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Norway's scientific collaboration with China and South Korea in a global context

An analysis based on articles in *Web of Science*

Gunnar Sivertsen

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Preface

This report presents the results of a small study commissioned by the Norwegian Ministry of Education and Research with the aim of mapping Norway's scientific collaboration with China and South-Korea within the context of global scientific collaboration. Regarding the relations to China, the report updates the results presented a year ago in NIFU Working Paper 2022:1 with the addition of a closer analysis of Sino-Norwegian collaboration in the technological sciences. The analysis of the relations to South Korea is new. The report is mainly descriptive and limited to collaboration that can be documented from scientific articles in journals covered by the Web of Science.

Oslo, August 11, 2023

Vibeke Opheim
Director

Espen Solberg
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Summary

About the report

This study provides an overview of Norway's scientific collaboration with China and South-Korea within the context of global scientific collaboration. The study covers collaboration activity as it has developed since 2001, mainly focusing on the recent ten years. Collaboration is analysed in nine major areas of research: Biology, Biomedicine, Chemistry, Computer Science, Environmental Sciences, Health Sciences, Physics, Social Sciences and Humanities (SSH), and Technology. In a separate chapter, special attention is given to Sino-Norwegian collaboration in the technological sciences.

The study is limited to collaboration that can be documented from scientific articles in journals covered by the Web of Science. This data source allows for studying collaboration between the three countries within a global network representing 40 countries and 96 percent of the world's scientific output. At the same time, it allows for identifying the active institutions on both sides in each of the two bilateral relations between countries.

The contexts for collaboration

The number of articles indexed in Web of Science has tripled up to 2.4 million annually during the last twenty years. The growth reflects increasing research intensity measured as a percentage of GDP, particularly in emerging economies. The growth also reflects increasing international collaboration and mobility in science as well as the internationalization of scientific publishing. Within this global context, partly reflecting these general factors, but also because of internal policy changes, China has grown outstandingly to become the world's largest contributor to indexed scientific articles. South Korea has grown as well compared to Western countries and is now one of the world's most research-intensive nations. For these reasons, Norwegian research collaboration with the two countries can be expected to increase over time.

The collaboration with China is to a higher degree of based on bilateral collaboration (only Norway and China are represented in the article's authors'

addresses) while the collaboration with South Korea is to a high degree based on multilateral collaboration involving other countries as well.

Collaboration clusters and intensities

The increasing importance of China and South Korea in Norway's international collaboration profile is mainly due to the two countries' rapid growth within global science. Norway has relatively little collaboration with China and South Korea when the sizes of the three countries in the global network of scientific collaboration activity is considered. Norway's collaboration profile is dominated by the other Nordic and European countries. In general, the engagement with Asian countries is relatively low for Norway.

China and South Korea collaborate intensively with each other and with other Asian countries. In addition, collaboration with USA has high relative intensity. China differs from South Korea by having high intensity of collaboration with other English-speaking countries as well: Australia, Canada, UK, and New Zealand. This pattern is probably due to student and researcher mobility in China's relations. China also differs from South Korea by having a decreasing intensity of collaboration with the USA in recent years.

In general, we observe a European cluster of collaboration where Norway is mostly involved. This cluster can be contrasted with a cluster of close collaboration between North America, Australia, and East-Asia. There is also an emerging cluster of increasing collaboration within and throughout Asia. China and South Korea have major roles in the two latter clusters.

Relations with China

The role of China in Norway's international collaboration is increasing and now represents 17 percent of all articles with international collaboration. By using three criteria to assess the relative importance of an area of research in Sino-Norwegian scientific collaboration, we could rank them in this order:

1. Environmental sciences
2. Technology
3. Computer science
4. Physics and Chemistry
5. Biology
6. Biomedicine and Health Sciences
7. Social Sciences and Humanities

We find three fields of research under the umbrella Environmental sciences which stand out with high collaboration activity that seems to be organized and

supported in mutual interest between the most important institutions on both sides: 1) environmental sciences based on geophysical research, particularly in climate research, 2) marine science and engineering, and 3) hydrological engineering.

Technology and computer science reflect the priorities and strengths in the research profile of China as compared to the rest of the world. There is a Norwegian 'mark' on what seems to be specializations of shared interest within the two major areas of research: marine engineering, materials science, and environmental engineering within technology, and telecommunications within computer science.

