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A bibliometric analysis of Norwegian sciences

Trends and international comparisons

Henrik Karlstrøm, Fredrik N. Piro and Dag W. Aksnes

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Preface

This report presents a bibliometric analysis of Norwegian research in an international context. The analysis covers biosciences, natural sciences, engineering, mathematics, computer science, medicine, and health. The report is mainly descriptive serves as a technical background report for the ongoing evaluation of Norwegian research in these areas. The report is written on the commission of the Research Council of Norway (RCN) by senior researcher Henrik Karlstrøm and research professor Fredrik N. Piro and Dag W. Aksnes at the Nordic Institute for Studies in Innovation, Research and Education (NIFU).

Oslo, 09.04.24

Espen Solberg
Head of research

Innhold

Summary

The analysis presented in this report shows that from 2013 to 2022, Norway's publication output across the STEM fields—including biosciences, natural sciences, engineering, mathematics, computer science, medicine, and health—has increased. This development aligns with the trends observed in other Nordic countries, indicating that Norway's growth in these areas is in line with the patterns we find in comparable countries.

In terms of size, it is within Medicine & health sciences we find both the highest volume of Norwegian publications (in absolute numbers), the greatest degree of specialization compared to the global average (for Health sciences and Psychology), and the largest growth in production of papers in the period 2013-2022.

The growth in output has predominantly occurred in areas where Norway was already highly specialized, rather than in fields where it was previously 'lagging'.

In the scientific fields where the growth has been more modest, Norway's specialization indexes fall below the world average (Agriculture, fisheries, and forestry; Biomedicine and molecular biosciences; Engineering; Mathematics & statistics; Materials science; and Physics). Over time Norway has become increasingly specialized in fields that are either related to its industry structure, such as Geosciences, or related to health (Clinical medicine, Health sciences, Psychology). In addition, Norway has become increasingly specialized in Computer and information science.

Norwegian publications receive citations above the world average in all fields except Chemistry, Materials science, and Mathematics and statistics – three areas where Norway's degree of specialization also is low. Interestingly, even in other disciplines where specialization is not particularly high, such as Agriculture, fisheries and forestry; and Biomedicine and molecular biosciences, Norwegian research still obtains high citation indexes. In fact, Norway's highest citation indexes occur in fields with a relative low degree of specialization: Biomedicine and molecular biosciences; and Clinical medicine.

The table below presents key metrics for Norway's academic output. The overview shows patterns across various fields and how publication volume, growth in publications, degree of specialization, and citation impact interrelate.

Table 1. Key indicator scores for Norwegian subfields.

	Publications 2022	Growth 2013-2022 (%)	Specialization index	Citation impact
Biosciences				
Agriculture, fisheries, forestry	546	0.70	0.78	1.25
Biology	697	27.92	1.66	1.35
Biomedicine and molecular biosciences	1600	22.02	0.78	1.51
Engineering, ICT and mathematics				
Computer and information science	797	81.54	1.20	1.23
Engineering	2109	21.19	0.98	1.16
Mathematics and statistics	344	22.34	0.77	0.92
Medicine & health sciences				
Clinical medicine	3806	34.28	1.03	1.50
Health sciences	1854	66.32	2.03	1.14
Psychology	598	80.05	1.82	1.23
Natural sciences				
Chemistry	406	28.00	0.38	0.96
Geosciences	1387	50.12	1.65	1.36
Materials science	319	19.61	0.43	0.93
Physics	625	6.25	0.58	1.22

The profiles of the other Nordic countries provide interesting benchmarks for Norway's performance. In the table below, we compare the specialization index and citation index across Nordic countries and scientific fields. Given that both indexes are normalized to the world average (1.00), it makes sense to examine differences between the countries.

Table 2. Differences in specialization indexes and citation indexes across countries and scientific fields.

		Specialization Index	Citation index
Agriculture, fisheries, forestry	Norway	0.78	1.25
	Sweden	0.68	1.17
	Denmark	0.88	1.21
	Finland	0.89	1.22
Biology	Norway	1.66	1.35
	Sweden	1.19	1.49
	Denmark	1.04	1.49
	Finland	1.38	1.37
Biomedicine and molecular biosciences	Norway	0.78	1.51
	Sweden	1.06	1.46
	Denmark	1.15	1.43
	Finland	0.91	1.34
Chemistry	Norway	0.38	0.96
	Sweden	0.62	1.09
	Denmark	0.53	1.05
	Finland	0.62	1.06
Geosciences	Norway	1.65	1.36
	Sweden	1.00	1.33
	Denmark	0.90	1.35
	Finland	1.17	1.20
Materials science	Norway	0.43	0.93
	Sweden	0.71	1.08
	Denmark	0.38	1.11
	Finland	0.75	1.03
Physics	Norway	0.58	1.22
	Sweden	0.87	1.29
	Denmark	0.64	1.34
	Finland	0.97	1.27
Computer and information science	Norway	1.20	1.23
	Sweden	0.84	1.05
	Denmark	0.72	1.13
	Finland	1.35	1.12
Engineering	Norway	0.98	1.16
	Sweden	0.85	1.14
	Denmark	0.77	1.29
	Finland	1.00	1.20
Mathematics and statistics	Norway	0.77	0.92
	Sweden	0.72	0.90
	Denmark	0.42	0.89
	Finland	0.86	0.94
Clinical medicine	Norway	1.03	1.50
	Sweden	1.20	1.66

	Denmark	1.46	1.60
	Finland	0.94	1.42
Health sciences	Norway	2.03	1.14
	Sweden	1.64	1.13
	Denmark	1.54	1.08
	Finland	1.53	1.08
Psychology	Norway	1.82	1.23
	Sweden	1.02	1.17
	Denmark	0.86	1.22
	Finland	1.48	1.19

Across several disciplines, the four Nordic countries have rather similar profiles. For example, in Agriculture, Fisheries and Forestry, and Physics, all countries show lower specialization than the global average yet achieve higher citation rates. Conversely, in Biology, each country surpasses the world average in both specialization and citations. In Mathematics and Statistics, all four nations show less specialization and receive fewer citations than the global average. Chemistry and Materials Science follow a similar pattern of lower specialization, but here, Norway is the exception, with citation indexes that do not exceed the world average, unlike its Nordic neighbours.

In some fields, all countries consistently achieve citation indexes above the world average, albeit with significant variations across countries and fields. Notable examples include Health Sciences and Psychology, Biomedicine and Molecular Biosciences, Clinical Medicine, and Computer and Information Science. These variances highlight the diverse strengths and focal points of each country within these domains.

1 Introduction

This report presents a bibliometric analysis of Norwegian research in an international context. It examines the scientific publication output and scientific impact of Norway, comparing it with other countries. The report is based on an analysis of the entire Norwegian publication output in biosciences, natural sciences, engineering, mathematics, computer science, medicine, and health (STEM fields). As a result, it includes not only the contributions from the units covered by the evaluation.

The analysis is based on Web of Science data. In our analysis, we have examined both overall broad areas and detailed field levels. In these analyses we aim to provide information about: What characterizes Norwegian research in a global context? How is Norwegian science specialized compared with other countries, especially other Nordic countries? In which fields do we have comparative strengths compared with other countries, in terms of publication volume and/or citation impact? How has Norwegian science developed during the recent 10 years, in terms of publication productivity and citation impact? As yardstick we will use the global, or, alternatively, Nordic average. The latter is included in order to have a reference value which has more contextualized relevance than the global average and reflecting other high performing research nations.

Subfields have been classified together as to correspond with the broad division of the disciplines encompassed by the evaluations.

2 Data and methods

This chapter describes the data and methods applied in the report.

2.1 Data

The analysis is based on the Web of Science (WoS) Core collection database, covering the underlying sub databases: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Emerging Sources Citation Index, Conference Proceedings citation indexes, and Book Citation Index. We have applied a local version of WoS maintained by the Norwegian Agency for Shared Services in Education and Research.

This is a database covering more than 22,000 specialized and multidisciplinary scientific journals with peer review, in addition to a selection of scientific books and conference proceedings. Even if the coverage is not complete, the databases will include all major journals within natural sciences, medicine and technology and is generally regarded as constituting a satisfactory representation of the research within these fields (Aksnes & Sivertsen, 2019).

2.2 Methods

2.2.1 Publication output

The analysis is limited to the ten-year period 2013-2022, with the main emphasis on the recent years (data from 2023 was not available at the time of this report). The analysis is limited to the following publication types: full-papers (regular articles, proceedings articles) and review articles published in journals or books and books/monographs. Publications not covered by these categories are not included (for example material such as letters, editorials, corrections, book-reviews, meeting abstracts, etc.).

A main issue in all evaluative use of bibliometric indicators concerns the issue of counting methods. This is related to the fact that most publications have more

than one author. Thus, the question arises weather these should be credited individual authors, institutions and countries. Over the years, a large number of indicators have been developed (Gauffriau, 2017). In citation analyses the issue is particularly urgent as citation frequencies generally are extremely skewed (Aksnes et al., 2012). The most common approaches are either "whole counting", where a publication is fully credited all contributors or "fractionalized counting" where credit is divided proportionally. The Norwegian publication indicator is a compromise taking publication characteristics of fields into account and is developed internationally as Modified Fractional Counting (Sivertsen et al., 2019), but where other elements of the Norwegian publication indicator (weighting of journal/publisher level, and international collaboration) are omitted. Modified Fractional Counting was used in the recent version of RCN's S&T Indicator report, and is also used in all analyses here.

2.2.2 Citation indicators

The Web of Science database includes information on how many times the articles have been referred to or cited in the subsequent scientific literature indexed in WoS. In the citation indicators we have used accumulated citation counts (up to 2023) and calculated an overall (total) indicator for the period analysed.

The average citation rate varies a lot between the different scientific disciplines. As a response, various reference standards and normalisation procedures have been developed. The most common is the average citation rates of field in which the particular papers have been published.

One such indicator is the relative citation index *MNCS* showing whether the scientific publications have been cited above or below the world average (=1.0). Here, each article is compared with the average paper in the respective field and year by publication type.[1]

2.2.3 Specialisation indicators

The report includes an indicator of the scientific specialisation of Norway and other Nordic countries. This indicator shows whether a country has a higher or lower share of publications in a specific field compared to the global average. It is calculated by dividing the share of the given field in the publications of the given country on the share of the given field in the world total of publications. This means it characterizes the internal balance between different fields of the country, though the index does not reflect the volume of production in absolute terms. A

[1] See overview here: https://images.webofknowledge.com/images/help/WOS/hs_document_type.html

specialisation indicator > 1, indicates a relative, positive specialization (in terms of scientific publishing) in that particular field. It's important to note that the total score for any country will be 1. The fields of study vary greatly in size, which is important to consider when interpreting the results.

2.2.4 Field classification system

The study relies on the predefined subject classification system of WoS with 255 subject classes. [2] These categories are further aggregated into 16 broad fields.[3] In this report, the fields most relevant for the evaluation, have been selected.

It is important to emphasize that the field classification system in this report differs from the one applied in the other bibliometric reports of the evaluations. The other reports were based on the Cristin-classification system. This classification is not available for the publications output of other countries. Therefore, we have here relied on the WoS-system. Moreover, this analysis is limited to the WoS-indexed literature only. This also means that, even for categories having identical names, the figures for Norway cannot be directly compared across different reports.

[2] Subject field as defined by WoS, see overview: https://support.clarivate.com/ScientificandAcademicResearch/s/article/Web-of-Science-List-of-Subject-Classifications-for-All-Databases?language=en_US.

[3] For an overview, see https://www.norden.org/en/publication/comparing-research-nordic-higher-education-institutions-using-bibliometric-indicators

3 Biosciences

3.1 Agriculture, fisheries, and forestry

Figure 3.1 highlights a trend that will be observed in most other figures in this report: the rapid rise of Chinese research, and the stagnation of US research, clearly observed by three breaking points: in 2013 China produced half as many papers as the US in Agriculture, fisheries, and forestry. By 2020 China had reached the US level, and in 2022 China produced more than twice as many papers as the US. The Chinese growth in publications from 2013 to 2022 was 350 per cent. By comparison, the US growth was 12 per cent (Table 3.1)

An important aspect of understanding this development (Figure 3.2) is that the Chinese productivity growth has seemingly not occurred at the expense of scientific impact. In the period 2019-2021, Chinese papers in this field were cited well above the US level (35 per cent above the world average in China, and 7 per cent above the world average in the US). In fact, in our selection of leading and relevant R&D nations, only the Netherlands had a higher citation index during this period, with publications cited 43 per cent above the world average.

In the Nordic countries, Denmark and Sweden have consistently produced more papers than Finland and Norway over the ten-year period from 2013 to 2022 (Figure 3.1). However, Norway has experienced almost no growth in volume over the period; total growth was just 0.7 per cent, while the other Nordic countries have increased their output by between 7 and 19 per cent (Table 3.1).

All Nordic countries are cited well above the world average, with the highest citation index found in Norway (1.25) (Figure 3.2), which is a rather high level in the field internationally. This does not support the claim that citation impact increases with the degree of specialization, because as seen in Table 3.4, Norway is less specialized in Agriculture, fisheries and forestry compared to both Denmark and Finland. Norway's specialization index in Agriculture, fisheries and forestry is 0.78, indicating that Norway produces significantly fewer publications in this field compared to the world average profile. Overall, all four Nordic countries are less specialized than the world average, but with very different strengths across countries. Norway is highly specialized in Fisheries (5.00), Sweden in Forestry (1.98)

and Soil Science (1.39), Denmark in Soil Science (1.80) and Agriculture, Dairy & Animal Science (1.34); Finland in Forestry (4.05).

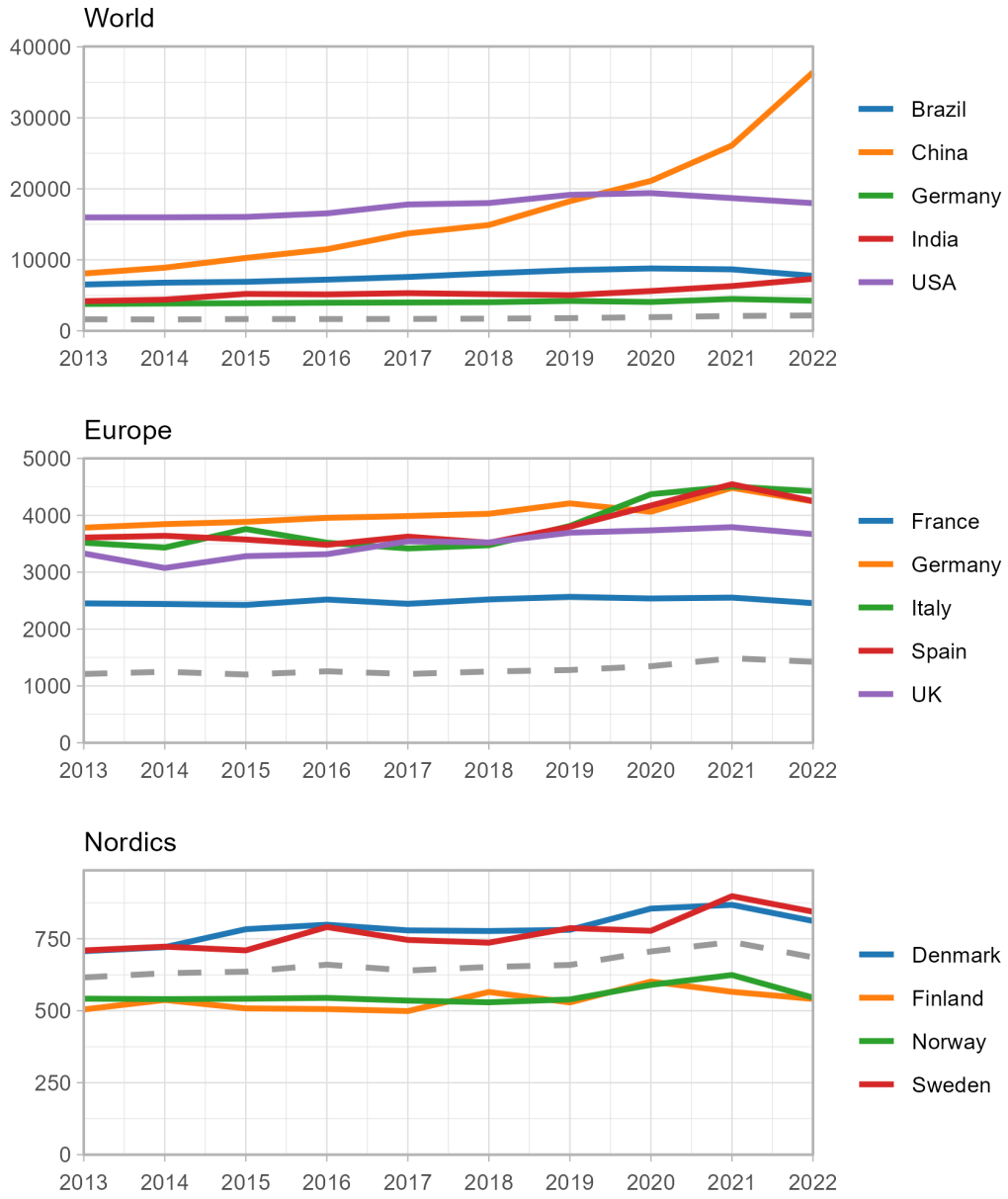


Figure 3.1. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Agriculture, fisheries and forestry, 2013-2022. Regional mean = dotted grey line.

