8.93%	7.57%	7.00%	8.15%	7.48%	7.44%
Poland	4.16%	4.84%	8.14%	7.85%	6.95%	7.01%	6.59%	6.49%
Denmark	3.70%	5.94%	6.99%	5.89%	5.93%	7.96%	6.17%	6.07%
Brazil	3.66%	4.78%	7.32%	7.19%	6.44%	6.98%	6.17%	6.06%
Norway	4.49%	5.94%	7.99%	6.28%	5.85%	6.26%	6.17%	6.14%
Greece	4.16%	4.78%	7.08%	4.96%	4.83%	4.54%	5.05%	5.06%
Republic of Ireland	3.50%	3.84%	5.08%	5.84%	6.00%	4.54%	4.86%	4.80%
Austria	3.46%	3.66%	6.05%	5.12%	4.80%	4.97%	4.73%	4.68%
Portugal	2.77%	4.59%	6.14%	5.26%	4.34%	4.93%	4.71%	4.67%
Israel	2.94%	3.88%	5.99%	4.02%	3.50%	4.42%	4.14%	4.13%
Romania	0.96%	2.53%	5.97%	5.18%	4.19%	4.97%	4.09%	3.97%
Taiwan	2.54%	3.59%	6.14%	4.10%	3.50%	3.90%	3.98%	3.96%

Table 4.3.3 Chemical sciences top 25 countries which collaborate most frequently with Scotland ranked by average citation impact

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
USA	50.69	34.02	40.24	24.77	18.33	7.38	27.62	29.24
England	45.07	31.08	35.79	24.01	17.89	6.98	25.29	26.80
Germany	49.83	30.26	38.05	26.68	16.85	7.19	26.23	28.14
France	52.37	32.15	49.19	27.43	20.33	8.25	30.19	31.62
Italy	55.76	31.32	46.54	25.72	19.12	7.72	29.42	31.03
Spain	46.09	29.23	42.58	25.27	18.78	7.90	27.22	28.31
The Netherlands	49.48	36.45	51.23	31.30	21.74	8.38	31.41	33.10
Canada	53.71	31.25	50.63	25.94	20.86	9.07	30.98	31.91
China	58.13	27.91	48.55	24.58	17.80	6.77	26.03	30.62
Australia	75.67	34.32	53.29	31.37	20.84	9.40	33.49	37.48
Switzerland	63.65	35.75	57.00	31.25	22.77	9.50	33.93	36.65
Japan	66.99	31.56	53.61	27.92	29.10	8.36	34.30	36.26
Russia	58.08	28.83	53.91	23.14	22.92	9.16	31.69	32.67
Sweden	70.55	32.36	64.67	30.45	29.23	9.83	37.37	39.52
Poland	45.56	29.81	47.88	22.10	14.66	8.44	25.84	28.08
Denmark	58.76	42.70	50.54	28.92	33.84	10.22	33.49	37.50
Brazil	27.21	27.71	48.46	23.37	14.13	8.98	23.98	24.98
Norway	45.93	32.21	47.94	34.42	14.96	9.91	29.82	30.90
Greece	33.97	27.87	46.22	23.80	14.86	9.84	26.55	26.09
Republic of Ireland	40.85	30.11	35.57	24.87	25.77	9.93	26.37	27.85
Austria	52.30	36.03	61.14	35.37	16.53	12.12	34.17	35.58
Portugal	36.95	25.31	53.47	22.23	19.70	9.58	27.38	27.87
Israel	93.44	30.29	74.41	25.77	39.42	10.77	43.40	45.68

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Romania	61.79	30.74	47.73	26.52	15.78	9.52	26.95	32.01
Taiwan	38.40	29.10	51.15	23.57	15.99	11.31	28.87	28.25

Table 4.3.4 Chemical sciences top 25 countries which collaborate most frequently with Scotland ranked by NCI

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
USA	2.41	2.13	2.62	2.56	2.59	2.43	2.47	2.46
England	2.24	1.96	2.42	2.49	2.58	2.31	2.35	2.33
Germany	2.43	1.98	2.48	2.78	2.26	2.32	2.38	2.38
France	2.50	2.06	2.85	2.83	2.55	2.63	2.59	2.57
Italy	2.70	2.02	2.93	2.58	2.36	2.42	2.51	2.50
Spain	2.27	1.93	2.71	2.69	2.21	2.42	2.40	2.37
The Netherlands	2.61	2.27	3.15	3.16	2.72	2.61	2.78	2.75
Canada	2.55	2.02	3.04	2.62	2.45	2.87	2.61	2.59
China	2.55	1.96	2.89	2.75	2.14	2.11	2.39	2.40
Australia	3.49	2.28	3.27	3.39	2.58	3.05	3.00	3.01
Switzerland	2.95	2.29	3.54	3.24	2.70	2.90	2.97	2.94
Japan	2.91	2.03	3.15	2.78	3.33	2.57	2.80	2.80
Russia	2.70	1.98	3.25	2.51	2.42	2.63	2.62	2.58
Sweden	3.08	2.08	3.84	3.24	3.18	3.15	3.15	3.10
Poland	2.53	2.10	3.38	2.39	2.12	2.70	2.58	2.54
Denmark	3.21	2.61	3.49	3.23	3.85	3.29	3.31	3.28
Brazil	1.58	1.96	3.39	2.49	2.17	2.68	2.50	2.38
Norway	2.57	2.19	3.41	3.74	2.27	3.12	2.95	2.88