Chinese science is traditionally strong in the physical sciences, less strong in the life sciences. The strengths of China are mirrored in the collaboration with Norway. There is much collaboration in physics and astrophysics, but this interaction is mostly mediated by multilateral collaboration, e.g., in high energy physics. Bilateral collaboration is relatively more important in chemistry where we observe a focus on materials science and physical chemistry.

Biology includes the sciences of bioproduction in our analysis. The activity in the Sino-Norwegian relation is not high, but the profile in biology is clearly focussed on the characteristic Norwegian orientation: Marine biology and fisheries research.

In most of the areas of research mentioned so far, the universities play a major role on the Norwegian side, but the research institutes are also important in some fields of research. As we turn to biomedicine and the health sciences, the Norwegian hospitals are also active collaboration partners. However, a large part of this collaboration with China is mediated by multilateral consortia and projects. Also, the strengths of Norwegian research in these areas are not mirrored in China.

The social sciences and humanities are areas of research without much collaboration between China and Norway. China is less active than Norway in journals covering these areas in Web of Science. The collaboration with Norway is dominated by studies in business and economics.

Relations with South Korea

The role of South Korea in Norway's international collaboration is increasing and now represents 2.5 percent of all articles with international collaboration. A total of 2,842 scientific articles were published and indexed in Web of Science in 2001-2022 with authors' addresses in both countries. Half of the articles were published during the last five years 2018-2022. The collaboration is mostly multilateral. Other countries than South Korea and Norway are involved in almost 90 percent of the articles.

Collaboration in Physics and the Health Sciences is mostly driven by participation in multinational and global collaboration. Environmental Sciences,

Technology, and Computer Science represent main areas with relatively more bilateral and trilateral collaboration. Collaboration in these areas may to a higher degree reflect a specific mutual interest between Korean and Norwegian researchers and their institutions. Collaborations in Technology and Computer Science have had the sharpest increases recently.

Sino-Norwegian collaboration in technology

A deeper analysis of technological collaboration with China is based on the journal categories "Engineering" and "Computer Science" in Web of Science. China now contributes to almost half of the world's articles in these categories while the share of the USA is steeply decreasing towards ten percent.

China and the USA collaborated intensely in technological research until recently. The last five years have shown a relative decrease in this bilateral relation which is not found in China's relations to other Western countries. In general, there is a lack of indications that the collaboration profiles of the two countries follow the borders of defence alliances.

From the Norwegian perspective, China recently, in 2019, became our largest collaboration partner in technological research. The relative intensity is even higher now than in the relations to the UK and the USA. The USA and the Nordic countries taken together were more important for Norway until ten years ago. At that time, Norway was on its way to become China's preferred Nordic partner in technological research. After a temporary closing down of Sino-Norwegian relations, the importance of Norway has risen again after 2017, but Denmark is now the preferred partner compared to its size. The shares of all four Nordic countries in China's collaboration profile are increasing.

1 Introduction

1.1 Purpose and scope

This study provides an overview of Norway's scientific collaboration with China and South-Korea within the context of global scientific collaboration. The study covers collaboration activity as it has developed since 2001, mainly focusing on the recent ten years. Collaboration is analysed in nine major areas of research: Biology, Biomedicine, Chemistry, Computer Science, Environmental Sciences, Health Sciences, Physics, Social Sciences and Humanities (SSH), and Technology. In a separate chapter, special attention is given to Sino-Norwegian collaboration in the technological sciences. The study is limited to collaboration that can be documented from scientific articles in journals covered by the Web of Science. This data source allows for studying collaboration between the three countries within a global network representing the 40 major science producing countries and 96 percent of the world's scientific output. At the same time, it allows for identifying the active institutions on both sides in each of the two bilateral relations between countries.

1.2 Data and methods

1.2.1 Web of Science

Web of Science is a searchable bibliographic database with broad global coverage of the sciences and a more limited coverage of the social sciences and humanities (Aksnes & Sivertsen, 2019). It covers the published literature only. Unpublished research in the corporate sector is not covered.

This study is based on searches and downloads in Web of Science that were performed in January 2023. The searches covered articles published in the years 2001-2022 and limited to:

- The three core indices *Science Citation Index Expanded*, *Social Science Citation Index* and *Arts & Humanities Citation Index*
- Original research articles and review articles with authors' addresses that can be linked to countries.