Table 3.1. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in agriculture, fisheries and forestry.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	8,075	36,410			350.93%
USA	15,972	17,982			12.58%
Brazil	6,525	7,747			18.72%
India	4,177	7,320			75.23%
Spain	3,609	4,252			17.82%
Italy	3,518	4,423			25.70%
Germany	3,783	4,245			12.23%
UK	3,329	3,669			10.20%
Japan	3,503	3,469			−0.96%
Australia	2,666	3,295			23.62%
Turkey	1,825	3,399			86.31%
Canada	2,812	3,213			14.28%
South Korea	2,186	3,047			39.40%
Iran	1,543	3,068			98.74%
France	2,451	2,455			0.19%
Sweden	710	844			18.98%
Denmark	707	812			14.84%
Norway	542	546			0.70%
Finland	505	541			7.24%

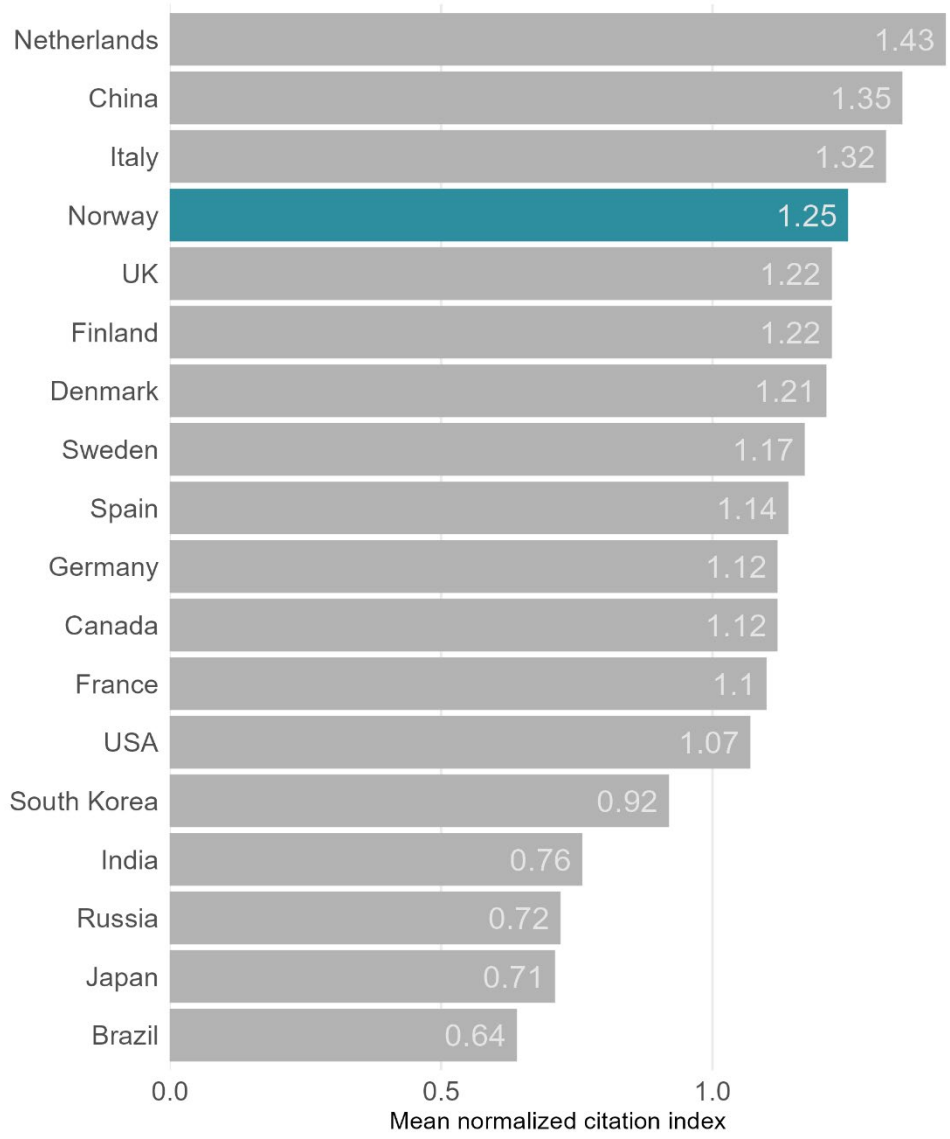


Figure 3.2. Mean normalized citation index of Norwegian publishing within agriculture, fisheries, and forestry for the period 2019-2021 with comparative countries. World mean = 1.

3.2 Biology

In Biology, China is yet to close the gap with the US, but the trend seen in Figure 3.3 clearly indicates that this may happen soon. In Biology, the Chinese production of papers has grown by 249 per cent in the period from 2013 to 2022, while the US has seen a 7 per cent decline in the same period.

In the Nordic countries, Sweden is the only country whose production has been above the regional Nordic average throughout the entire study period (2013-2022) (Figure 3.3). In other Nordic countries there has been a more varied pattern over time, as all three countries had more or less the same publication output in 2013. Throughout the period, Norway's production has increased the most (27.9 per cent), which is even higher than in Sweden (21.7 per cent). In 2022, Norway produced 607 papers in Biology (modified author shares), which is somewhat higher than Denmark (576) and Finland (500), but below Sweden (879).

All Nordic countries are well cited above the world average (Figure 3.4), but Sweden and Denmark's citation indexes (both 1.49) are higher than those in Finland (1.37) and Norway (1.35).

All Nordic countries are more specialized in biology than the world average (Table 3.4), with the highest specialization index in Norway (1.66), which is markedly higher than in other Nordic countries: 1.38 in Finland, 1.19 in Sweden and 1.04 in Denmark. Like the other Nordic countries, Norway has a strong focus on Ecology (2.51) and Evolutionary Biology (2.68) but stands out with a very high specialization in Marine & Freshwater Biology (3.94). No other Nordic country demonstrates such a strong specialization in one particular field. In the subject field *Biology* itself, Norway (0.94) is slightly below the world average, which is rather similar to Denmark and Finland, but below Sweden (1.27).

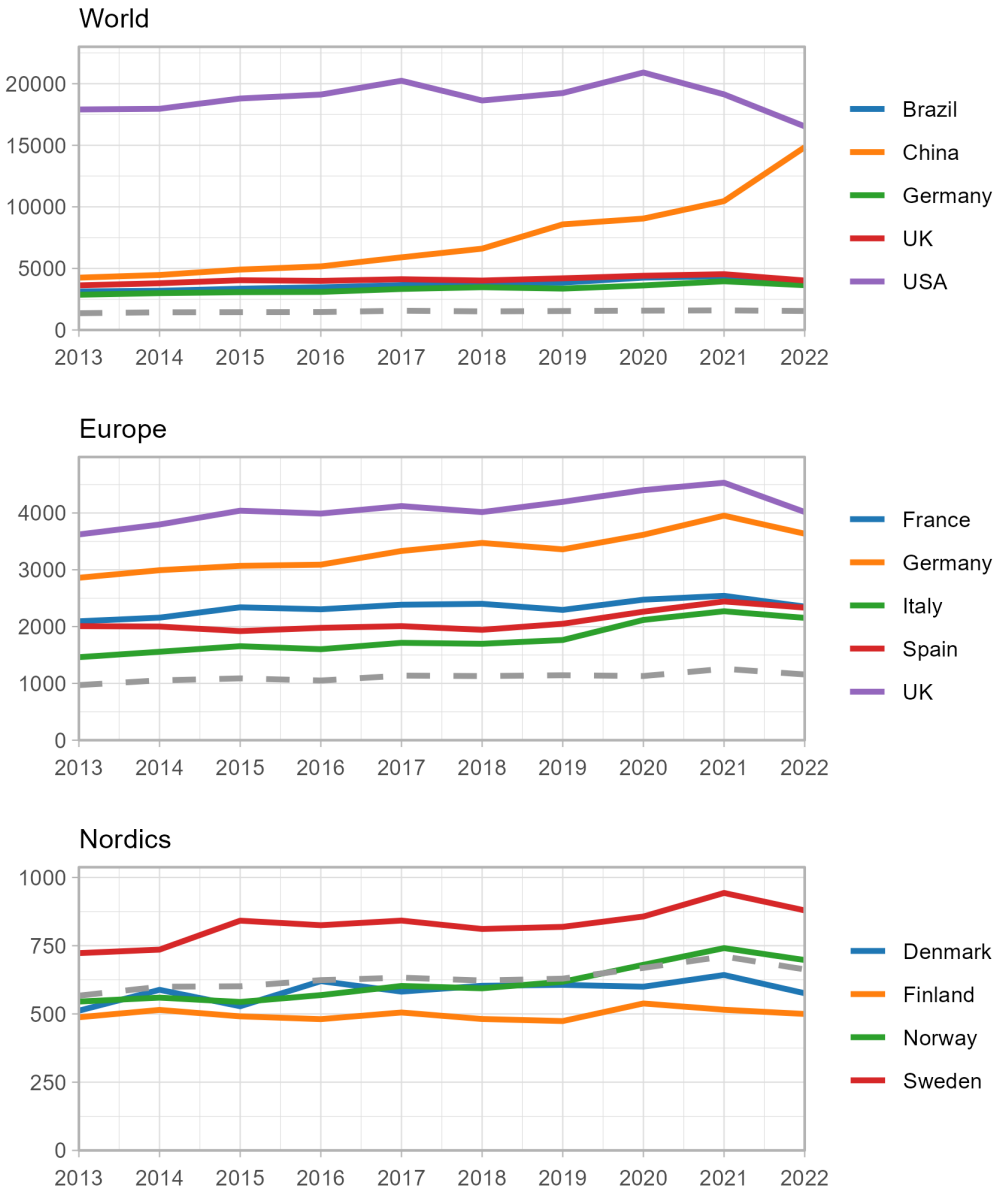
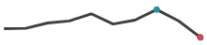
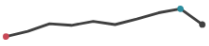
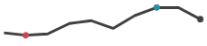
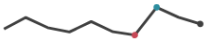


Figure 3.3. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Biology, 2013-2022. Regional mean = dotted grey line.

Table 3.2. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in biology.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
USA	17,907	16,537			−7.65%
China	4,251	14,845			249.24%
UK	3,622	4,017			10.92%
Brazil	3,126	3,693			18.12%
Germany	2,860	3,635			27.12%
Australia	2,755	2,977			8.06%
Canada	2,733	2,941			7.62%
India	1,593	2,923			83.54%
France	2,093	2,352			12.36%
Russia	1,152	2,208			91.61%
Japan	2,249	2,418			7.52%
Spain	2,008	2,334			16.25%
Italy	1,461	2,153			47.36%
Mexico	1,166	1,503			28.97%
South Korea	714	1,071			49.92%
Sweden	723	879			21.65%
Norway	545	697			27.92%
Denmark	512	576			12.48%
Finland	488	500			2.48%

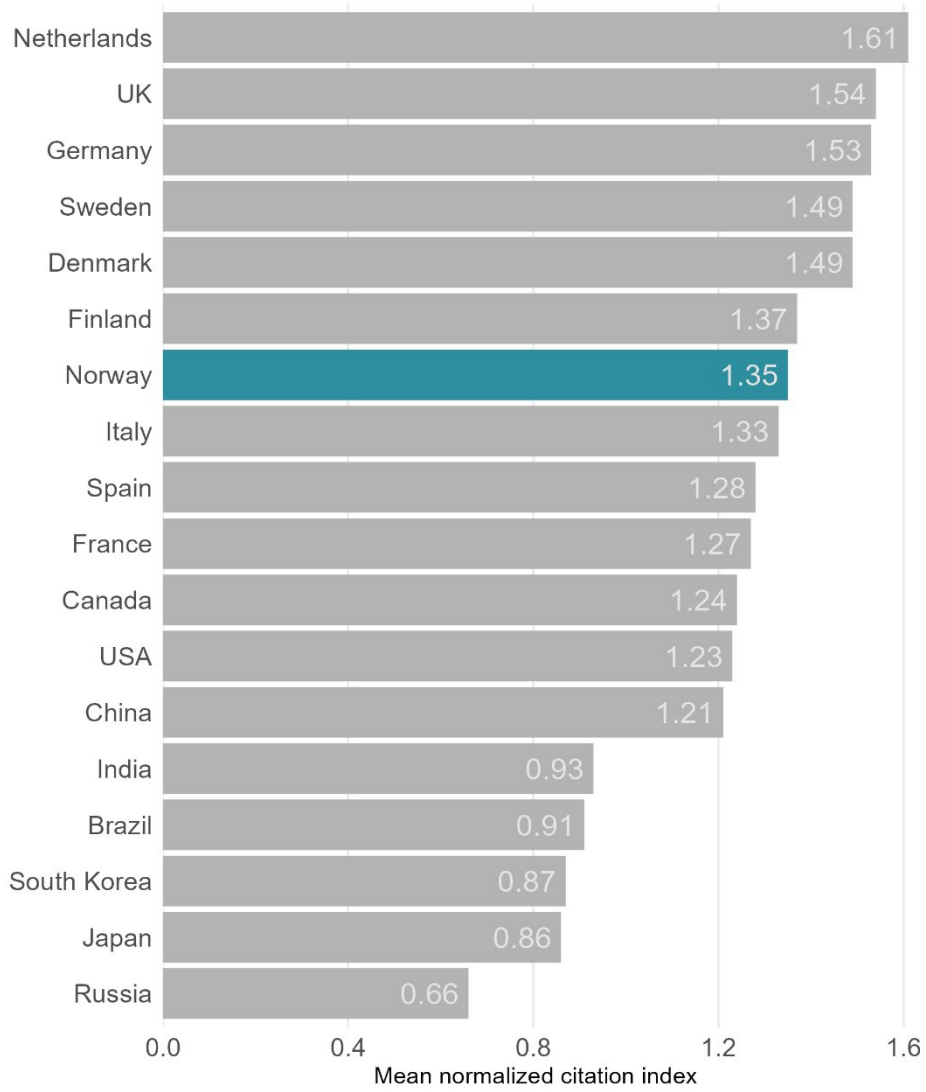


Figure 3.4. Mean normalized citation index of Norwegian publishing within biology for the period 2019-2021 with comparative countries. World mean = 1.

3.3 Biomedicine and molecular biosciences

With a 229 per cent total growth in China from 2013 to 2022, increasing in all years, compared to a negative total growth in the US (10 per cent), China exceeded the US at the world's largest producer of scientific papers in Biomedicine and molecular biosciences in 2021 (Figure 3.5). In Europe, Germany and UK have consistently been the largest producers in this field, but with a total growth in Italy of 31 per cent, low growth in Germany, and decline in the UK, these three top-producing countries now have fairly similar outputs. In the Nordic region, Sweden and Denmark have consistently produced more than Norway and Finland. In 2022 the Swedish output was 2.4 times that of Norway (3828 against 1600 fractionalized

papers), and the Danish output was 1.9 times higher. Although not following a linear trend, the Norwegian production has increased by 22 per cent in the period (from 1311 to 1600 papers). This is more than twice the growth in Denmark (9 per cent growth) and Finland (10 per cent growth), and more than three times the growth in Sweden (7 per cent growth) (Table 3.3).

Norway has one of the highest citation indexes in the world (1.51) in Biomedicine and molecular biosciences, only behind the US and the UK (Figure 3.6). The other Nordic countries have indexes between 1.34 and 1.46. However, this citation index for Norway does not correspond with the country's level of specialization in this field (Table 3.4). Norway's specialization index is well below the world average (0.78), and the lowest among the Nordic countries, where the indexes range from 0.91 in Finland to 1.15 in Denmark. Despite a low degree of specialization compared to the world, in absolute numbers this field is Norway's fourth largest, with volume only exceeded by Clinical medicine, Engineering, and Health sciences.

The visual representation of Norway's specialization in Table 3.4 is predominantly red, indicating that Norway is less specialized in most fields compared to the world average. There is no 'logical' pattern in terms of the subfields where Norway is *more* specialized than in others, except for Neurosciences (1.13) which will be discussed later in Chapter 6. Norway's specialization index is high in Physiology (2.09), Behavioral Sciences (1.44), and Toxicology (1.25). For some of the subfields with low specialization, the index values are extremely low: especially in Pathology (0.29) and Cell & tissue engineering (0.31), but also low in Anatomy & morphology (0.52), Biophysics (0.52), Biochemistry & molecular biology (0.66). The Nordic countries do not show much variation in Biomedicine and molecular biosciences. Where there is low specialization in one country, there are usually low specialization indexes in the other countries as well. Some noticeable exceptions though are Norway's index in Pathology, Biophysics and Cell biology (and to some extent also Pharmacology & Pharmacy), which are substantially lower than in the other Nordic countries. In Biochemistry & Molecular biology Norway (0.66) is the only country with a value below the world average.

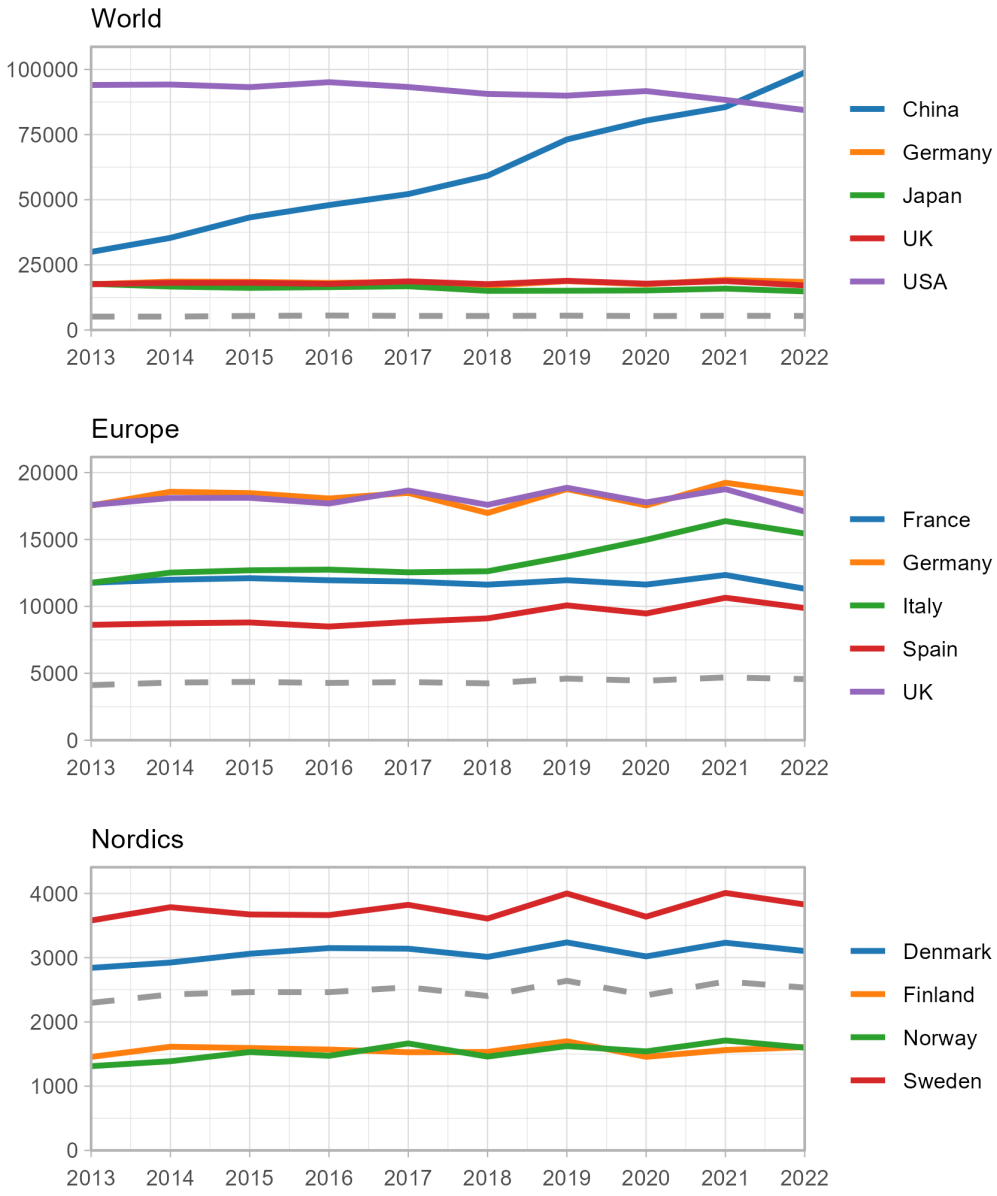
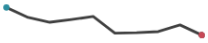
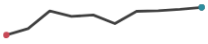
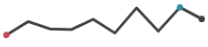


Figure 3.5. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Biomedicine and molecular biosciences, 2013-2022. Regional mean = dotted grey line.