Country	2010	2011	2012	2013	2014	2015	Weighted Average	Unweighted Average
Greece	2.03	1.97	3.21	2.48	2.22	2.78	2.53	2.45
Republic of Ireland	2.33	1.91	2.28	2.43	2.85	3.06	2.54	2.48
Austria	2.73	2.37	4.16	3.49	2.53	3.49	3.24	3.13
Portugal	2.09	1.74	3.73	2.28	3.09	2.83	2.74	2.63
Israel	3.91	2.07	4.07	2.62	3.55	3.05	3.24	3.21
Romania	4.00	2.28	3.69	2.87	2.36	2.87	2.95	3.01
Taiwan	2.31	2.02	3.48	2.42	2.33	3.13	2.74	2.62

4.4 Chemical Sciences Research Productivity and Efficiency

Levels of research publications are, of course, related to the size of the countries within which that research is taking place. In order to enable these factors to be understood divided the number of patents, the numbers of papers and counts of citations to those papers relative to the following factors[18]:

- Gross Domestic Product (GDP) in 2015 Q4 value[19]
- Gross Domestic Expenditure on R&D (GERD) excluding Private Non-Profit (PNP)[20]
- Business Enterprise Expenditure on R&D (BERD)[20]
- Government Expenditure on R&D (GovERD) [20]
- Higher Education Expenditure on R&D (HERD) [20]
- R&D personnel and Researchers (full-time equivalent) [20,21]

The following tables show the value of the ratios, and include Scotland's ranking in parenthesis (rank / number of comparator countries with available data)[22]. Data for GDP, R&D expenditure and researcher numbers cannot be desegregated to the level of chemical sciences. However, the analysis will still have indicative value and will be in line with similar work that Scottish Enterprise has previously commissioned. As seen below, Scotland consistently ranks highly for publication volume and publication citation metrics, and ranks in the middle for patent volume metrics.

[18] Please refer to Section 2.2 for a description and links for data sources. Specifically for Scotland, economic data were obtained from Scottish Government's reports with the exception of R&D personnel and Researchers, which was obtained from European Commission's Eurostat database.
[19] Taiwan's GDP data were obtained from the government's website (https://eng.stat.gov.tw). For India, Iran and Singapore, GDP data were obtained from World Bank's World Development Indicator database.
[20] Brazil, India and Iran were excluded from GERD, BERD, GovERD, HERD, and R&D personnel and Researchers analysis as these data were not available at OECD's data portal.
[21] The United States does not report total R&D Personnel so only Researchers used in the analysis.
[22] Not all economic factor data are available for all comparator countries in all years. The yearly ranking ignores the comparator countries whose data are not available for that year. For more details, please refer to Section 2.2.

Table 4.4.1 Chemical sciences patents divided by national productivity or R&D expenditure factors

Patents divided by	2010	2011	2012	2013	2014	2015
GDP in 2015 Q4 values						
ratio per billion GBP (rank/number of comparators)	1.71 (16/28)	1.26 (18/28)	1.52 (17/28)	1.06 (19/28)	0.95 (21/28)	1.41 (15/24)
Gross Domestic Expenditure on R&D excluding PNP						
ratio per billion GBP (rank/number of comparators)	112.67 (11/23)	83.51 (13/24)	102.66 (11/23)	65.18 (16/24)	59.62 (14/21)	NA[23]
Business Enterprise Expenditure						
ratio per billion GBP (rank/number of comparators)	337.74 (6/23)	231.09 (9/24)	276.58 (6/23)	178.52 (12/24)	151.03 (12/21)	229.66 (-)[24]
Government Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	715.75 (16/24)	575 (16/24)	827 (14/24)	558.59 (16/24)	523.81 (18/23)	NA[23]
Higher Education Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	215.91 (16/24)	168.94 (19/24)	201.44 (15/24)	137.37 (18/24)	124.88 (17/23)	NA[23]
R&D Personnel and Researchers						
ratio per Full-Time-Equivalent (rank/number of comparators)	0.0070 (8/22)	0.0052 (10/23)	0.00643 (9/23)	0.0043 (11/22)	0.0039 (13/19)	NA[23]

Table 4.4.2 Chemical sciences publications divided by national productivity or R&D expenditure factors

Publications divided by	2010	2011	2012	2013	2014	2015
GDP in 2015 Q4 values						
ratio per billion GBP (rank/number of comparators)	0.05 (1/28)	0.05 (2/28)	0.05 (2/28)	0.04 (2/28)	0.04 (4/28)	0.05 (3/24)
Gross Domestic Expenditure on R&D excluding PNP						
ratio per billion GBP (rank/number of comparators)	2.99 (1/23)	3.01 (1/24)	3.08 (1/23)	2.74 (1/24)	2.8 (1/21)	NA[23]