Table 3.3. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in biomedicine and molecular biosciences.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	29,971	98,823			229.73%
USA	94,038	84,401			−10.25%
India	11,542	20,763			79.89%
Germany	17,536	18,432			5.11%
UK	17,579	17,089			−2.79%
Japan	17,723	14,810			−16.44%
Italy	11,761	15,442			31.29%
France	11,765	11,320			−3.79%
Canada	10,887	10,672			−1.98%
Spain	8,620	9,878			14.59%
South Korea	8,450	9,599			13.60%
Brazil	7,161	9,033			26.14%
Australia	7,182	8,601			19.75%
Iran	3,382	7,823			131.31%
Netherlands	5,972	6,363			6.54%
Sweden	3,579	3,828			6.97%
Denmark	2,842	3,104			9.21%
Norway	1,311	1,600			22.02%
Finland	1,455	1,608			10.47%

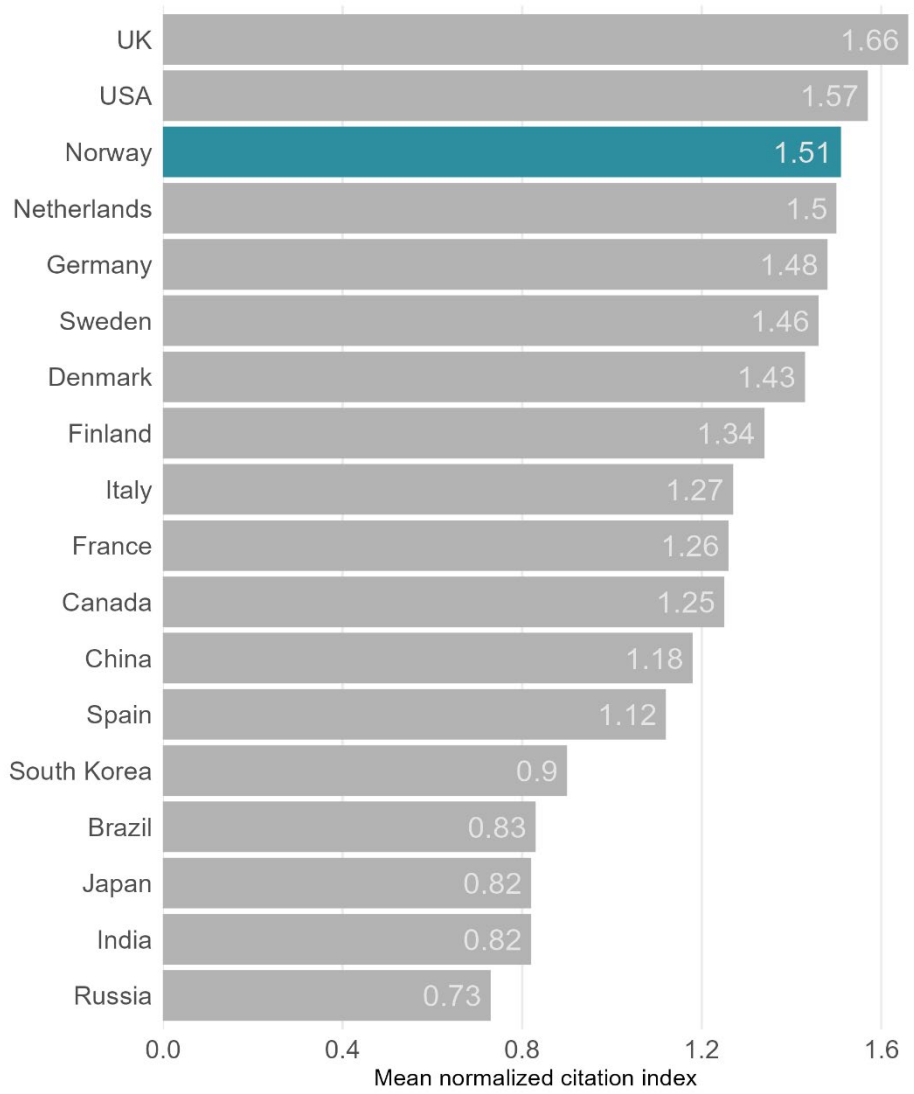


Figure 3.6.Mean normalized citation index of Norwegian publishing within biomedicine and molecular biosciences for the period 2019-2021 with comparative countries. World mean = 1.

3.4 Specialisation

Table 3.4. Relative field specialisation of Nordic countries within the subfields of the fields of agriculture, fisheries and forestry, biology, and biomedicine and molecular biosciences, 2022. World average = 1.

	Norway	Sweden	Denmark	Finland
Agriculture, fisheries, forestry				
Agricultural Economics & Policy	0.59	0.95	0.76	0.77
Agriculture, Dairy & Animal Science	0.65	0.51	1.34	0.60
Agriculture, Multidisciplinary	0.40	0.33	0.63	0.60
Agronomy	0.43	0.41	0.63	0.51
Fisheries	5.00	0.79	1.23	1.09
Food Science & Technology	0.75	0.53	1.12	0.85
Forestry	1.14	1.98	0.43	4.05
Horticulture	0.54	0.20	0.14	0.09
Plant Sciences	0.47	0.62	0.60	0.71
Soil Science	0.54	1.39	1.80	1.01
Veterinary Sciences	0.66	0.85	0.99	0.70
Overall	*0.78*	*0.68*	*0.88*	*0.89*
Biology				
Biodiversity Conservation	1.87	1.11	1.02	1.91
Biology	0.94	1.27	1.00	0.87
Ecology	2.51	1.89	1.36	2.57
Entomology	0.56	0.49	0.70	0.99
Evolutionary Biology	2.68	2.27	1.58	2.53
Limnology	1.16	1.40	1.36	1.13
Marine & Freshwater Biology	3.94	1.01	1.41	1.27
Mathematical & Computational Biology	0.73	0.70	0.53	0.60
Mycology	0.85	1.27	1.01	0.79
Ornithology	1.60	0.85	1.26	1.65
Zoology	1.00	0.68	0.74	0.75
Overall	*1.66*	*1.19*	*1.04*	*1.38*
Biomedicine and molecular biosciences				
Anatomy & Morphology	0.52	0.35	0.46	0.34
Behavioral Sciences	1.44	1.71	1.22	1.52
Biochemical Research Methods	0.80	1.50	1.60	1.31
Biochemistry & Molecular Biology	0.66	1.06	1.02	1.04
Biophysics	0.52	1.34	0.90	0.82
Biotechnology & Applied Microbiology	0.70	0.86	0.96	0.82
Cell & Tissue Engineering	0.31	0.94	0.40	0.82
Cell Biology	0.65	1.09	0.91	1.02
Chemistry, Medicinal	0.29	0.64	0.60	0.51
Developmental Biology	0.98	1.11	0.75	1.37
Genetics & Heredity	0.99	1.03	1.23	1.18
Immunology	0.92	1.42	1.08	0.91
Medical Laboratory Technology	1.19	0.56	0.81	0.38
Medicine, Research & Experimental	0.53	0.82	1.06	0.63
Microbiology	0.80	1.01	1.43	0.88
Microscopy	0.96	0.67	0.84	0.58

		Norway	Sweden	Denmark	Finland
	Neurosciences	1.13	1.39	1.54	1.07
	Parasitology	0.66	0.69	0.70	0.37
	Pathology	0.29	0.61	0.65	0.83
	Pharmacology & Pharmacy	0.56	0.79	0.96	0.64
	Physiology	2.09	1.62	3.38	1.34
	Reproductive Biology	1.12	1.35	2.23	1.01
	Toxicology	1.25	1.67	1.25	0.98
	Virology	0.68	0.99	0.80	1.35
Overall		*0.78*	*1.06*	*1.15*	*0.91*

4 Natural sciences

4.1 Chemistry

China surpassed the US in chemistry publications as early as 2013 (Figure 4.1), and over the last ten-year period, there has been a 132 per cent growth in Chinese publications (Table 4.1). In the Nordic region, the numbers are considerably more stable (Figure 4.1), with Sweden being the highest producer (though the growth rate in the most recent years was slightly negative), Denmark producing at the Nordic average, and Finland and Norway producing the least (Table 4.1), with just 408 (fractionalized) publications. Norway, however, has experienced the strongest growth rate in the region (31 per cent), moving from 318 publications in 2013 to 408 publications in 2022.

China is the most highly cited country in Chemistry research in the sample of countries we study, with publications cited 45 per cent more than the world average in 2019-2021 (Figure 4.2). Norway is the only Nordic country with a citation index below the world average (0.96), but the other Nordic countries are not cited much above the world average (Denmark +5 per cent, Finland +6 per cent; and Sweden +9 per cent).

All Nordic countries have a very low degree of specialization in Chemistry, with Norway having the lowest of all (Table 4.5). While the other countries have specialization indexes in the range of 0.53 to 0.62, Norway's specialization index is only 0.38, indicating that Chemistry's share of Norway's scientific production is 62 per cent less than the world average. No Nordic country has a specialization index above world average in any of the subfields in chemistry. In eight of the nine subfields of Chemistry, Norway has the lowest specialization value in the Nordic region. The only exception is Electrochemistry where Norway's specialization index is 0.75, which is the highest in the region.

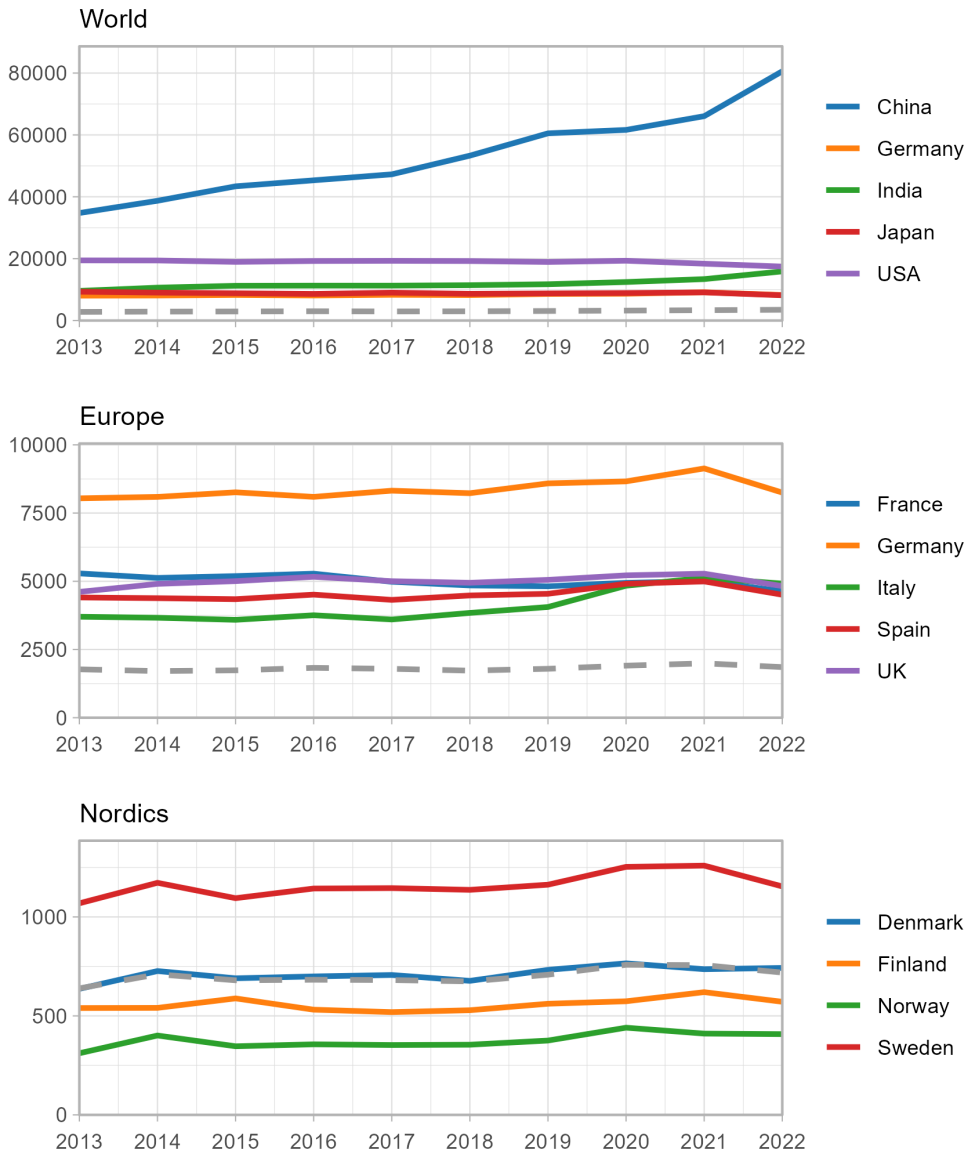
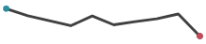
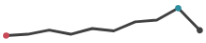
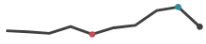
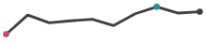
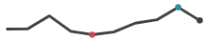


Figure 4.1. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Chemistry, 2013-2022. Regional mean = dotted grey line.

Table 4.1. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in chemistry.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	34,755	80,581			131.86%
USA	19,443	17,450			−10.25%
India	9,586	15,885			65.71%
Japan	9,320	8,166			−12.38%
Germany	8,041	8,251			2.61%
Russia	5,614	7,527			34.08%
South Korea	5,621	7,075			25.88%
Iran	3,969	5,266			32.67%
France	5,288	4,637			−12.32%
UK	4,611	4,824			4.61%
Italy	3,700	4,915			32.83%
Spain	4,407	4,506			2.26%
Poland	2,636	3,671			39.30%
Saudi Arabia	973	3,903			301.24%
Egypt	1,053	3,623			243.97%
Sweden	1,069	1,154			7.98%
Denmark	637	742			16.62%
Finland	540	571			5.88%
Norway	311	408			31.04%

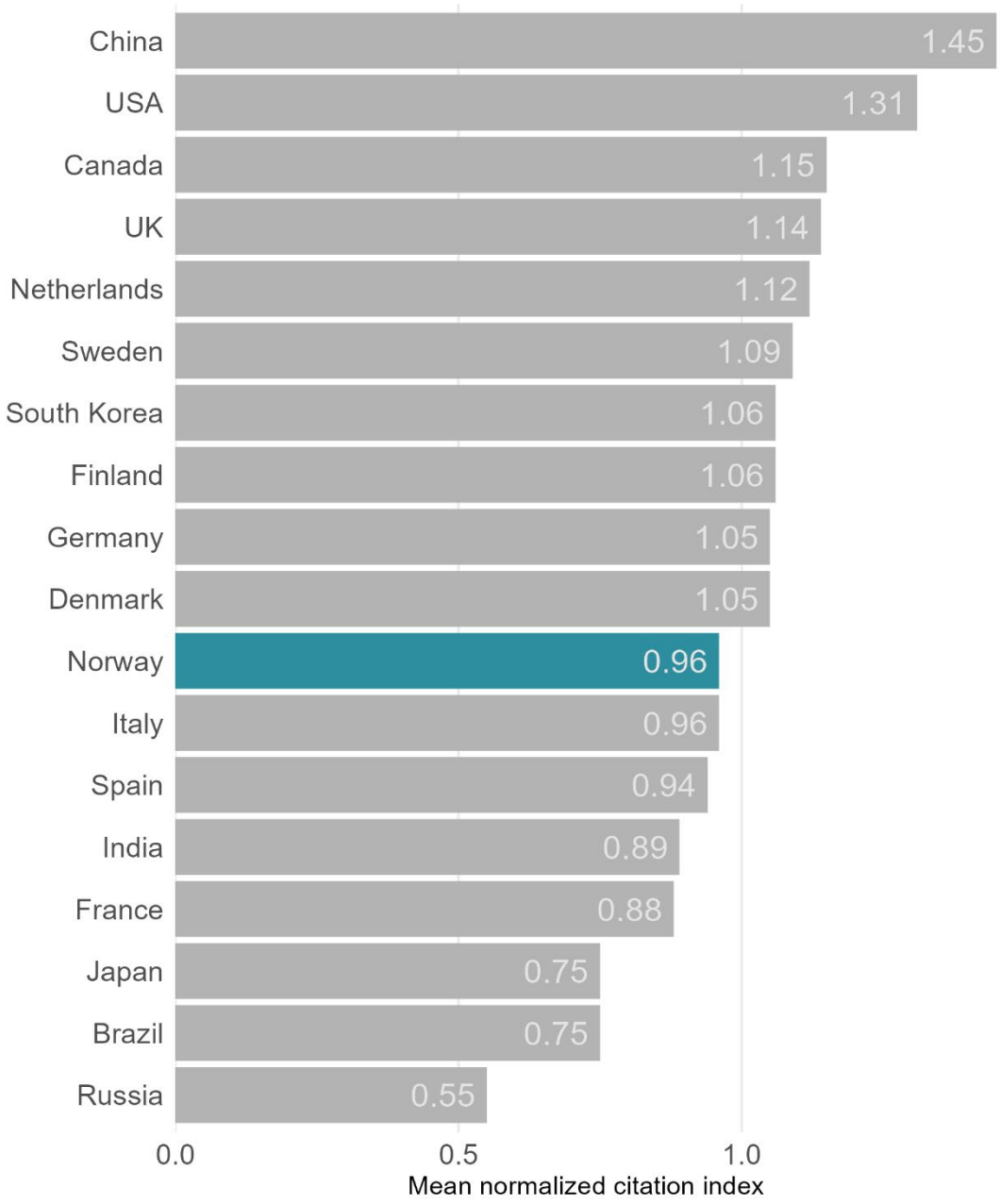


Figure 4.2. Mean normalized citation index of Norwegian publishing within chemistry for the period 2019-2021 with comparative countries. World mean = 1.

4.2 Geosciences

Whereas the US has a total growth of 16.9 per cent in its production of papers in Geosciences in the period 2013-2022, China has had a staggering growth of 330 per cent: producing 22 per cent fewer papers than the US in 2013, reaching parity with the US in 2016, and in 2022 having almost 2.9 times as many publications as the US (Figure 4.3). In terms of citations, the US is still above China: papers from

US are cited 27 perc cent above the world average, while Chinese papers are cited 17 per cent above the world average (Figure 4.4.). In the Nordic countries, Sweden has consistently been marginally above Norway in terms of publication output (Norway and Sweden combined produce 55 per cent more than Denmark and Finland combined) (Figure 4.3). For example, in 2022 Sweden produced 1484 publications compared to 1387 in Norway (Table 4.2). The growth rate has been rather identical in the Nordic countries (between 47 and 53 per cent). In 2022, Norway produced 1387 (fractionalized) papers in Geosciences.

Norway has the highest citation index in the Nordic region in the period 2019-2021 with publications cited 36 per cent above the world average (Figure 4.4). All Nordic countries are well cited above the world average (Denmark +35 per cent, Sweden +33 per cent, Finland +20 per cent).

Norway stands out as a country with a very strong specialization in Geosciences (1.65, Table 4.5). Norway is above the world average in all subfields of Geosciences, and most of all in Oceanography (3.85), Geography, Physical (2.59), and Meteorology & Atmospheric Science (2.18). In sum, the very high values for Norway (by themselves and relative to other Nordic countries) must be understood in terms of Norway's position as a country with both a long coastline (and mountains), with a historical large share of the country's industry being positioned either at sea, or in close proximity to the sea. By comparison, Sweden has a specialization index in Geosciences equal to the world average, Denmark is ten per cent below, and Finland 17 per cent above.

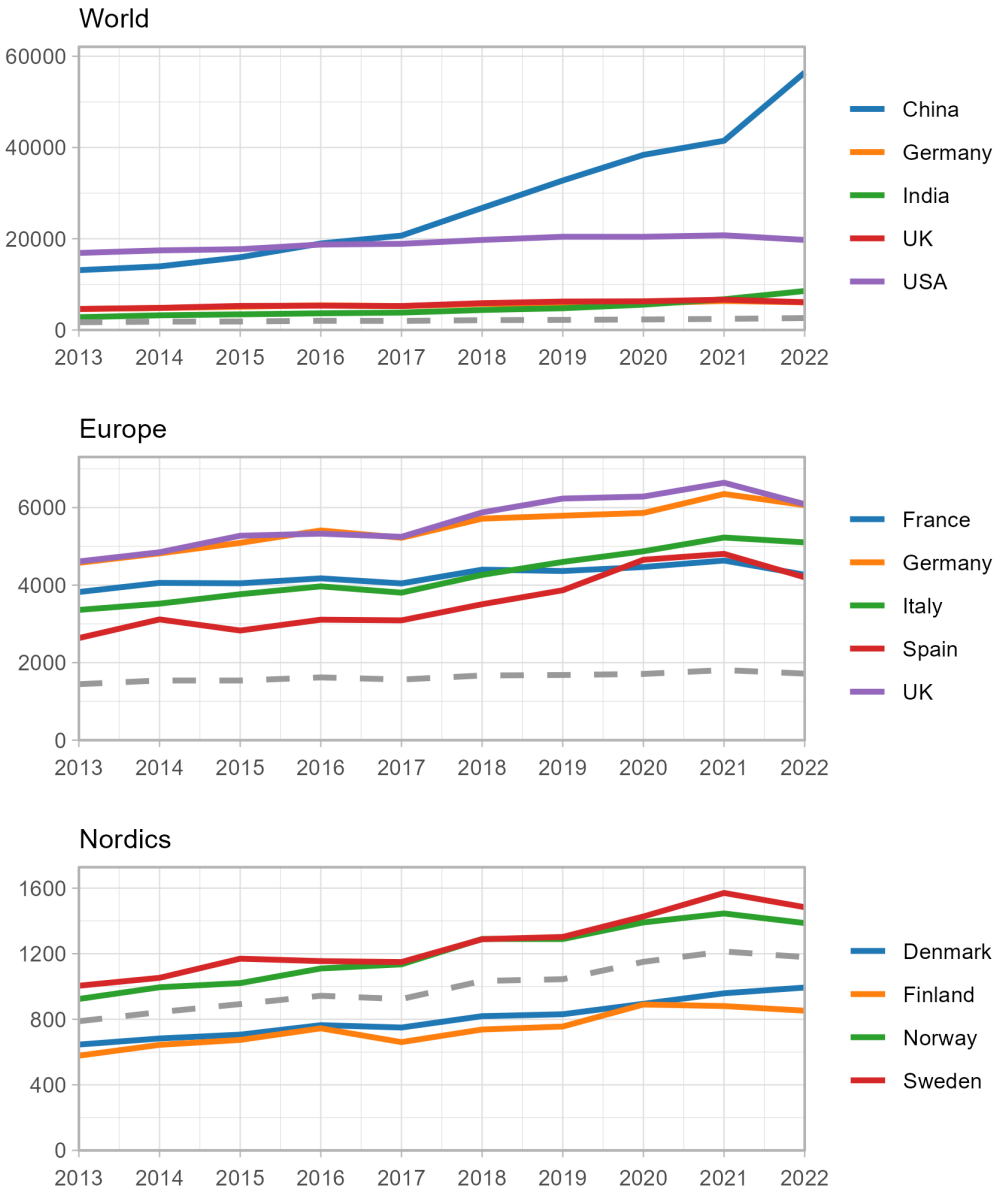


Figure 4.3. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Geosciences, 2013-2022. Regional mean = dotted grey line.

Table 4.2. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in geosciences.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	13,111	56,432			330.43%
USA	16,882	19,735			16.90%
India	2,806	8,540			204.34%
UK	4,612	6,089			32.04%
Germany	4,576	6,064			32.52%
Italy	3,361	5,102			51.82%
Spain	2,635	4,202			59.48%
France	3,822	4,269			11.69%
Canada	3,282	4,423			34.79%
Russia	2,203	3,579			62.43%
Australia	2,846	4,325			51.96%
Japan	2,913	3,722			27.74%
Brazil	1,470	3,621			146.31%
South Korea	1,582	3,424			116.41%
Iran	1,073	3,236			201.61%
Sweden	1,005	1,484			47.69%
Norway	924	1,387			50.12%
Denmark	646	994			53.89%
Finland	578	852			47.51%

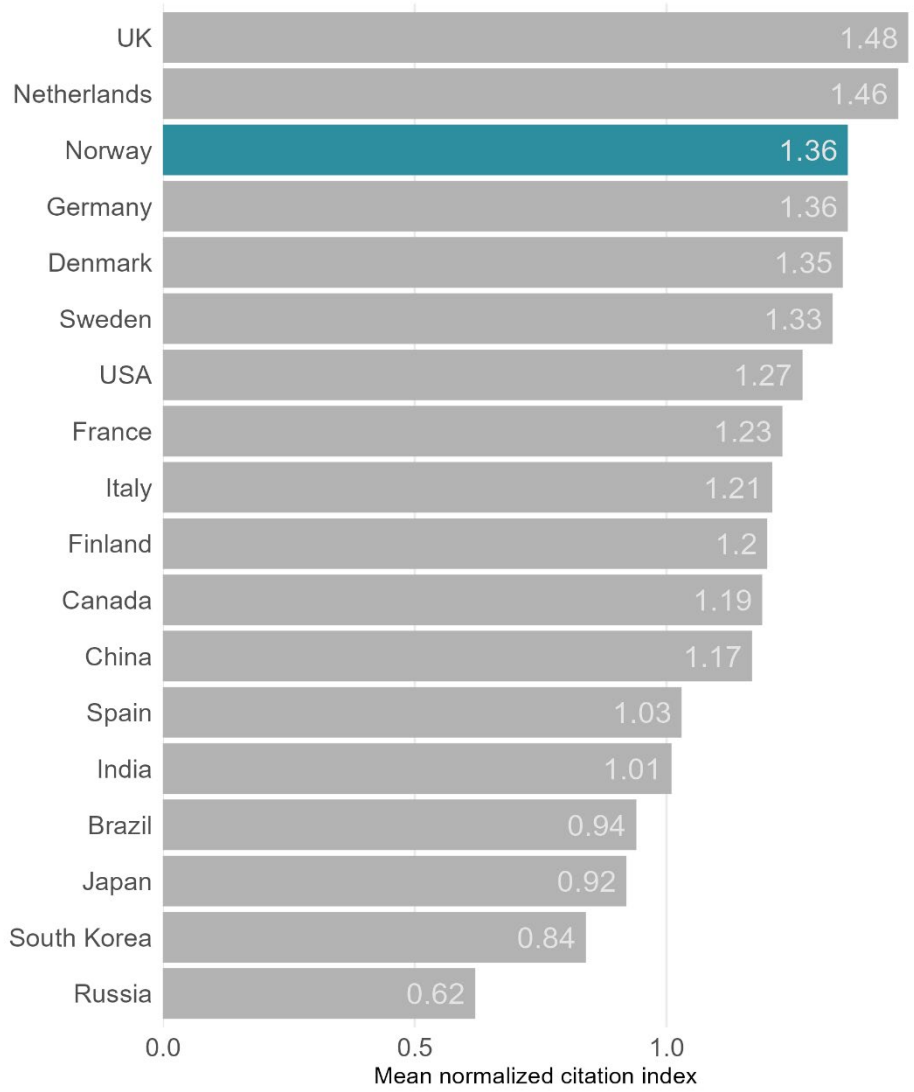


Figure 4.4. Mean normalized citation index of Norwegian publishing within geosciences for the period 2019-2021 with comparative countries. World mean = 1.

4.3 Materials science

The world's five largest countries in terms of article output in Materials science, are also among the world's six leading manufacturing countries. The only exception is Japan, which does not appear in the chart of the world's most productive countries in Figure 4.5. In 2022, China accounted for 29.4 per cent of global manufacturing output (the US 16.6 per cent; Japan 7.5 per cent; Germany 5.8 per cent; India 3.3 per cent; South Korea 3 per cent). While countries such as the US, Germany and the UK have all seen increase in publication volume from 2013 to 2022, the most significant growth in papers has occurred in emerging economies, such as China (+107 per cent), India (+220 per cent), and Saudi Arabia (+380 per cent).

Growth in the Nordic has been far more modest, ranging from 19-29 per cent (Table 4.3).

In the Nordic region, Sweden has produced substantially more output than the other Nordic countries, which have all remained below the Nordic average in all years. Norway's output has been the lowest in the region in all years, with a total growth of 19.6 per cent (Table 4.3). With just 319 (fractionalized) publications in 2022, Materials science is the scientific field with the lowest volume for Norway.

Norway's low publication volume is accompanied by a relative low citation index (0.93), meaning that Norwegian papers in 2019-2021 were cited seven per cent below the world average (Figure 4.6). Here, it is the two largest producers of Materials science papers, that are most cited: China (1.39) and the US (1.29). The other Nordic countries are also cited above the world average (Denmark +8 per cent, Sweden +3 per cent, and Finland +2 per cent).

Norway's low citation index may be considered in relation to Norway's low degree of specialization in materials science (0.43) (Table 4.5), but Denmark is even less specialized (0.38) and still achieves a citation index above the world average. In fact, all Nordic countries are less specialized in Materials science compared to the world average, both overall and across all subfields, with the exception of a strong specialization in Paper & Wood in Sweden (3.70) and Finland (5.03).

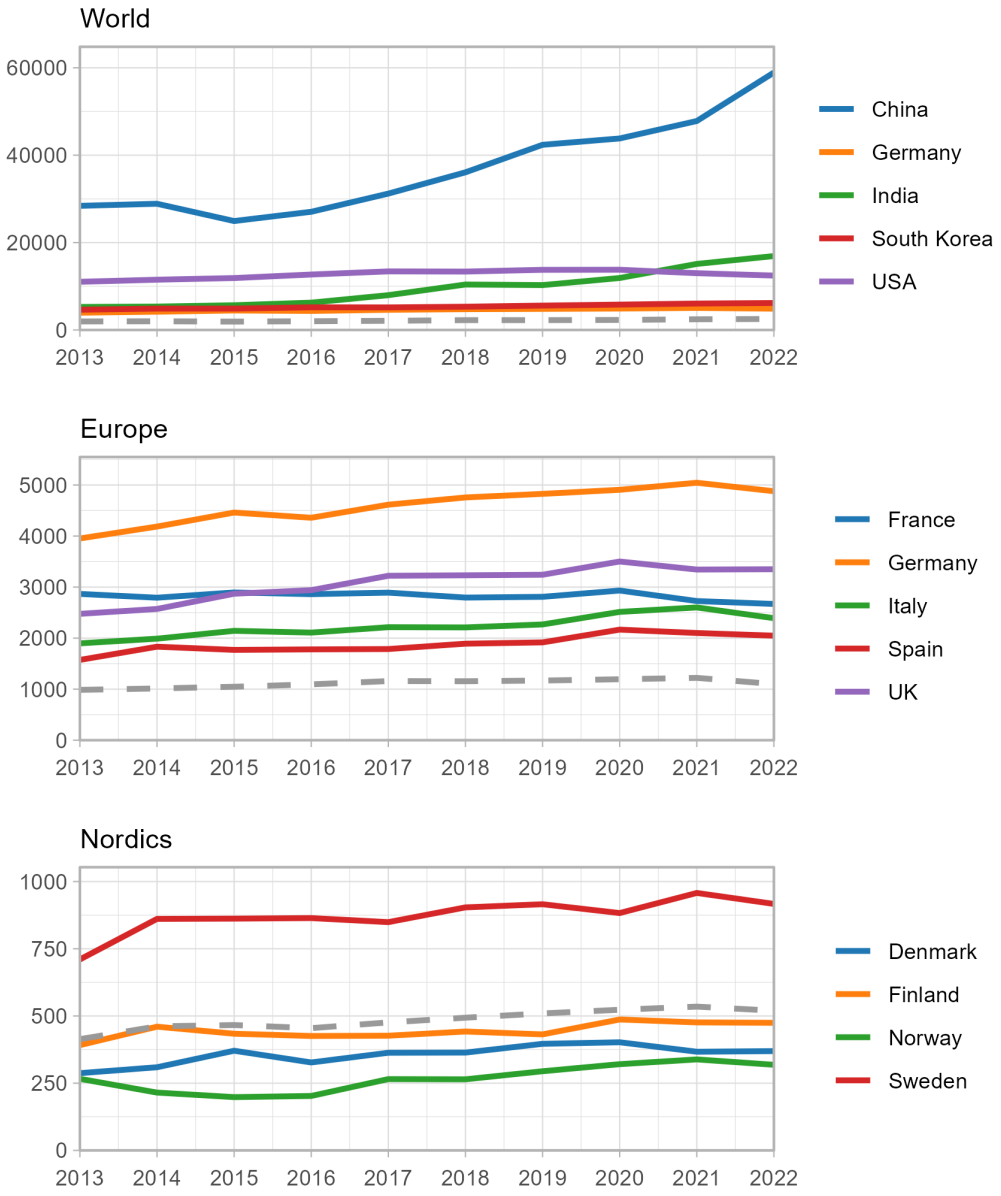


Figure 4.5. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Materials science, 2013-2022. Regional mean = dotted grey line.

Table 4.3. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in materials science.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	28,411	58,916			107.37%
India	5,272	16,916			220.88%
USA	11,027	12,452			12.92%
South Korea	4,631	6,168			33.19%
Germany	3,952	4,878			23.43%
Japan	4,807	4,586			−4.61%
Russia	1,999	3,561			78.14%
UK	2,476	3,349			35.28%
Iran	1,887	2,940			55.78%
France	2,866	2,669			−6.86%
Italy	1,898	2,391			26.00%
Turkey	1,173	2,305			96.55%
Australia	1,483	2,137			44.14%
Saudi Arabia	468	2,247			380.63%
Canada	1,519	2,059			35.60%
Sweden	710	917			29.08%
Finland	392	475			21.21%
Denmark	287	369			28.52%
Norway	266	319			19.61%

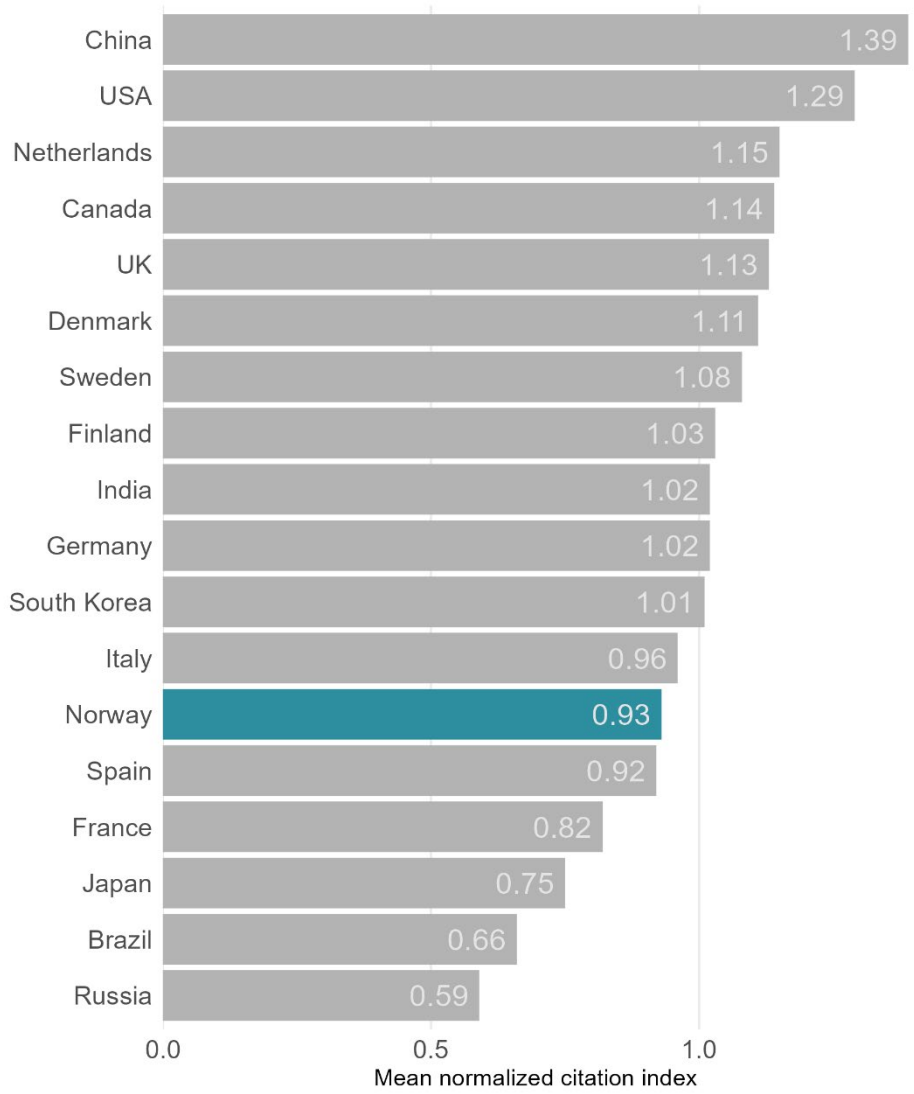


Figure 4.6. Mean normalized citation index of Norwegian publishing within materials science for the period 2019-2021 with comparative countries. World mean = 1

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4.4 Physics

In Physics, most countries except China and India have a decline in papers over the years 2013-2022 (Table 4.4). China, already at a high level in 2013 has seen a 93 per cent growth up to 2022, and by 2022 the Chinese-US ratio has increased from 1.00 to 2.46 (Figure 4.7).

In the Nordic region, Norway, however, as one of few countries, has increased its output in Physics (total growth has been 6.25 per cent in the period 2013-2022), while it has decreased in the other Nordic countries (Table 4.4). Still, Norway has the lowest publication volume in the region, producing 625 (fractionalized) papers in 2022. Compared to the largest Nordic country, Sweden, the gap has been narrowed from a ratio of 0.33 to 0.38.

Norway also has the lowest citation index in the Nordic region (Figure 4.8), but with a citation index of 1.25, Norway is still rather well cited (i.e., 25 per cent above the world average). The citation indexes of the other Nordic countries vary between 1.27 and 1.34.

Finland (0.97) and Sweden's specialization index (0.87) are slightly below the world average (Table 4.5), whereas the specialization index in Denmark (0.64) and Norway (0.58) are well below the world average. Norway's only subfield in Physics with an index well above the world average is the small subfield Acoustics. In larger fields in Physics, such as Condensed matter (0.35) and Particles & Fields (0.65) Norway has a very low degree of specialization. For the other Nordic countries there are more cases of subfields with values above 1.00 (world average), especially in Finland (Nuclear; and Particles & Fields, where also Sweden is above 1.00). In two fields, Astronomy and Astrophysics; and Atomic, Molecular & Chemical Physics, all Nordic countries except Norway have values above 1.00.