[23] At the time of analysis, 2015 data were not yet available on GERD, BERD, GovERD, HERD, R&D Personnel and Researchers for Scotland.
[24] At the time of analysis, 2015 GERD, BERD, GovERD, HERD, R&D Personnel and Researchers data were not available for comparator countries,

Publications divided by	2010	2011	2012	2013	2014	2015
Business Enterprise Expenditure						
ratio per billion GBP (rank/number of comparators)	8.95 (1/23)	8.32 (1/24)	8.29 (1/23)	7.49 (1/24)	7.09 (1/21)	7.39 (-)[24]
Government Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	18.97 (6/24)	20.7 (5/24)	24.79 (5/24)	23.44 (5/24)	24.61 (6/23)	NA[23]
Higher Education Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	5.72 (5/24)	6.08 (8/24)	6.04 (6/24)	5.76 (8/24)	5.87 (7/23)	NA[23]
R&D Personnel and Researchers						
ratio per Full-Time-Equivalent (rank/number of comparators)	0.17 (1/22)	0.19 (1/23)	0.19 (1/23)	0.18 (1/22)	0.18 (1/19)	NA[23]

Table 4.4.3 Chemical sciences publication citations divided by national productivity or R&D expenditure factors

Total citations divided by	2010	2011	2012	2013	2014	2015
GDP in 2015 Q4 values						
ratio per billion GBP (rank/number of comparators)	1.29 (2/28)	1.00 (2/28)	0.99 (2/28)	0.67 (2/28)	0.45 (2/28)	0.2 (4/24)
Gross Domestic Expenditure on R&D excluding PNP						
ratio per billion GBP (rank/number of comparators)	85.35 (1/23)	65.84 (1/24)	66.7 (1/23)	41.11 (1/24)	28.2 (1/21)	NA[23]
Business Enterprise Expenditure						
ratio per billion GBP (rank/number of comparators)	255.84 (1/23)	182.19 (1/24)	179.69 (1/23)	112.6 (1/24)	71.43 (1/21)	32.03 (-)[24]
Government Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	542.19 (6/24)	453.33 (5/24)	537.28 (5/24)	352.34 (5/24)	247.75 (6/23)	NA[23]
Higher Education Expenditure on R&D						
ratio per billion GBP (rank/number of comparators)	163.55 (1/24)	133.19 (4/24)	130.87 (1/24)	86.65 (2/24)	59.07 (1/23)	NA[23]
R&D Personnel and Researchers						
ratio per Full-Time-Equivalent (rank/number of comparators)	5.44 (1/22)	4.20 (1/23)	4.29 (1/23)	2.87 (1/22)	1.98 (1/19)	NA[23]

Appendix A BIBLIOMETRICS AND CITATION ANALYSIS

Bibliometrics are about publications and their citations. The academic field emerged from 'information science' and now usually refers to the methods used to study and index texts and information.

Publications cite other publications. These citation links grow into networks, and their numbers are likely to be related to the significance or impact of the publication. The meaning of the publication is determined from keywords and content. Citation analysis and content analysis have therefore become a common part of bibliometric methodology. Historically, bibliometric methods were used to trace relationships amongst academic journal citations. Now, bibliometrics are important in indexing research performance.

Bibliometric data have particular characteristics of which the user should be aware, and these are considered here.

Journal papers (publications, sources) report research work. Papers refer to or 'cite' earlier work relevant to the material being reported. New papers are cited in their turn. Papers that accumulate more citations are thought of as having greater 'impact', which is interpreted as significance or influence on their field. Citation counts are therefore recognized as a measure of impact, which can be used to index the excellence of the research from a particular group, institution or country.

The origins of citation analysis as a tool that could be applied to research performance can be traced to the mid-1950s, when Eugene Garfield proposed the concept of citation indexing and introduced the Science Citation Index, the Social Sciences Citation Index and the Arts & Humanities Citation Index, produced by the Institute of Scientific Information (currently Clarivate Analytics).

We can count citations, but they are only 'indicators' of impact or quality – not metrics. Most impact indicators use average citation counts from groups of papers, because some individual papers may have unusual or misleading citation profiles. These outliers are diluted in larger samples.

A.1 Data Source

The data used in this report came from the Clarivate Analytics Web of Science databases which give access not only to journals but also to conference proceedings, books, patents, websites, chemical structures, compounds and reactions. Web of Science has a unified structure that integrates all data and search terms together and therefore provides a level of comparability not found in other databases. It is widely acknowledged to be the world's leading source of citation and bibliometric data. The Web of Science focuses on research published in journals, conferences and books in science, medicine, arts, humanities and social sciences.

The Web of Science was originally created as an awareness and information retrieval tool but it has acquired an important primary use as a tool for research evaluation, using citation analysis and bibliometrics. Data coverage is both current and retrospective in the sciences, social sciences, arts and humanities, in some cases dating back to 1900. Within the research community this data source was previously referred to by the acronym 'ISI'.

Unlike other databases, the Web of Science and underlying databases are selective, that is: the journals abstracted are selected using rigorous editorial and quality criteria. The authoritative, multidisciplinary content covers over 12,000 of the highest impact journals worldwide, including Open Access journals, and over 150,000 conference proceedings. The abstracted journals encompass the majority of significant, frequently cited scientific reports and, more importantly, an even greater proportion of the scientific research output which is cited. This selective process ensures that the citation counts remain relatively stable in given research fields and do not fluctuate unduly from year to year, which increases the usability of such data for performance evaluation.