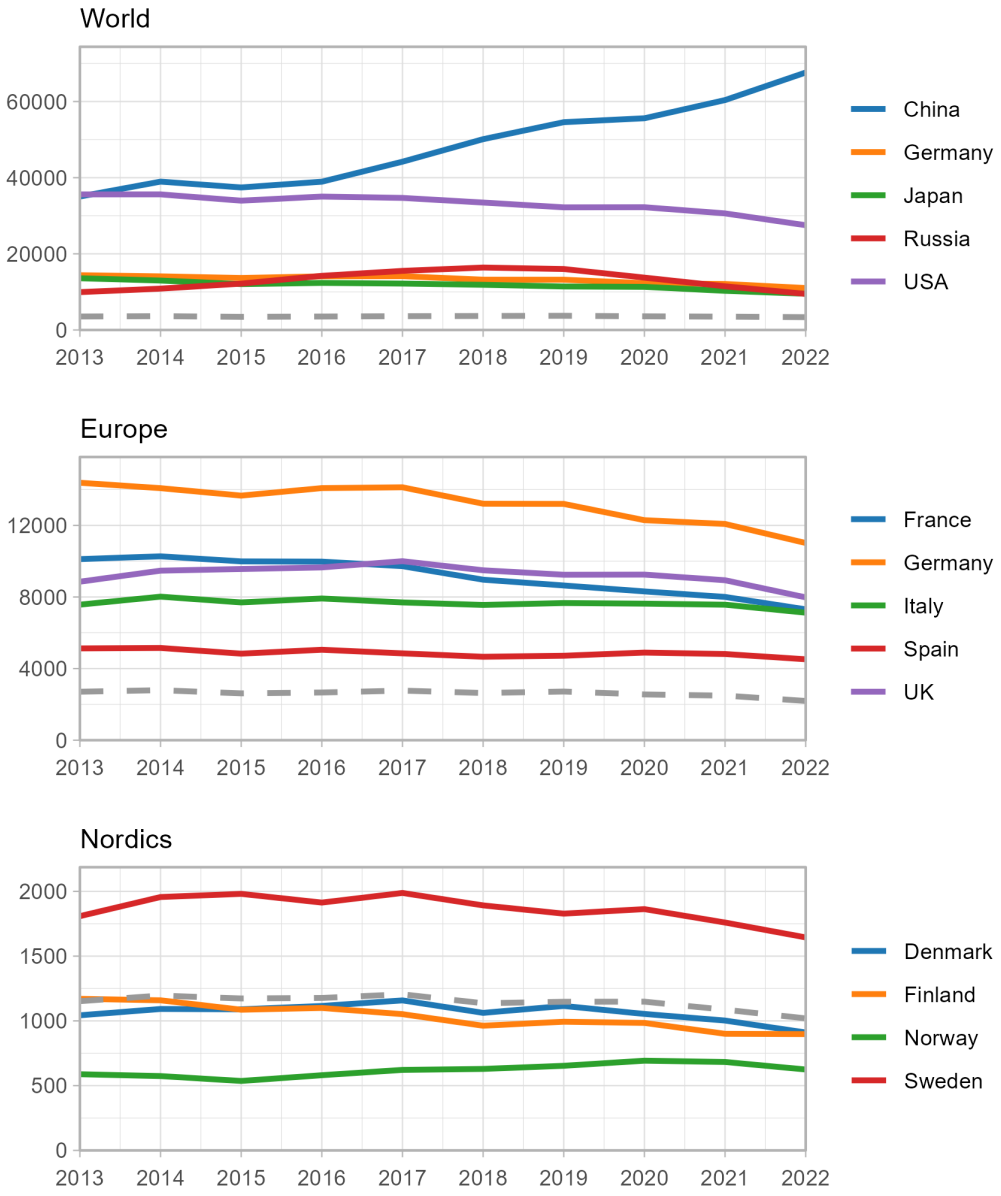


Figure 4.7. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Physics, 2013-2022. Regional mean = dotted grey line.

Table 4.4. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in physics.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	35,053	67,617			92.90%
USA	35,604	27,515			−22.72%
Russia	9,939	9,475			−4.67%
Germany	14,383	11,017			−23.40%
Japan	13,582	9,517			−29.93%
India	9,138	13,013			42.41%
France	10,117	7,310			−27.74%
UK	8,855	7,979			−9.89%
Italy	7,573	7,123			−5.94%
South Korea	6,602	5,816			−11.90%
Spain	5,127	4,521			−11.82%
Canada	4,296	3,912			−8.94%
Iran	3,278	3,630			10.72%
Poland	3,459	3,100			−10.40%
Brazil	3,073	2,902			−5.55%
Sweden	1,809	1,645			−9.08%
Finland	1,170	898			−23.26%
Denmark	1,043	910			−12.72%
Norway	588	625			6.25%

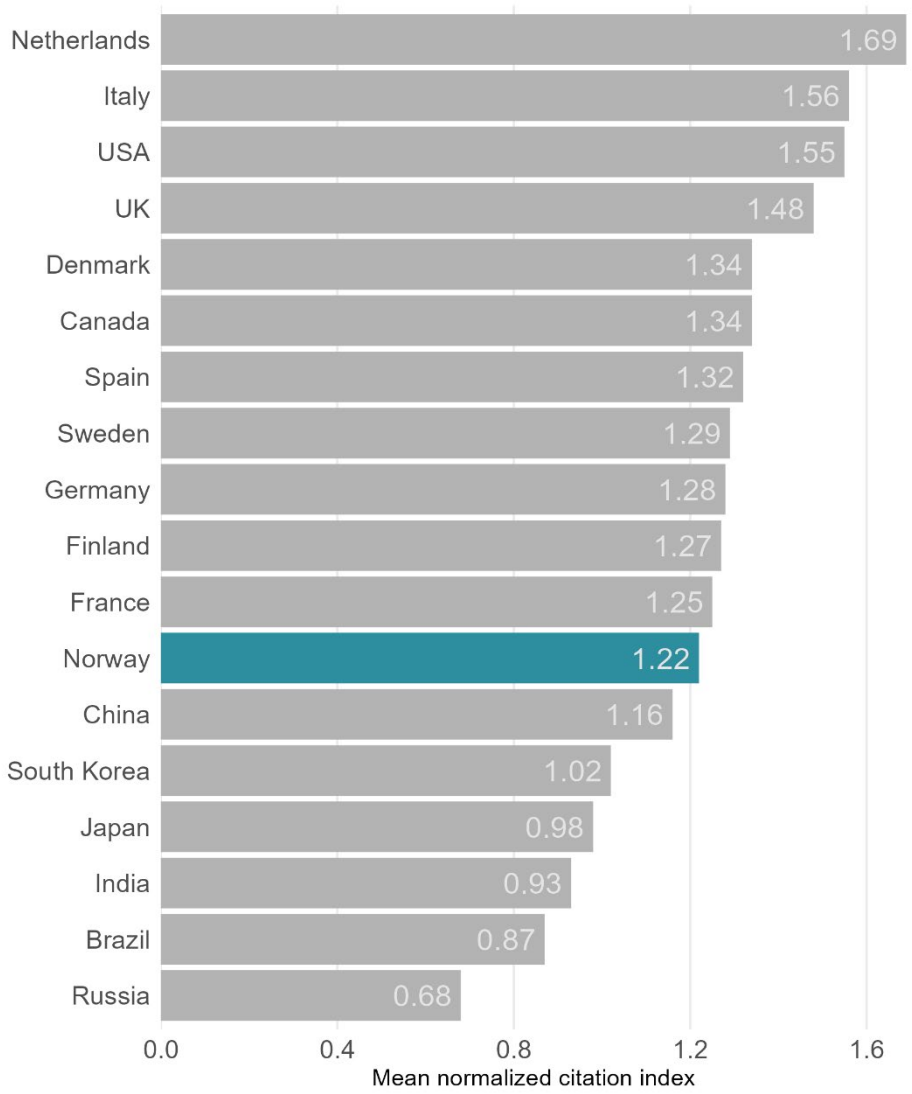


Figure 4.8. Mean normalized citation index of Norwegian publishing within physics for the period 2019-2021 with comparative countries. World mean = 1.

4.5 Specialisation

Table 4.5. Relative field specialisation of Nordic countries within the subfields of the fields of chemistry, geosciences, materials science, and physics, 2022. World average = 1.

	Norway	Sweden	Denmark	Finland
Chemistry				
Chemistry, Analytical	0.43	0.59	0.56	0.56
Chemistry, Applied	0.29	0.50	0.78	0.61
Chemistry, Inorganic & Nuclear	0.33	0.57	0.36	0.75
Chemistry, Multidisciplinary	0.39	0.72	0.55	0.64
Chemistry, Organic	0.17	0.39	0.41	0.51
Chemistry, Physical	0.47	0.71	0.65	0.67
Crystallography	0.19	0.50	0.50	0.45
Electrochemistry	0.75	0.58	0.49	0.46
Polymer Science	0.20	0.42	0.27	0.57
Overall	*0.38*	*0.62*	*0.53*	*0.62*
Geosciences				
Environmental Sciences	1.15	1.02	0.89	1.18
Geochemistry & Geophysics	2.12	0.75	0.92	0.92
Geography, Physical	2.59	1.33	1.68	1.51
Geology	1.55	0.79	0.98	0.85
Geosciences, Multidisciplinary	2.49	0.86	0.93	0.91
Meteorology & Atmospheric Sciences	2.18	1.40	0.78	1.90
Mineralogy	1.35	1.05	0.31	1.72
Oceanography	3.85	1.01	1.10	0.92
Paleontology	1.05	1.58	1.22	0.37
Remote Sensing	1.25	0.75	0.47	1.39
Overall	*1.65*	*1.00*	*0.90*	*1.17*
Materials science				
Biomaterials	0.46	0.69	0.41	0.77
Ceramics	0.09	0.23	0.25	0.42
Characterization & Testing	0.72	0.60	0.21	0.61
Coatings & Films	0.44	0.90	0.73	0.75
Composites	0.36	0.47	0.66	0.43
Multidisciplinary Materials Science	0.49	0.72	0.36	0.72
Paper & Wood	0.85	3.70	0.34	5.03
Textiles	0.18	0.20	0.07	0.85
Nanoscience & Nanotechnology	0.29	0.74	0.47	0.70
Overall	*0.43*	*0.71*	*0.38*	*0.75*
Physics				
Acoustics	1.32	0.73	1.09	2.00
Astronomy & Astrophysics	0.94	1.40	1.32	1.52
Imaging Science & Photographic Technology	1.03	0.58	0.54	1.11
Mechanics	0.80	0.76	0.49	0.46
Nuclear Science & Technology	0.30	1.10	0.40	1.43
Optics	0.29	0.57	0.57	0.92
Applied Physics	0.49	0.77	0.40	0.88
Atomic, Molecular & Chemical Physics	0.69	1.10	1.15	1.01
Condensed Matter	0.35	0.80	0.36	0.79
Fluids & Plasmas	0.88	1.16	0.51	0.84
Mathematical Physics	0.45	1.05	0.69	0.78

		Norway	Sweden	Denmark	Finland
	Multidisciplinary Physics	0.39	0.67	0.53	0.75
	Nuclear	0.65	1.11	0.33	1.59
	Particles & Fields	0.65	1.30	0.73	1.08
	Quantum Science & Technology	0.36	0.69	1.18	0.83
	Spectroscopy	0.37	0.57	0.60	0.40
Overall		*0.58*	*0.87*	*0.64*	*0.97*

5 Engineering, ICT and mathematics

5.1 Computer and information sciences

In most countries there has been a decline in publications in Computer and information sciences from the year 2019, having increased up until then (Figure 5.1). This is likely an effect of the pandemic which reduced the number of conferences and consequently proceeding papers, which appear frequently in this field. The US and China started rather equally in 2013, and the US kept pace with China (albeit with a lower growth rate) up until 2019 when the US started to decline, while China continued to increase.

In the Nordic region, Norway and Denmark have had lower output than Sweden and Finland (Figure 5.1), but in the later parts of the period 2013-2022, Norway 's output (797 papers) has exceeded those of both Denmark (636) and Finland (780). The total growth in Norway's output in Computer and information science has in fact been exceptional: a total growth of 81.5 per cent in the period 2013-2022, compared to 44.1 per cent in Denmark, 30.4 in Sweden and 13.6 in Finland (Table 5.1).

The rapid growth in Norway has also been accompanied by high citation scores (Figure 5.2). In the period 2019-2021, Norwegian papers were cited 23 per cent above the world average (citation index 1.23), which is the highest in the Nordic region. The three other Nordic countries have indexes ranging from 1.12 to 1.13. In this field, while China has become the largest producer of papers, it is still the US that has the highest citation index (1.55, well above China's 1.35).

Apart from Artificial intelligence, both Norway and Finland have specialization indexes above the world average in all subfields of Computer and information science, thus also in total (Table 5.4). No Nordic countries are specialized in AI above the world average.

Norway's specialization index in Computer and information sciences is 1.20 (i.e., papers in Computer and information sciences represent 20 per more of Norway's total scientific output than the world average), whereas Finland's is 1.35. Sweden and Denmark have indexes well below 1.00 both in total, but also in almost all subfields. In the case of Norway, the high overall specialization index is

not due to one or a few subfields where Norway publishes actively, it is consistent across all subfields except AI (0.97) and Information systems (1.10), being the only subfields with specialization values below the Norwegian total (1.20).

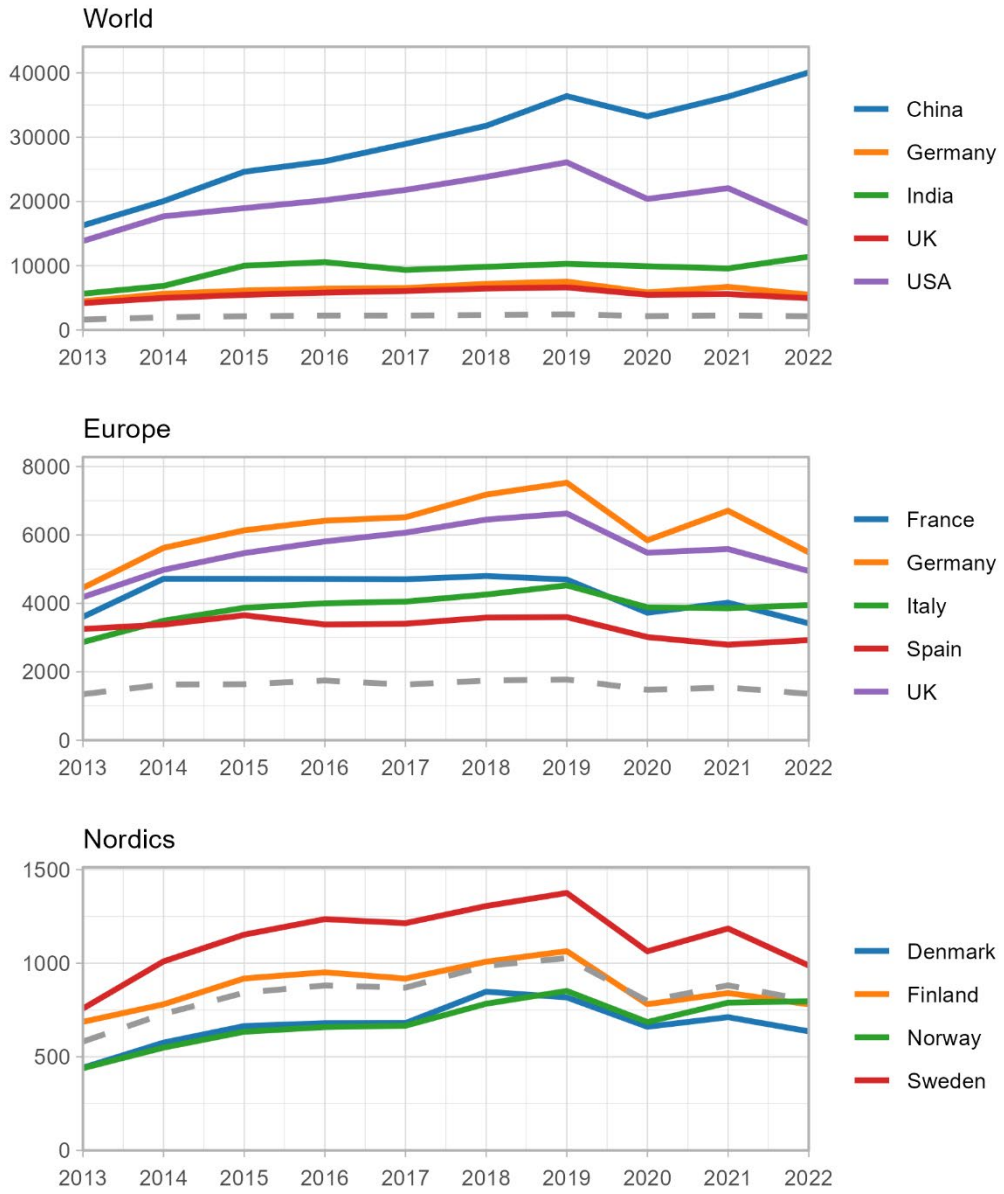
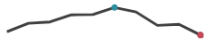
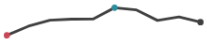


Figure 5.1. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Computer and information sciences, 2013-2022. Regional mean = dotted grey line.

Table 5.1. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in computer and information sciences.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	16,268	40,057			146.23%
USA	13,835	16,563			19.71%
India	5,642	11,392			101.90%
Germany	4,453	5,491			23.31%
UK	4,183	4,944			18.20%
Japan	3,696	3,384			−8.45%
France	3,603	3,416			−5.20%
Italy	2,867	3,952			37.84%
Canada	2,532	3,193			26.14%
South Korea	2,197	3,332			51.68%
Spain	3,250	2,926			−9.96%
Australia	2,183	3,088			41.50%
Brazil	1,626	2,131			31.05%
Saudi Arabia	587	2,315			294.40%
Iran	1,409	1,910			35.51%
Sweden	758	987			30.36%
Finland	687	780			13.55%
Norway	439	797			81.54%
Denmark	441	636			44.07%

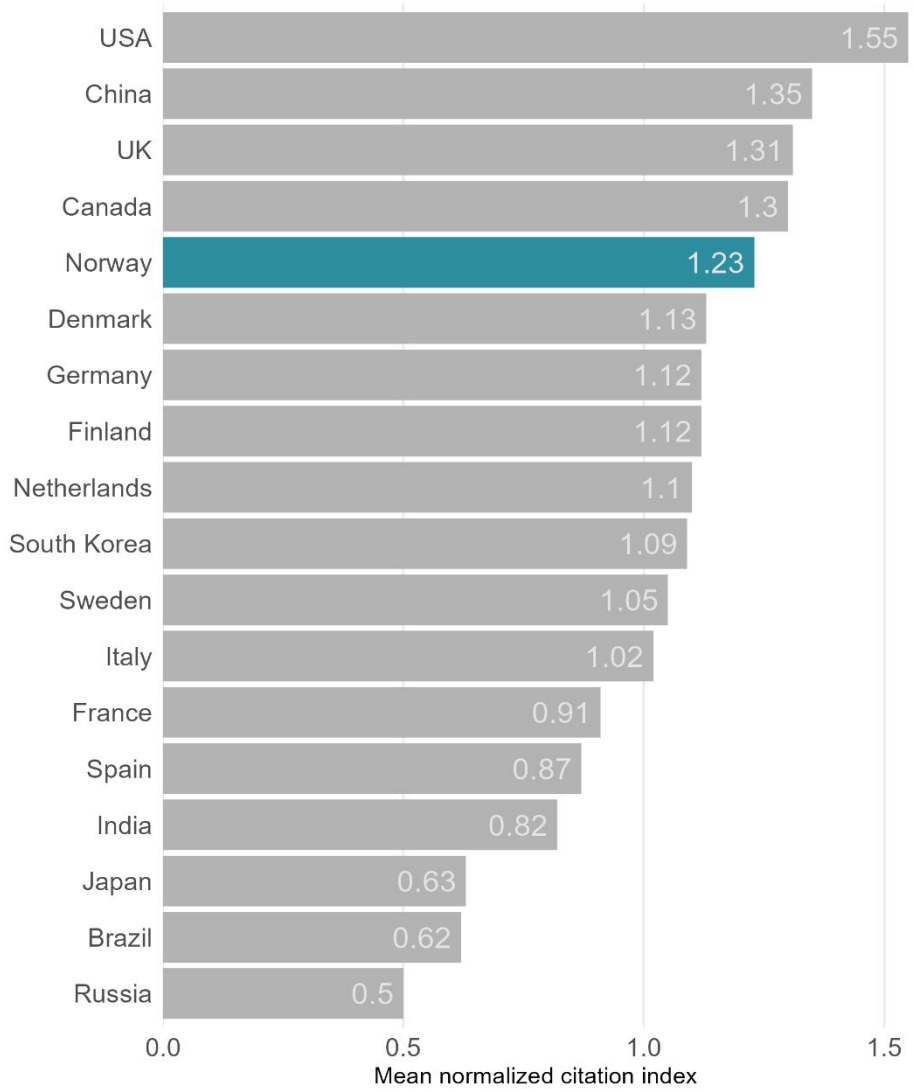


Figure 5.2. Mean normalized citation index of Norwegian publishing within computer and information sciences for the period 2019-2021 with comparative countries. World mean = 1.

5.2 Engineering

In Engineering, as observed for Computer and information science, there has been a tremendous growth in China (111 per cent increase from 2013 to 2022), while the US has seen a decline (down 16 per cent) (Figure 5.3). In the Nordic region, Sweden stands substantially above the other countries in publication output. In fact, Norway, Denmark and Finland have all had a publication output below the Nordic average for all years (which is being raised by Sweden) (Figure 5.3).

In the Nordic region, Norway (21.2 per cent) and Denmark (27.75 percent) have increased their output over time, whereas Finland's output has declined (-6.3%), while Sweden's output has remained roughly the same (+1.25%), although

there has been a strong decline from the year 2017 onward. In 2022, Norway produced 2109 papers in engineering, which is 35 per cent less than Sweden (3248 papers) (Table 5.2).

Sweden has the highest publication output, but the lowest citation index (1.14), which is nevertheless rather similar to Norway (1.16) and Finland (1.20). Denmark has the highest citation index in our set of countries (1.29) (Figure 5.4). Despite these relatively high citation indexes, none of the Nordic countries are especially specialized in Engineering (Table 5.4). Finland (1.00) and Norway (0.98) are at the world average, while Sweden (0.85) and Denmark (0.77) are somewhat lower.

Across the countries there are strong differences at the level of subfields, which in many cases may be explained by the countries' different industry structures. For example, in Norway there are very high specialization indexes in Ocean (4.84), Petroleum (4.39), Marine (3.99), and in Energy & Fuels (1.47) and Operations Research & Management (1.33). Sweden is highly specialized in Transportation Science & Technology (1.84); and Finland in Mining & Mineral Processing (1.62) and Telecommunications (1.89). Denmark does not have any areas with very high specialization indexes, but like all Nordic countries has a relative high specialization in Green & Sustainable Science & Technology.

In several subfields all Nordic countries are substantially less specialized than the world average. For example (Norwegian specialization indexes in brackets): Aerospace (0.28), Biomedical engineering (0.71), Chemical engineering (0.72), Mechanical engineering (0.86), Instruments & instrumentation (0.64), Metallurgy & Metallurgical Engineering (0.74), and Thermodynamics (0.68).

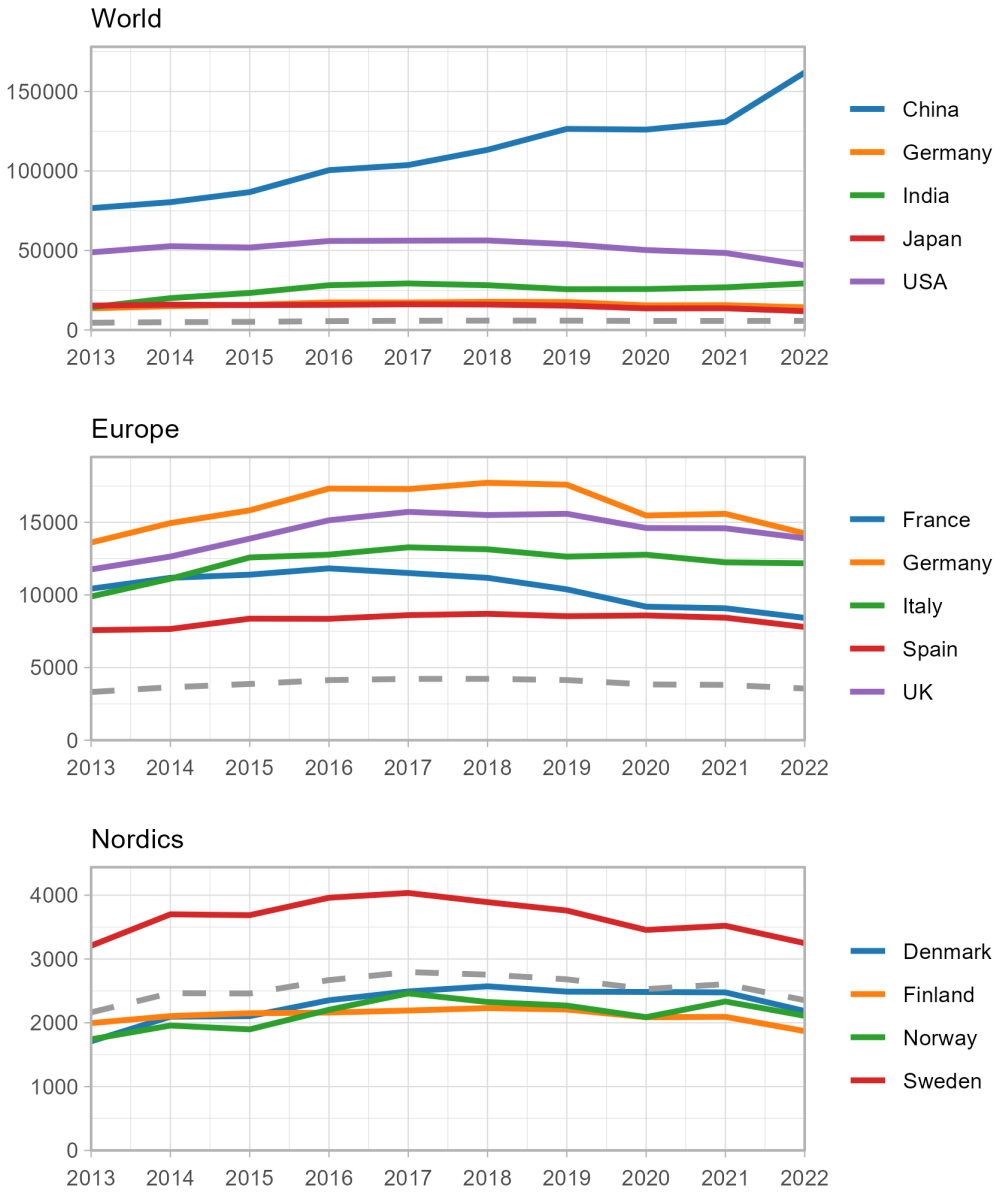


Figure 5.3. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Engineering, 2013-2022. Regional mean = dotted grey line.

Table 5.2. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in engineering.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	76,621	161,910			111.31%
USA	48,813	40,741			−16.54%
India	14,286	29,272			104.90%
Germany	13,609	14,241			4.64%
Japan	15,314	11,835			−22.72%
UK	11,758	13,902			18.23%
South Korea	11,659	14,678			25.89%
Italy	9,894	12,178			23.08%
Russia	4,672	7,355			57.42%
Iran	6,882	11,492			67.00%
France	10,428	8,421			−19.25%
Canada	9,447	10,112			7.04%
Australia	6,841	8,268			20.86%
Spain	7,573	7,794			2.92%
Turkey	4,450	7,659			72.12%
Sweden	3,208	3,248			1.25%
Denmark	1,710	2,184			27.75%
Norway	1,740	2,109			21.19%
Finland	1,995	1,870			−6.28%

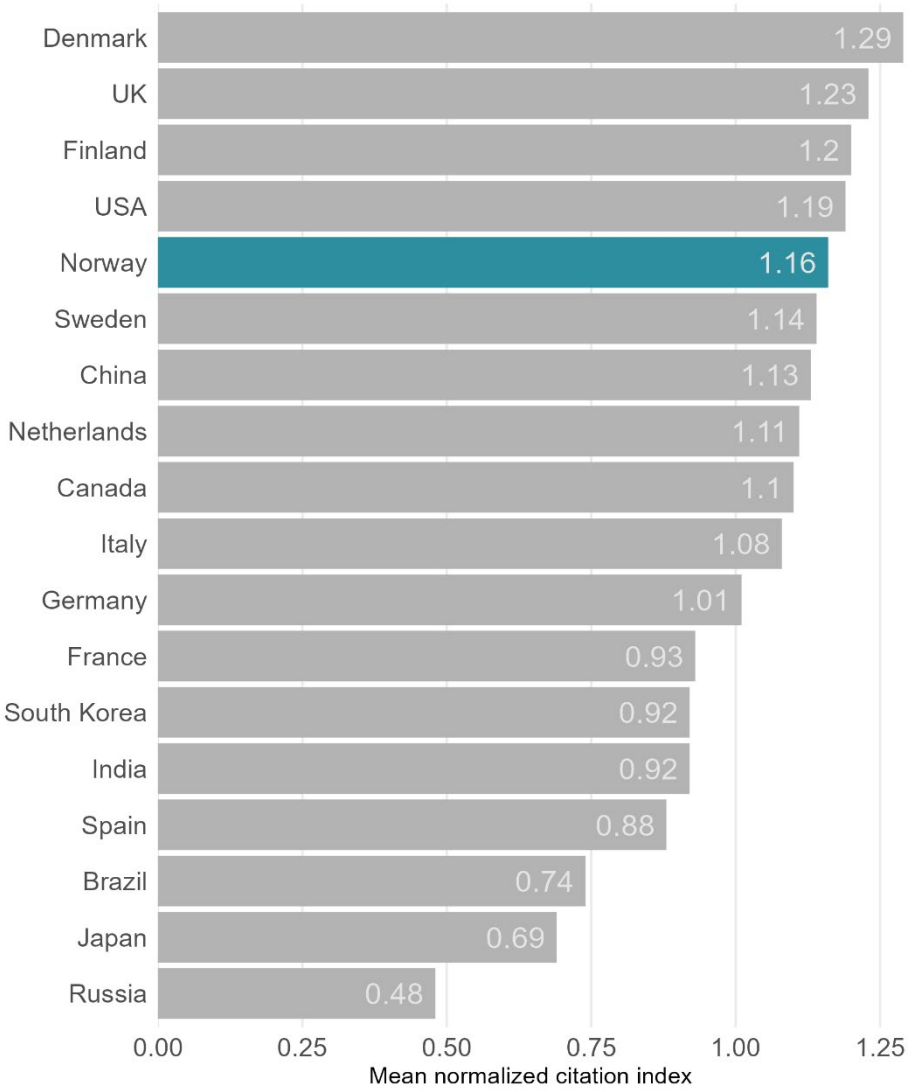


Figure 5.4. Mean normalized citation index of Norwegian publishing within engineering for the period 2019-2021 with comparative countries. World mean = 1.

5.3 Mathematics and statistics

At the global level, the Chinese takeover as the leading country scientific publishing is also observed in Mathematics and statistics. In 2013, China and the US published almost the exact same number of papers (Table 5.3), but by 2022, China had almost doubled its publication output, while the US saw hardly any increase at all (Figure 5.5). In the Nordic region, Sweden is the only country with a publication output above the Nordic average in all years 2013-2022 (Figure 5.5).

Here, the total growth in papers in Mathematics and statistics has been highest in Sweden (45.4 per cent) and Denmark (32.2 per cent), while Norway (22.3 per cent) and Finland (16.9 per cent) have increased more moderately (Table 5.3).

Despite Denmark's high growth, it remains the Nordic country with the lowest output in 2022, while Finland and Norway produce almost identically (331 and 344 (fractionalized) publications in 2022, respectively). Sweden, with 569 publications in 2022 produced 65 per cent more publications than Norway.

With all Nordic countries publishing less than 600 papers in 2022 (Denmark as few as 248 papers), Mathematics and statistics is a relatively small field in absolute numbers, and with low citation indexes (2019-2021) in the Nordic countries (Figure 6.5): Finland (0.94), Norway (0.92), Sweden (0.90) and Denmark (0.89), meaning that all Nordic countries were cited below the world average.

The Nordic countries have all low specialization in Mathematics and statistics: Finland (0.86), Norway (0.77) and Sweden (0.72), and Denmark with an extremely low specialization index (0.42).

All Nordic countries are above the world average in specialization index for Logic, and both Norway and Sweden above the world average in Statistics & Probability. However, for the subfields Mathematics and Applied Mathematics all Nordic countries have specialization indexes below 1.00. For example, compared to the world average, Norway produces 37 per cent fewer publications in Mathematics and 2 per cent fewer in Applied Mathematics.

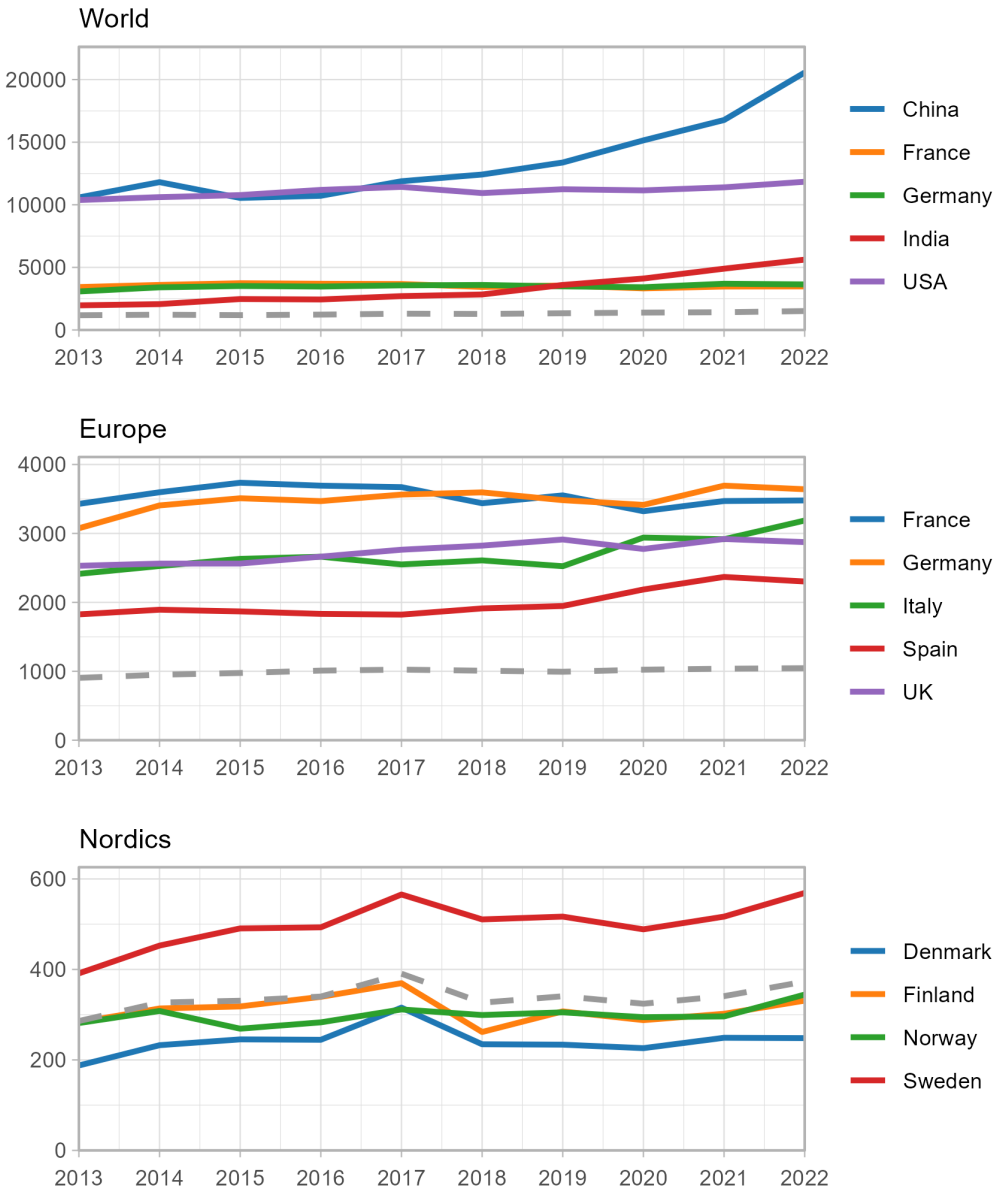


Figure 5.5. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Mathematics and statistics, 2013-2022. Regional mean = dotted grey line.

Table 5.3. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in mathematics and statistics.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
China	10,585	20,564			94.27%
USA	10,379	11,838			14.05%
India	1,967	5,619			185.64%
Russia	2,393	3,245			35.63%
France	3,429	3,478			1.45%
Germany	3,075	3,641			18.43%
Italy	2,414	3,187			32.05%
UK	2,530	2,874			13.58%
Iran	1,518	2,603			71.49%
Spain	1,825	2,302			26.12%
Japan	1,961	2,324			18.52%
Saudi Arabia	594	2,157			262.98%
Turkey	1,299	2,148			65.37%
Canada	1,768	1,982			12.07%
South Korea	1,466	1,793			22.26%
Sweden	391	569			45.41%
Finland	283	331			16.92%
Norway	282	344			22.34%
Denmark	188	248			32.18%

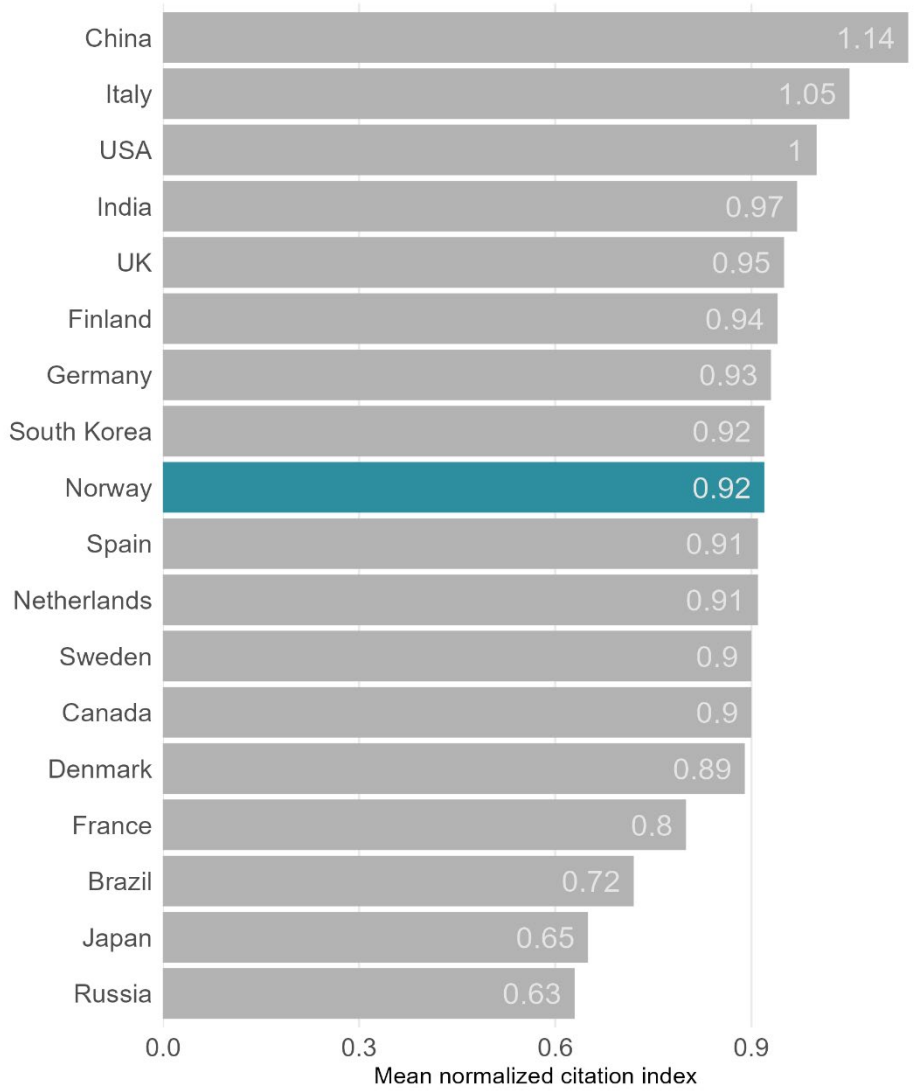


Figure 5.6. Mean normalized citation index of Norwegian publishing within mathematics and statistics for the period 2019-2021 with comparative countries. World mean = 1.