Clarivate Analytics has extensive experience with databases on research inputs, activities and outputs and has developed innovative analytical approaches for benchmarking and interpreting international, national and institutional research impact.

A.2 Database Categories

The source data can be grouped in various classification systems. Most of these are based on groups of journals that have a relatively high cross-citation linkage and naturally cluster together. Custom classifications use subject maps in third-party data such as the Organization for Economic Co-operation and Development (OECD) categories set out in the Frascati manual.

Clarivate Analytics frequently uses the broader field categories in the Essential Science Indicators system and the finer journal categories in the Web of Science. There are 22 fields in Essential Science Indicators and 254 fields in Web of Science. In either case, our bibliometric analyses draw on the full range of data available in the underlying database, so analyses in our reports will differ slightly from anything created ‘on the fly’ from data in the web interface. In the current report, we used the Web of Science fields.

Most analyses start with an overall view across the data, then move to a view across broad categories and only then focus in at a finer level in the areas of greatest interest to policy, program or institutional purpose.

A.3 Assigning Papers to Addresses

A paper is assigned to each country and each institution whose address appears at least once for any author on that paper. One paper counts once and only once for each assignment, however many address variants may occur for the country or institution. No weighting is applied.

For example, a paper has five authors, thus:

Author	Institution	Country		
Gurney, KA	Univ Leeds	UK	Counts for Univ Leeds	Counts for UK
Adams, J	Univ Leeds	UK	No gain for Univ Leeds	No gain for UK
Kochalko, D	Univ C San	USA	Counts for UCSD	Counts for USA
Munshi, S	Gujarat Univ	India	Counts for Gujarat Univ	Counts for India
Pendlebury, D	Univ Oregon	USA	Counts for Univ Oregon	No gain for USA

So this one paper with five authors would be included once in the tallies for each of four universities and once in the tallies for each of three countries.

Work carried out within Clarivate Analytics, and research published elsewhere, indicates that fractional weighting based on the balance of authors by institution and country makes little difference to the conclusions of an analysis at an aggregate level. Such fractional analysis can introduce unforeseen errors in the attempt to create a detailed but uncertain assignment. Partitioning credit would make a greater difference at a detailed, group level but the analysis can then be manually validated.

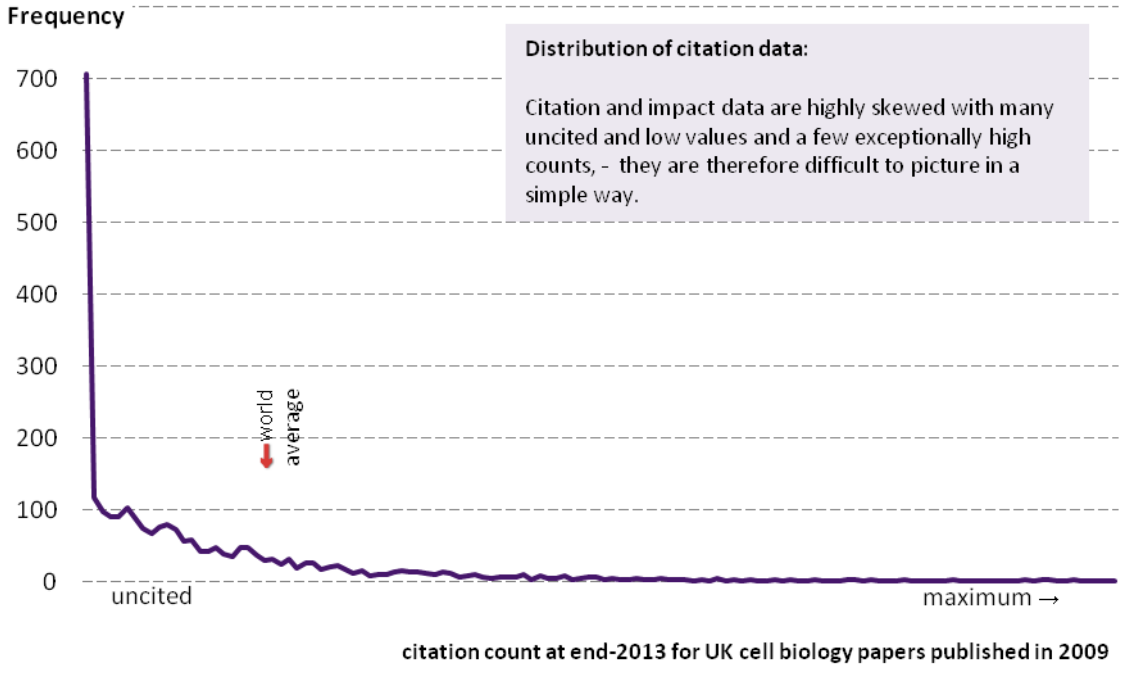
A.4 Citation Counts

A publication accumulates citation counts when it is referred to by more recent publications. Some papers get cited frequently and many get cited rarely or never, so the distribution of citations is highly skewed.