5.4 Specialisation

Table 5.4. Relative field specialisation of Nordic countries within the subfields of the fields of computer and information sciences, engineering, and mathematics and statistics, 2022. World average = 1.

	Norway	Sweden	Denmark	Finland
Computer and information sciences				
Artificial Intelligence	0.97	0.65	0.55	0.98
Cybernetics	1.37	0.77	0.98	1.79
Information Systems	1.10	0.67	0.66	1.51
Interdisciplinary Applications	1.47	0.97	0.89	1.44
Software Engineering	1.48	1.49	0.91	1.68
Theory & Methods	1.28	0.90	0.78	1.37
Overall	*1.20*	*0.84*	*0.72*	*1.35*
Engineering				
Agricultural Engineering	0.61	0.47	0.60	1.04
Automation & Control Systems	1.40	1.29	0.66	0.79
Hardware & Architecture	0.99	1.06	0.42	0.79
Construction & Building Technology	1.19	0.91	0.93	1.17
Energy & Fuels	1.47	0.93	1.21	0.99
Aerospace	0.28	0.58	0.43	0.30
Biomedical	0.71	0.67	0.58	1.08
Chemical	0.72	0.59	0.63	0.79
Civil	1.15	0.62	0.49	0.65
Electrical & Electronic	0.70	0.84	0.97	1.25
Environmental	0.91	1.11	1.07	1.02
Geological	1.09	0.36	0.14	0.34
Industrial	1.85	1.45	1.08	1.54
Manufacturing	0.89	1.12	0.64	1.06
Marine	3.99	0.77	0.82	1.23
Mechanical	0.86	0.74	0.43	0.59
Multidisciplinary Engineering	0.53	0.48	0.38	0.44
Ocean	4.84	0.78	1.12	0.97
Petroleum	4.39	0.10	0.43	0.06
Green & Sustainable Science & Technology	1.22	1.40	1.22	1.54
Instruments & Instrumentation	0.64	0.54	0.57	0.80
Metallurgy & Metallurgical Engineering	0.74	0.81	0.23	0.92
Mining & Mineral Processing	0.92	0.87	0.22	1.62
Operations Research & Management	1.33	0.75	0.98	0.99
Robotics	0.93	1.34	0.94	1.05
Telecommunications	0.65	1.00	0.73	1.89
Thermodynamics	0.68	0.67	0.60	0.66
Transportation Science & Technology	1.12	1.84	0.82	1.26
Overall	*0.98*	*0.85*	*0.77*	*1.00*
Mathematics and statistics				
Logic	1.90	1.18	1.01	2.54
Mathematics	0.63	0.63	0.34	0.93
Applied Mathematics	0.78	0.72	0.32	0.80
Interdisciplinary Applications	0.78	0.50	0.43	0.53
Statistics & Probability	1.18	1.22	0.89	0.90
Overall	*0.77*	*0.72*	*0.42*	*0.86*

6 Medicine & health sciences

6.1 Clinical medicine

Unlike the scientific fields described previously in this report, China has not caught up with the US in clinical medicine (Figure 6.1). The Chinese total growth here has been massive, though (up 213 per cent), and because the US has had a more moderate (yet, rather strong, up 32 per cent) growth, the ratio between US and Chinese publications have changed from 5.3 to 2.2 from 2013 to 2022.

In the Nordic region all four countries have had a positive growth, foremost in Denmark (39 per cent) and Norway (34 per cent), but also in Finland (26 per cent) and Sweden (19 per cent) (Table 6.1). It is worth mentioning, though, that whereas Denmark and Finland have gone through a period of continuous growth, Norway's growth primarily occurred between 2014 and 2015, with no additional growth after that (Figure 6.1).

In Norway, the publication output has increased from 2834 (fractionalized) papers in 2013 to 3806 papers in 2022 (Table 6.1), making Clinical medicine Norway's largest field of science (with almost twice as many publications as Engineering in second place).

Norwegian papers in Clinical medicine are well cited (citation index 1.5), 50 per cent above the world average (Figure 6.2). All Nordic countries have high citation indexes; highest in Sweden (1.66) and lowest in Finland (1.42).

Yet, Norway is not particularly specialized in clinical medicine, just 3 per cent above the world average (specialization index is 1.03). The specialization is far more pronounced in Denmark (1.46) and Sweden (1.20), whereas Finland is specialized slightly less than the world average (0.94) (Table 6.4). In Table 6.4, the colorization provides a rapid understanding of Sweden and Finland being highly specialized in many more subfields of Clinical medicine than Norway. The highest degree of specialization in Norway is found in Psychiatry (2.12) and Rheumatology (1.89). In addition to the rather small subfields Audiology & Speech-Language Pathology; and Clinical neurology (1.32) and Neuroimaging (1.29) cf. Norway's strong specialization in Neurosciences (see Table 3.4). In Oncology, Norway's

specialization index is 17 per cent lower than the world average, while it is above the world average in Cardiac & Cardiovascular systems (1.09).

The subfields in which all Nordic countries are relatively highly specialized include Audiology, Cardiac & Cardiovascular systems, Clinical neurology, Endocrinology & Metabolism, Geriatrics & Gerontology, Neuroimaging, Obstetrics & Gynecology, Peripheral Vascular Disease, and Psychiatry. The three fields where all Nordic countries are less specialized than the world average involve two rather small subfields, Ophthalmology and Tropical medicine, in addition to Surgery.

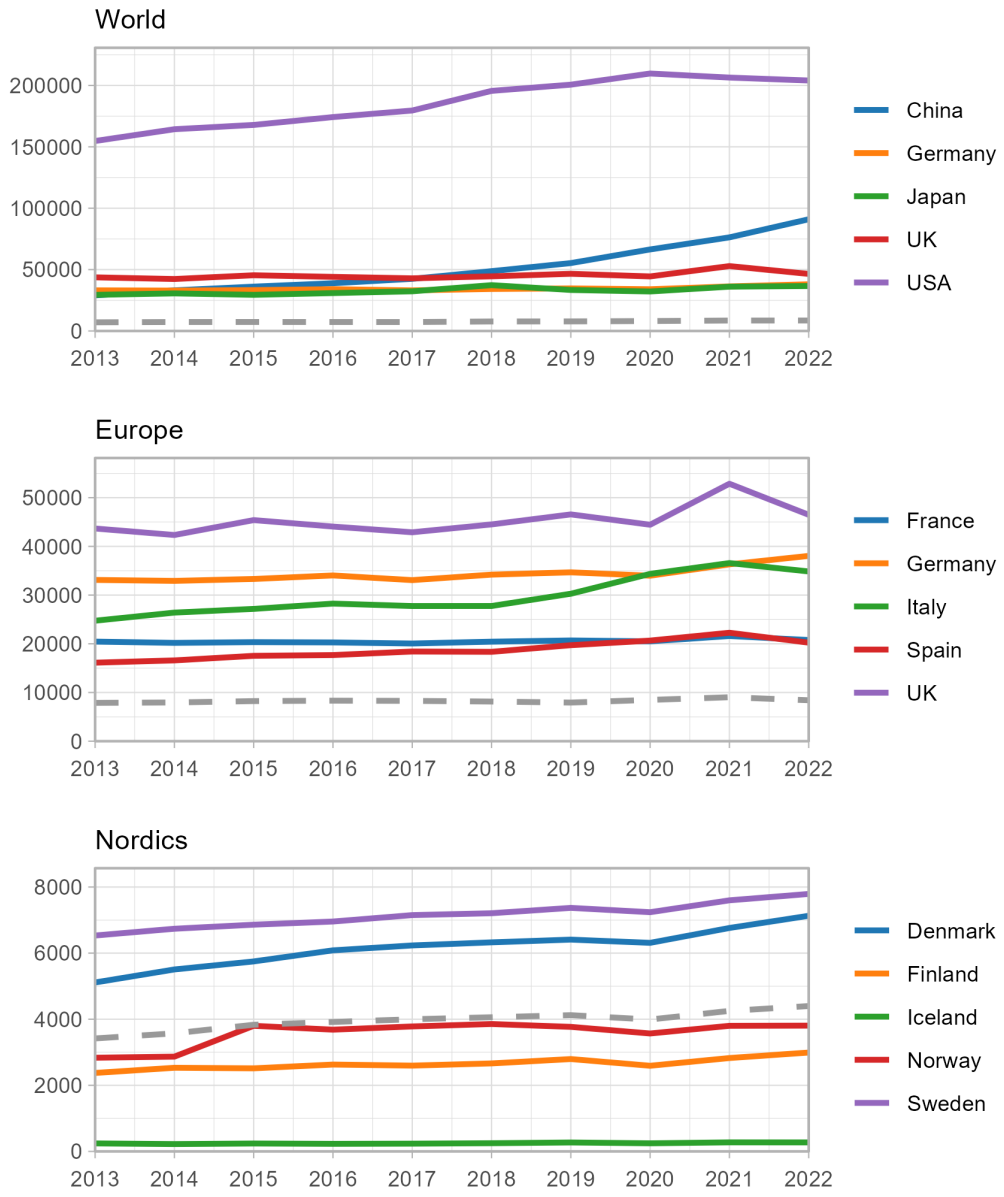


Figure 6.1. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Clinical medicine, 2013-2022. Regional mean = dotted grey line.

Table 6.1. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in clinical medicine.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
USA	154,746	204,024			31.84%
China	28,992	90,990			213.84%
UK	43,672	46,485			6.44%
Germany	33,110	38,047			14.91%
Japan	29,427	36,595			24.36%
Italy	24,738	34,852			40.88%
India	15,100	28,336			87.66%
Canada	19,323	24,795			28.32%
Australia	17,395	23,771			36.65%
Spain	16,124	20,234			25.49%
France	20,449	20,772			1.58%
Turkey	16,062	18,801			17.05%
South Korea	15,273	16,631			8.89%
Netherlands	14,367	15,711			9.36%
Brazil	10,970	12,226			11.45%
Sweden	6,533	7,790			19.25%
Denmark	5,111	7,129			39.48%
Norway	2,834	3,806			34.28%
Finland	2,374	2,991			26.02%

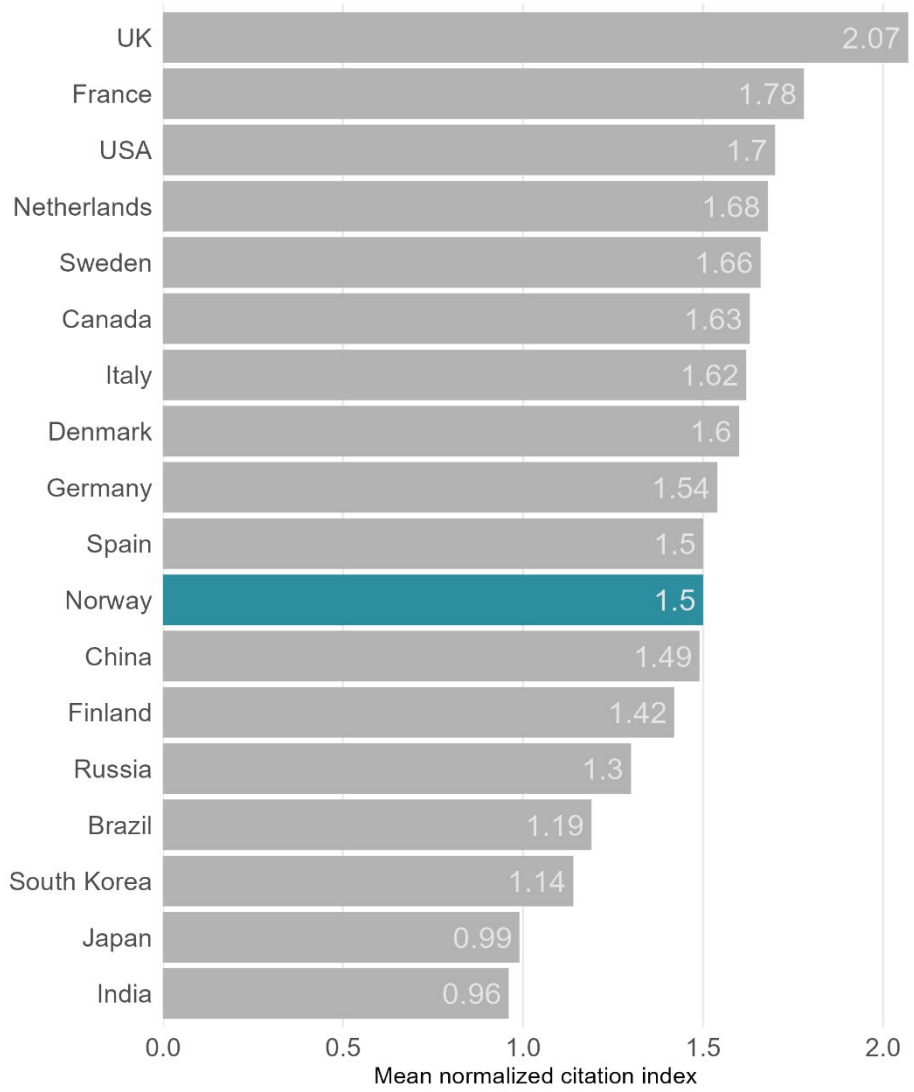


Figure 6.2. Mean normalized citation index of Norwegian publishing within clinical medicine for the period 2019-2021 with comparative countries. World mean = 1.

6.2 Health sciences

Although the US remains the world's leading nation also in Health sciences publishing (Figure 6.3), with a total growth of 28.7 per cent between 2013 and 2022, Chinas has had an incredible 485 per cent increase (Table 6.2), which has reduced the ratio between these countries from 10.6 to 2.3. The Nordic countries have also witnessed a strong increase in this field over a ten-year period: Finland up 80 per cent, Denmark up 73 per cent, and Norway up 66 per cent (Table 6.2). The growth was not as exceptional, yet also strong, in Sweden (up 42 per cent). In 2022 Norway produced 1854 (fractionalized) papers, which is 30 per cent less than Sweden did.

All Nordic countries are cited above the world average (Figure 6.4): Norway 14 per cent more than the world average, Sweden 13 per cent, Finland and Denmark both 8 per cent.

The specialization index is also very strong in all Nordic countries, foremost in Norway, where Health Sciences' share of the Norwegian publication output is more than twice as high as the world average (specialization index 2.03) (Table 6.4). Other Nordic countries have specialization indexes in the range of 1.53-1.64. Except for Integrative & Complementary Medicine, Norway is specialized above the world average in all subfields of Health sciences. The fields where Norway is both extremely specialized (defined as specialization indexes above 1.5) *and* much more than other Nordic countries are Health Care sciences & Services (2.46) and Sport Sciences (3.10). Subfields where all Nordic countries are highly specialized (defined as above 1.5), include (Norwegian values in brackets): Nursing (2.80), Public, Environmental & Occupational Health (1.89), Rehabilitation (2.91) (except Finland at 1.35), Sport Sciences (3.10). Apart from Denmark, all Nordic countries are also highly specialized in Substance abuse (2.06).

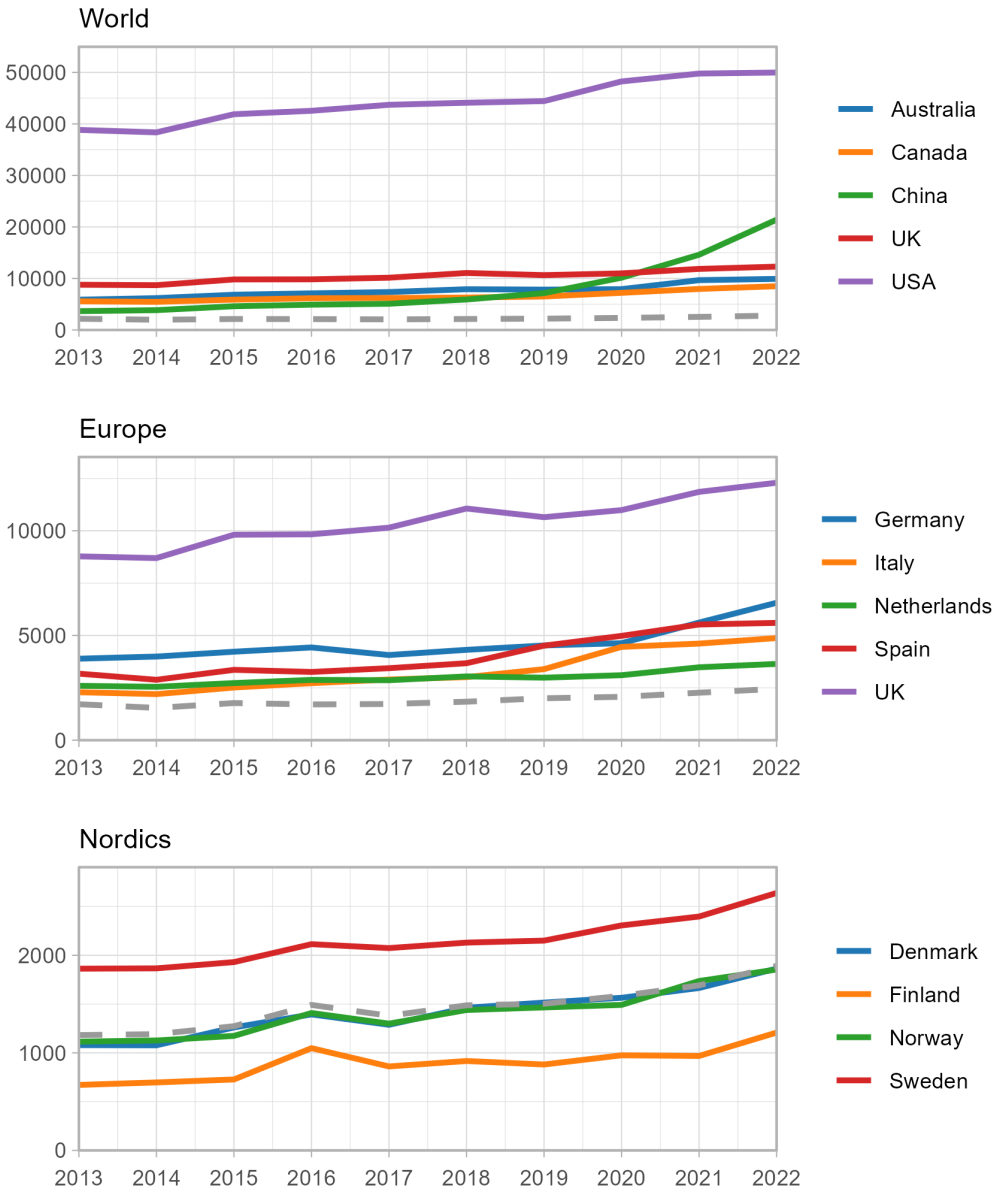


Figure 6.3. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Health sciences, 2013-2022. Regional mean = dotted grey line.