Why is it that many papers are never cited? Certainly some papers remain uncited because their content is of little or no impact, but that is not the only reason. It might be because they have been published in a journal not read by researchers to whom the paper might be interesting. It might be that they represent important but 'negative' work reporting a blind alley to be avoided by others. The publication may be a commentary in an editorial, rather than a normal journal article and thus of general rather than research interest, or it might be that the work is a 'sleeping beauty' that has yet to be recognized for its significance.

Other papers can be very highly cited: hundreds, even thousands of times. Again, there are multiple reasons for this. Most frequently cited work is being recognized for its innovative significance and impact on the research field of which it speaks. Impact here is a good reflection of quality: it is an indicator of excellence. But there are other papers which are frequently cited because their significance is slightly different: they describe key methodology; they are a thoughtful and wide-ranging review of a field; or they represent contentious views which others seek to refute.

Citation analysis cannot make value judgments about why an article is uncited nor about why it is highly cited. The analysis can only report the citation impact that the publication has achieved. We normally assume, based on many other studies linking bibliometric and peer judgments, that high citation counts correlate on average with the quality of the research.



The figure shows the skewed distribution of more or less frequently cited papers from a sample of UK authored publications in cell biology. The skew in the distribution varies from field to field. It is to compensate for such factors that actual citation counts must be normalized, or rebased, against a world baseline.

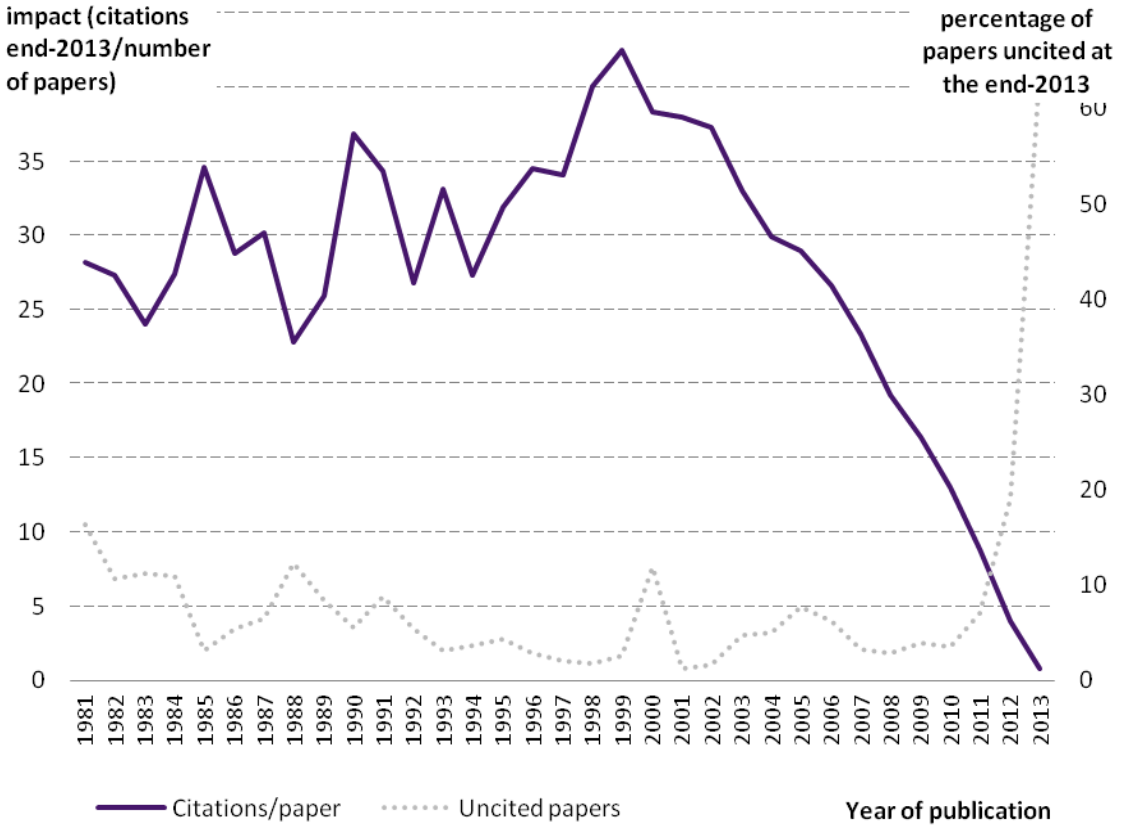
We do not seek to account separately for the effect of self-citation. If the citation count is significantly affected by self-citation then the paper is likely to have been infrequently cited. This is therefore only of consequence for low impact activity. Studies show that for large samples at national and institutional level, the effect of self-citation has little or no effect on the analytical outcomes and would not alter interpretation of the results.

A.5 Time Factors

Citations accumulate over time. Older papers therefore have, on average, more citations than more recent work. The graph below shows the pattern of citation accumulation for a set of 33 journals in the journal category ***Materials Science, Biomaterials***. Papers less than eight years old are, on average, still accumulating additional citations. The citation count goes on to reach a plateau for older sources.

The graph shows that the percentage of papers that have never been cited drops over about five years. Beyond five years, between 5% and 10% or more of papers remain uncited.