Table 6.2. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in health sciences.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
USA	38,837	49,975			28.68%
China	3,658	21,411			485.38%
UK	8,778	12,294			40.04%
Australia	5,881	9,913			68.56%
Canada	5,567	8,491			52.52%
Germany	3,893	6,561			68.54%
Brazil	4,277	5,842			36.60%
Spain	3,177	5,602			76.35%
India	1,573	5,142			226.90%
Italy	2,290	4,877			112.92%
Japan	2,297	3,942			71.57%
South Korea	2,211	3,903			76.51%
Netherlands	2,597	3,642			40.27%
Iran	1,092	3,540			224.09%
France	2,150	2,981			38.60%
Sweden	1,863	2,639			41.67%
Denmark	1,079	1,864			72.68%
Norway	1,115	1,854			66.32%
Finland	671	1,208			79.91%

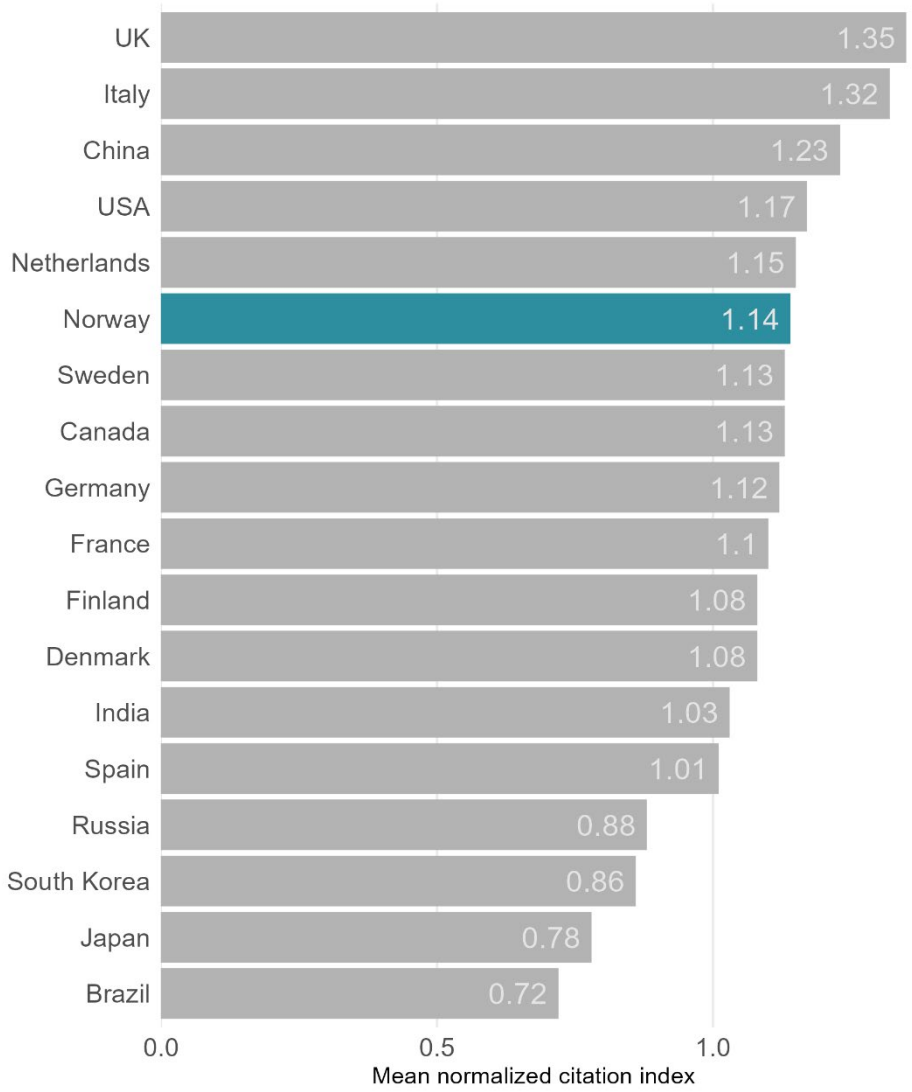


Figure 6.4. Mean normalized citation index of Norwegian publishing within health sciences for the period 2019-2021 with comparative countries. World mean = 1.

6.3 Psychology

China has throughout the period 2013 to 2022, closed the gap with the US in Psychology papers, from a ratio of 19.7 to 3.0 (Table 6.3). Yet, similar to Clinical medicine and Health sciences, Psychology is a field where China has not taken global leadership (Figure 6.5). In 2013, China published only 890 (fractionalized) articles in Psychology, which at the time was only twice as many as for example Sweden. Norway's production has increased from 332 papers in 2013 to 598 papers in 2022, representing a total growth of 80 per cent, only surpassed by Denmark (91 per cent) in the Nordic region.

The Norwegian growth in Psychology papers has been accompanied by solid citation scores (Figure 6.6). In 2019-2021 the Norwegian Psychology papers were cited 23 per cent above the world average. Papers from Denmark, Sweden and Finland were cited in the range 22 to 17 per cent above the world average.

Norway is highly specialized in Psychology, with Psychology's share of the Norwegian scientific output being 82 per cent higher than the world average. The Norwegian specialization index (1.82) is higher than in Finland (1.48) and differs substantially from the indexes in Sweden (1.02) and Denmark (0.86). Across subfields of Psychology, Norway also has high specialization values in all subfields, and particularly so in Education psychology (2.23), once again emphasizing the more societal (social science-based) direction of Norwegian research. The latter is also a strong field in Finland (3.50), but not so in Sweden and Denmark.

In the main categories/subfields of Psychology (General, Applied, Biological and Clinical), Norway has very strong specialization values, while in Sweden only Clinical psychology is above the world average. In Denmark only Biological psychology is above the world average, whereas in Finland both General and Applied psychology are.

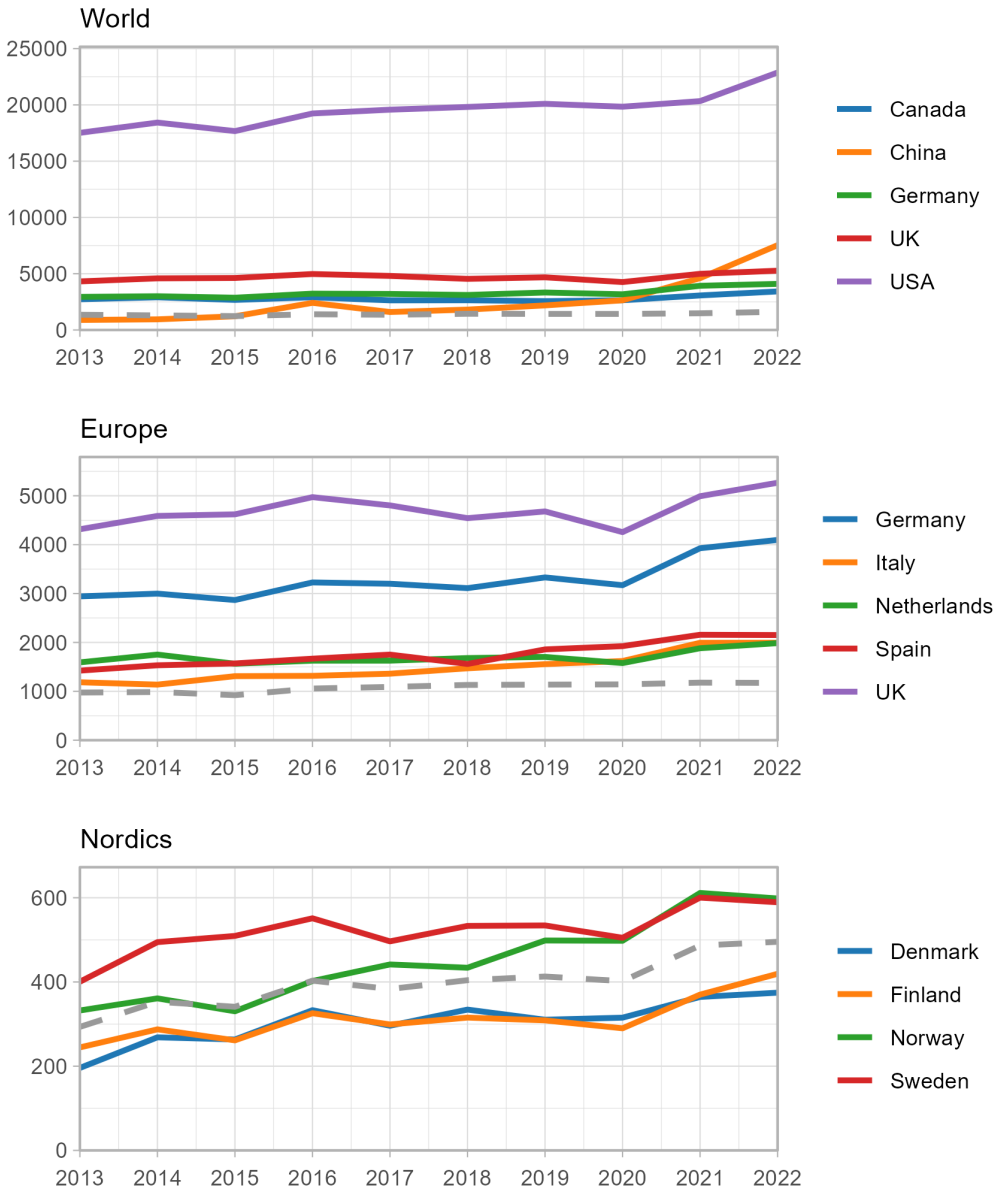
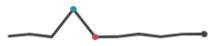
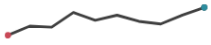
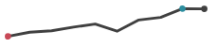
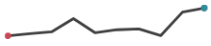
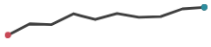


Figure 6.5. Number of publications (modified author shares) for the largest contributors across three regions (worldwide, Europe and the Nordics). Psychology, 2013-2022. Regional mean = dotted grey line.

Table 6.3. Publishing output, total growth and yearly trend of 15 most productive countries and Nordics in psychology.

Country	2013 author shares	2022 author shares	Publishing trend	Yearly growth	Total growth
USA	17,517	22,876			30.59%
China	890	7,535			746.46%
UK	4,316	5,267			22.03%
Germany	2,942	4,097			39.26%
Canada	2,731	3,424			25.38%
Japan	627	852			35.86%
Australia	1,718	2,671			55.52%
Spain	1,423	2,151			51.16%
Italy	1,185	1,994			68.29%
Netherlands	1,593	1,986			24.68%
France	943	1,214			28.64%
Turkey	250	952			280.82%
Israel	534	934			74.99%
Switzerland	619	903			45.78%
Belgium	611	736			20.46%
Norway	332	598			80.05%
Sweden	401	589			47.12%
Finland	245	419			71.45%
Denmark	196	375			91.26%

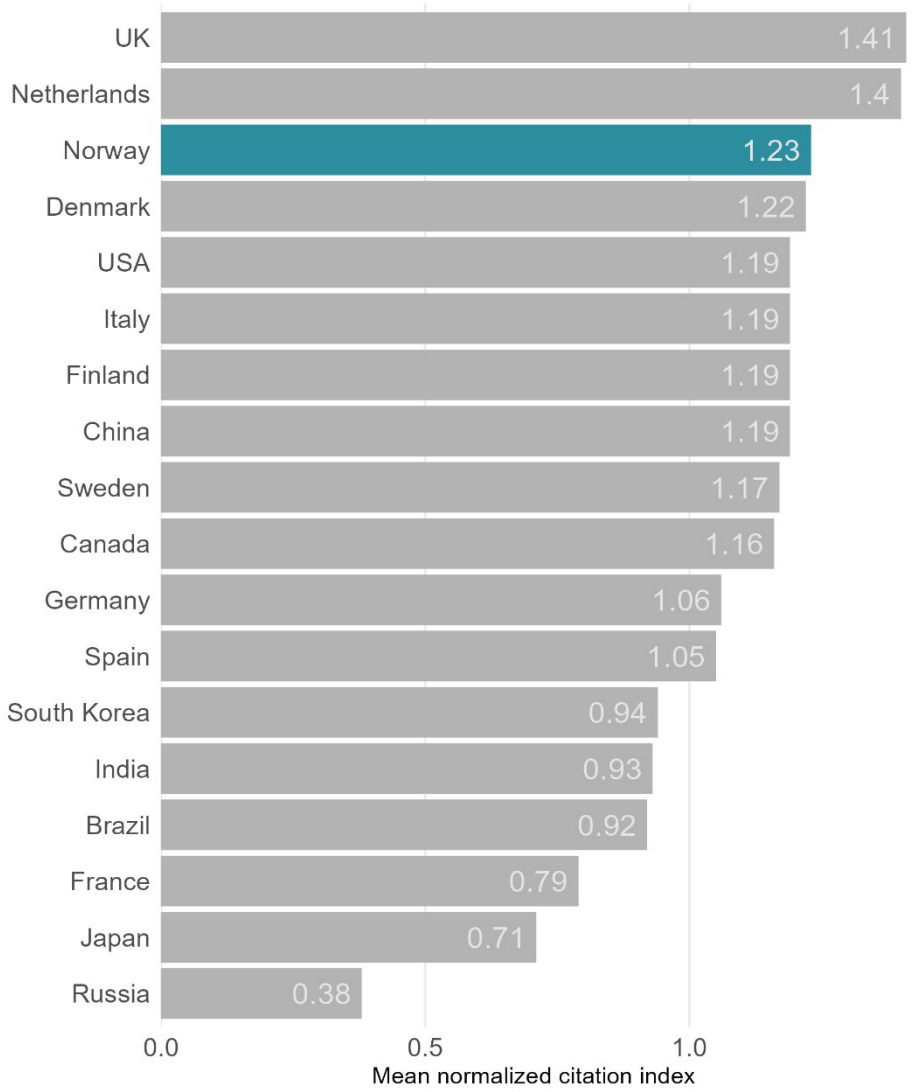


Figure 6.6. Mean normalized citation index of Norwegian publishing within psychology for the period 2019-2021 with comparative countries. World mean = 1.

6.4 Specialisation

Table 6.4. Relative field specialisation of Nordic countries within the subfields of the fields of clinical medicine, health sciences, and psychology, 2022. World average = 1.

	Norway	Sweden	Denmark	Finland
Clinical medicine				
Allergy	0.37	1.92	1.99	1.58
Andrology	0.23	0.90	2.10	0.74
Anesthesiology	0.84	1.07	2.58	1.06
Audiology & Speech-Language Pathology	1.55	2.63	1.97	2.59
Cardiac & Cardiovascular Systems	1.09	1.41	2.06	1.08
Clinical Neurology	1.32	1.54	1.85	1.36
Critical Care Medicine	0.44	1.10	0.98	0.46
Dentistry, Oral Surgery & Medicine	1.25	1.28	0.71	1.68
Dermatology	0.40	1.06	2.49	0.87
Emergency Medicine	0.97	1.48	1.25	0.97
Endocrinology & Metabolism	1.06	1.95	3.39	1.73
Gastroenterology & Hepatology	0.85	1.11	1.57	0.59
Geriatrics & Gerontology	1.08	1.35	1.06	1.29
Hematology	1.04	1.49	1.60	0.89
Infectious Diseases	0.89	1.18	1.36	0.69
Medicine, General & Internal	1.38	0.75	0.91	0.50
Neuroimaging	1.29	1.36	1.70	1.50
Obstetrics & Gynecology	1.07	1.19	1.24	1.00
Oncology	0.83	1.02	1.12	0.73
Ophthalmology	0.68	0.55	0.78	0.79
Orthopedics	0.83	1.46	1.57	1.24
Otorhinolaryngology	0.39	1.14	1.26	1.58
Pediatrics	1.04	1.26	0.90	1.43
Peripheral Vascular Disease	1.23	1.37	1.45	1.27
Psychiatry	2.12	1.48	1.89	1.33
Radiology, Nuclear Med. & Medical Imaging	1.00	1.12	1.75	0.96
Respiratory System	0.67	1.35	1.70	0.80
Rheumatology	1.89	2.22	2.97	0.60
Surgery	0.53	0.94	0.81	0.85
Transplantation	0.96	1.04	0.96	0.67
Tropical Medicine	0.45	0.43	0.53	0.31
Urology & Nephrology	0.84	1.32	1.13	0.55
Overall	*1.03*	*1.20*	*1.46*	*0.94*
Health sciences				
Gerontology	1.37	2.07	1.00	2.18
Health Care Sciences & Services	2.46	1.47	1.34	1.16
Health Policy & Services	1.83	1.70	1.28	1.21
Integrative & Complementary Medicine	0.55	0.25	0.18	0.11
Medical Ethics	1.78	1.26	1.77	1.09
Medical Informatics	2.10	1.42	1.37	2.04

		Norway	Sweden	Denmark	Finland
	Medicine, Legal	1.17	0.95	1.38	1.09
	Nursing	2.80	2.52	1.95	2.31
	Nutrition & Dietetics	1.17	1.02	1.26	1.41
	Primary Health Care	1.24	0.76	1.28	0.49
	Public, Environ. & Occup. Health	1.89	1.65	1.70	1.66
	Rehabilitation	2.91	2.84	2.26	1.35
	Social Sciences, Biomedical	2.89	1.92	2.90	1.15
	Sport Sciences	3.10	1.51	1.79	1.58
	Substance Abuse	2.06	1.81	0.78	1.88
Overall		*2.03*	*1.64*	*1.54*	*1.53*
Psychology					
	General Psychology	1.48	0.95	0.88	1.09
	Applied	1.79	0.95	0.67	1.53
	Biological	1.62	0.73	1.43	0.88
	Clinical	1.74	1.09	0.73	0.85
	Developmental	1.85	1.36	0.79	1.85
	Educational	2.23	0.83	0.41	3.50
	Experimental	1.65	0.87	1.40	1.54
	Mathematical	1.98	0.63	0.62	0.63
	Multidisciplinary	2.09	0.99	0.83	1.45
	Psychoanalysis	1.34	0.92	0.53	0.03
	Social	1.09	1.07	1.10	1.83
Overall		*1.82*	*1.02*	*0.86*	*1.48*

References

Aksnes, D. W., Schneider, J. W., & Gunnarsson, M. (2012). Ranking national research systems by citation indicators. A comparative analysis using whole and fractionalised counting methods. *Journal of Informetrics*, *6*(1), 36-43.

Aksnes, D. W., & Sivertsen, G. (2019). A Criteria-based Assessment of the Coverage of Scopus and Web of Science. *Journal of Data and Information Science*, *4*(1), 1-21.

Gauffriau, M. (2017). A categorization of arguments for counting methods for publication and citation indicators. *Journal of Informetrics*, *11*(3), 672-684.

Sivertsen, G., Rousseau, R., & Zhang, L. (2019). Measuring scientific contributions with modified fractional counting. *Journal of Informetrics*, *13*, 679-694.

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