Account must be taken of these time factors in comparing current research with historical patterns. For these reasons, it is sometimes more appropriate to use a fixed five-year window of papers and citations to compare two periods than to look at the longer term profile of citations and of uncitedness for a recent year and an historical year.



A.6 Discipline Factors

Citation rates vary between disciplines and fields. For the UK science base as a whole, ten years produces a general plateau beyond which few additional citations would be expected. On the whole, citations accumulate more rapidly and plateau at a higher level in biological sciences than physical sciences, and natural sciences generally cite at a higher rate than social sciences.

Papers are assigned to disciplines (journal categories or research fields) by Clarivate Analytics, bringing cognate research areas together. Before 2007, journals were assigned to the older, well established Current Contents categories which were informed by extensive work by Thomson and with the research community since the early 1960s. This scheme has been superseded by the 252 Web of Science journal categories which allow for greater disaggregation for the growing volume of research which is published and abstracted.

Papers are allocated according to the journal in which the paper is published. Some journals may be considered to be part of the publication record for more than one research field. As the example below illustrates, the journal *Acta Biomaterialia* is assigned to two journal categories: ***Materials Science, Biomaterials and Engineering, Biomedical***.

Very few papers are not assigned to any research field and as such will not be included in specific analyses using NCI data. The journals included in the Clarivate Analytics databases and how they are selected are detailed here http://scientific.thomsonreuters.com/mjl/.

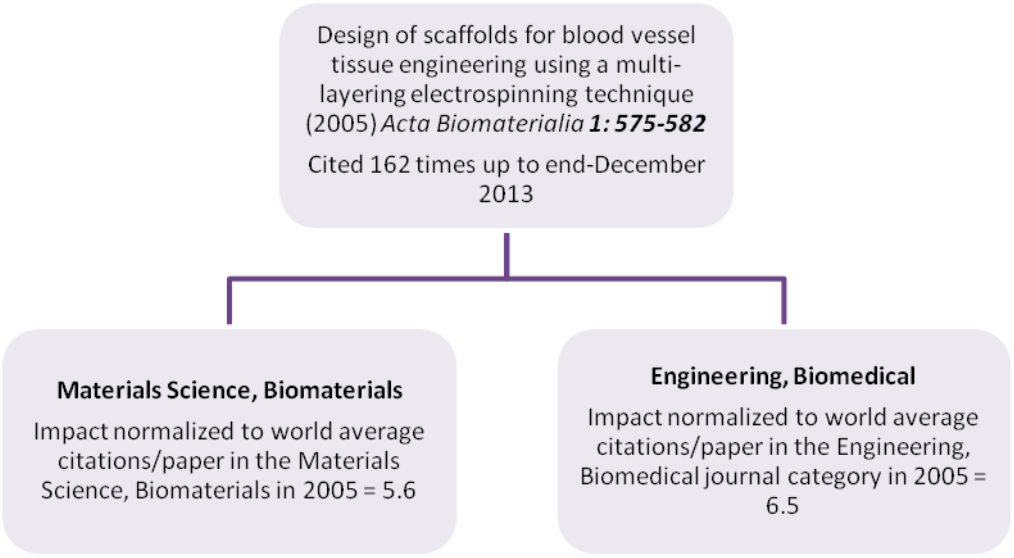
Some journals with a very diverse content, including the prestigious journals *Nature* and *Science* were classified as ***Multidisciplinary*** in databases created prior to 2007. The papers from these ***Multidisciplinary*** journals are now re-assigned to more specific research fields using an algorithm based on the research area(s) of the references cited by the article.

A.7 Normalized Citation Impact

Because citations accumulate over time at a rate that is dependent upon the field of research, all analyses must take both field and year into account. In other words, because the absolute citation count for a specific article is influenced by its field and by the year it was published, we can only make comparisons of indexed data after normalizing with reference to these two variables.

We only use citation counts for reviews and articles in calculations of impact, because document type influences the citation count. For example, a review will often be cited more frequently than an article in the same field, but editorials and meeting abstracts are rarely cited and citation rates for conference proceedings are extremely variable. The most common normalization factors are the average citations per paper for (1) the year and (2) the field (i.e., journal category). This normalization is also referred to as 'rebasing' the citation count.

Impact is therefore most commonly analyzed in terms of 'normalized citation impact'. The following schematic illustrates how the NCI is calculated at the paper level and journal category level.



This article in the journal *Acta Biomaterialia* is assigned to two journal categories: ***Materials Science, Biomaterials and Engineering, Biomedical***. The world average baselines for, as an example, ***Materials science, Biomaterials*** are calculated by summing the citations to all the articles and reviews published worldwide in the journal *Acta Biomaterialia* and the other 32 journals assigned to this category for each year, and dividing this by the total number of articles and reviews published in the journal category. This gives the category-specific normalized citation impact. (For example, ***Materials Science, Biomaterials*** is 5.6 and for Engineering, Biomedical is 6.5). Most papers (nearly two-thirds) are assigned to a single journal category while a minority of them are assigned to more than five.

World average impact data are sourced from the Clarivate Analytics National Science Indicators baseline data for 2015.

Appendix B PATENT ANALYSIS METHOD DETAILS

B.1 Patent Collection Collation Method

The patent collections for the study are produced using technology-specific search strings for the subject matter at hand. The study is restricted to publications between 2010 and 2015.

Each search string uses technology classification codes and indexing, as appropriate, to produce relevant individual technology collections. The classification codes used are based on:

1. Derwent Patent Classification
2. International Patent Classification
3. Cooperative Patent Classification

There will most likely be a small amount of overlap between technologies as well as the inclusion of some noise in the dataset; however this has been minimized to the best extent possible.

The use of classification search strings for the creation of distinct technology datasets within the landscape is a standard best practice for information science, informatics and bibliometrics of this type.

Once the searches are finalized, the collections are merged together to create the final patent collection. The patent information is checked for naming variations, typographical differences and where appropriate merges and acquisitions activity and subsidiaries, so that as much as possible company name changes and transactions are reflected in the final analysis.

B.2 Search string creation and quality control

The creation of search strings for both patent collections (life sciences and chemical sciences) is performed iteratively, with the results reviewed and evaluated at every stage to make sure that is as accurate as possible.

As each search string is created, the results are sampled and reviewed for relevancy, and classifications amended as appropriate. Further, the results of each search are data-mined for further classification codes of relevance, which are then incorporated into the search strategy. This process is repeated for each search until revisions perform only minor variations in results.

Scotland Patent Research Output

The technological domains of life sciences and chemical sciences are defined using appropriate patent classifications, as explained earlier. Origin of inventions is defined by the first country of filing, also termed as the earliest priority country, of a patent application for an invention.

The priority country offers a statistically useful technique for monitoring the volume of research activity happening across different countries and regions. The research output of Scotland was identified by the priority filing location being the UK patent office. We have also included European patents and applications as well as PCT applications for the priority filing location.

To single-out Scottish activity from the rest of the UK, PCT and EP, an additional search was carried out using the inventor, assignee attorney / agent and correspondent addresses. The address field available in Thomson Innovation lists the country of residence of the inventor or organization.

To supplement the above data, a list of major companies and organizations headquartered in Scotland was prepared and a search for patent filings for these entities claiming priority from the UK, PCT or EP was carried out. The data was then consolidated to generate a robust dataset containing all patenting activity originating from Scotland. It should be noted that this is not always an accurate indication of Scottish innovation, as many foreign companies have R&D facilities in Scotland. Additionally, complex corporate structures will result in a non-Scottish applicant address being used, despite the invention being developed solely in Scotland and the applicant appearing to be a UK company.

Patent Data Analytical Output

The patent data is de-duplicated to reduce it to one member per DWPI patent family as stated in the data convention. Volume of patents is reported separately for the life sciences and chemical sciences segments. The total citations awarded to patents is also calculated and reported separately for life sciences and chemical sciences.

Scottish Patent Strength Ranking

There are a series of patent metrics available in the patent data that can be used as indicators of patent strength. Our proprietary patent ranking system evaluates various parameters and ranks the patent collection into strong vs. weak patents. The metrics that we measure are listed below.

- Market Protection Time (based on remaining life)
- Geographic Market Protection (based on geographic spread of filings)
- Novelty (based on grants of examined patents)
- Impact on the Field (based on citation frequency statistics)
- Technical Coverage (based on the spread of technical domains covered by the invention)

These measurements, made on individual inventions, can be aggregated to evaluate entities or technical areas.

The Scottish patents in the fields of life science and chemical science are scored based on the above ranking system.

Scottish Patents – Sub-technology areas

The two areas of life science and chemical science are further broken down into their respective sub-areas and the Scottish patents are categorized across these sub-areas based on the patent classifications as applicable.

A summary of findings is reported for each of the two areas separately and also include the strength ranking for each of the sub-areas respectively.

Benchmarking against countries of interest

Countries of interest as identified by the client were included: UK as a whole, USA, Canada, France, Germany, Italy, Japan, Russia, the G8, Belgium, Denmark, Finland, Netherlands, Spain, Sweden, Switzerland, Republic of Ireland, the EU-28 in aggregate, Australia, Brazil, China, India, Iran, Israel, Singapore, South Africa, South Korea, Taiwan and New Zealand. The volume of patents for these countries of interest was defined by the number of patents claiming priority from the respective countries. The volume is reported separately for the life sciences and chemical sciences areas. Total citations and average citations to patents originating from the countries of interest is also reported distinctly for the two areas and presented to provide a comparative picture.

B.3 Technical categories and definitions of life sciences patents

Category	*Definitions*
Agricultural	
Sowing / Planting / Harvesting	This category covers agricultural processes comprising sowing, planting or harvesting
Transgenic Plants / Tissue Culture	This category covers plant tissue culture and genetically modified plants e.g. transgenic plants
Fertilizers / Pesticides	This category covers fertilizers and pesticides used in the agriculture sector
Horticulture / Cultivation	This category covers plant cultivation and plant horticulture
Food	
Food	This category covers food products, compositions and their processing
Beverages	This category covers alcoholic and non-alcoholic beverages including tea and coffee
Medicine	
Biologics/ Biopharmaceutical	This category covers biopharmaceutical drugs originated from biological origin such as antibodies, therapeutic proteins, interferon, cytokines, etc.
Vaccines	This category covers vaccines used in prevention and/or treatment of various diseases
Regenerative Medicines	This category covers medicines based on the process of replacing, engineering or regenerating human cells, tissues or organs to restore normal function
Pharmaceutical Drug	This category covers the pharmaceutical drugs used to prevent or treat the various disease
Diagnostics	
Micro Diagnostics	This category covers micro diagnostics techniques such as microfluidics, lab on chip, etc.
Imaging	This category covers imaging based diagnosis
Immunoassay	This category covers diagnostic method based on the immune system
Nucleic Acid Based Diagnostics	This category covers diagnosis based on nucleic acid molecules
Diagnostics In General	This category covers diagnosis based on laboratory diagnosis excluding the above categories
Medicinal Device	
Electromedical Devices	This category covers electromedical devices used in therapeutic and diagnostic purposes such as ultrasonic devices, endoscopes, etc.
Stents	This category covers stent implants
Ophthalmic	This category covers ophthalmic devices comprising lens systems
Implants / Prosthesis	This category covers implants or prosthesis of the human body including arms / legs prosthesis, pacemakers, hearing aids, etc.
Surgical Instruments	This category covers devices or instruments used in surgery
Other Medical Devices	This category covers medicinal devices or instruments excluding the above categories
Disease	

Category	*Definitions*
Cancer	This category covers all types of cancer
Cardiovascular Disease	This category covers disease associated with blood and cardiovascular system
Respiratory Disease	This category covers disease associated with respiratory system
Neurodegenerative & Muscular Disease	This category covers disease associated with central nervous system and muscular diseases
Gastrointestinal Disease	This category covers disease associated with gastric and intestinal area
Metabolic Disease	This category covers disease associated with metabolism such as obesity, diabetics etc.
Infectious Disease	This category covers bacterial, viral, fungal and parasitic infectious diseases
Immune Disorder	This category covers disease associated with the immune system
Other Diseases	This category covers all types of diseases excluding the above categories
Animal / Veterinary Science	This category covers animal / veterinary science comprising animal husbandry, animal diseases, therapy and diagnosis

B.4 Technical categories and definitions of chemical sciences patents

Categories	*Definitions*
Organic Chemistry	
Heterocyclic	This category covers heterocyclic chemical compounds mainly having fused ring and mononuclear structure
Aromatic	This category covers aromatic polycarbocyclic chemical compounds comprising 3-6 fused ring structure
Alicyclic	This category covers alicyclic polycarbocyclic chemical compounds comprising 3-6 fused ring structure
Aliphatic	This category covers aliphatic chemical compounds comprising amines, carboxylic acids, aldehydes, ketones, ester, ether, etc. functional group
Other Organic Compound	This category covers miscellaneous organic chemical compounds containing alkali, alkali earth metal, transition series element, lanthanide, etc.
Chemical Engineering	
Separation Techniques	This category covers separation techniques and processes for separating different chemicals such as solid-solid separation, separation of suspended particles from liquid or gases, etc.
Electrochemical Processes And Electrophoresis	This category covers electrochemical methods and apparatus such as electrophoresis, electrodialysis, etc.
Chemical / Physical Processes / Apparatus	This category covers physical / chemical methods / apparatus such as laboratory, reaction apparatus, colloid chemistry, investigation by physical or chemical properties, etc.
Heat Transfer & Refrigeration	This category covers gas liquefication, solidification, refrigeration machines, plants or systems, heat exchangers or transfer, etc.
Waste Water Treatment	
Chemical Engineering In General	This category covers chemical engineering processes, apparatus excluding the above categories
Material Science / Applied Chemistry	
Coatings & Films	This category covers chemical processes, material and apparatus used in coating & films
Textiles & Paper	This category covers chemical characteristics, treatment in the fabric, textile and paper industries
Glass / Ceramics / Cements	This category covers glass, refractories, ceramic, cements product and process of preparation and apparatus for the same
Medicinal Chemistry	This category covers pharmaceutical drug and chemical compounds / reagents used in diagnosis in the medicinal industry
Dyes / Paints / Printing	This category covers various dyes formulations, their precursors along with various chemicals used in the paints and printing industry
Catalysts	This category covers chemical catalysts, preparation methods, apparatus for the same
Petroleum	

Categories	*Definitions*
Crude Oil and Natural Gas	This category covers crude oil and natural gas production, treatment, testing, etc.
Gaseous And Liquid Fuels	This category covers Gaseous And Liquid Fuel preparation, treatment, testing, etc.
Other Petroleum Products	This category covers petroleum products excluding the above categories
Polymer	
Natural Polymers	This category covers natural polymers such as natural rubber, etc.
Inorganic Polymers	This category covers inorganic polymers such as silicon, phosphorus, boron polymers, etc.
Additives	This category covers polymer additives
Polymer in General	This category covers polymers not covered in the above polymer categories
Inorganic Chemistry	This category covers inorganic chemical compounds
Nanoscience & Nanotechnology	This category covers nanotechnology in the field of chemistry such as carbon nanotubes