As an example, a search for articles published in the year 2021 with the two limitations mentioned above results in 2.5 million articles published in 14,229 different journals among which:

- 693,445 are articles with authors' affiliations in China
- 88,836 are articles with authors' affiliations in South Korea
- 24,303 are articles with authors' affiliations in Norway

Data at country level for 40 countries were downloaded as statistics from searches and transformed to a database at NIFU for further analysis. Data with evidence of collaboration between countries are also searchable. In the sample from 2021:

- 1,549 are articles with the combined presence of authors' affiliations in China and Norway
- 460 are articles with the combined presence of authors' affiliations in South Korea and Norway

For this type of search results, article level data from the two bilateral relations under study was downloaded and transformed to the same database. This procedure allowed for identification of contributing institutions in the three countries.

1.2.2 Classification of articles into major areas of research

In the Web of Science, journals are classified into 152 different "Research Areas" (e.g., Agriculture, Cell Biology, Literature, Materials Science, Sociology). All articles appearing in a journal are classified in the same category. To provide a useful overview, we merged the 152 research areas into nine major areas and added a tenth category of general journals. They are listed below along with examples of the most frequent subcategories appearing among the articles. In cases of doubt, we have consulted the journal level and the frequency of articles showing collaboration between the three countries. The ten major categories are (with examples):

- Biology (Plant sciences, Zoology, Marine & Freshwater Biology, Agriculture, Fisheries, Forestry)
- Biomedicine (Biochemistry & Molecular Biology, Cell Biology, Genetics)
- Chemistry (Chemistry, Polymer Science)
- Computer Science (Computer Science, Automation & Control Science)

- Environmental Sciences (Geosciences, Environmental Science, Climate research)
- Health sciences (Clinical sciences, Health care sciences)
- Physics (Physics, Astronomy & Astrophysics)
- SSH (Social Sciences and Humanities)
- Technology (Engineering, Materials Science, Mathematics, Energy & Fuels, Telecommunications)
- General journals (e.g., PLOS One, Scientific Reports, Nature Communications, Nature, PNAS, Science)

Many journals are classified as belonging to more than one Research Area in Web of Science. As we merge them into ten main categories, some journals will still be classified in more than one group. The articles in these journals remain relevant for the analysis in each group, but double counting is unavoidable.

For the closer look at Sino-Norwegian collaboration in technology in chapter 6, we merged and deduplicated articles in the Research Areas "Engineering" and "Computer Science" in Web of Science. This resulted in a dataset of 2,886 articles from 2001-2022 with affiliations in both China and Norway. We used the same classification for the analysis of the global context in chapter 6.

1.2.3 A selection of 40 countries for the global context

Scientific collaboration between countries in bilateral relations needs to be studied within the context of the global collaboration network. Collaborations between Norway and China, and between Norway and South Korea, have been increasing year by year, but are they increasing more than in other bilateral relations? A field of research may seem to be prioritized in the collaboration between China and Norway, but how does the frequency of articles with contributions from both countries compare to the frequencies in other bilateral relations?

We have selected 40 countries to represent the global collaboration network in science. We limit the number of countries to facilitate data collection and an easier overview as we present the results. Still, without double counting of overlapping contributions, the 40 countries are involved in 96 percent of the 2.5 million scientific articles from 2021 that we mentioned above as the result of our search strategy.

The 40 countries are selected according to the size of their scientific production in 2021. The range is from China as the largest (693,445 articles) to New Zealand as the smallest (15,899 articles). South Korea (88,822) articles is number 12 according to size while Norway (24,303) is number 30. These countries are included:

Africa: Egypt and South Africa.

Asia and Oceania: Australia, China, India, Iran, Israel, Japan, Malaysia, New Zealand, Pakistan, Saudi Arabia, Singapore, South Korea, Taiwan, Thailand, Turkey.

Europe: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Russia, Spain, Sweden, Switzerland.

The Americas: Brazil, Canada, Mexico, United States.

1.3 Overview of the chapters and the revision since 2021

Chapter 2 presents some contexts for understanding the collaboration with China and South Korea in an analysis based on data from Web of Science. We present the factors that can explain the growth of all countries in the data source and their increased collaboration over time. A special attention is given to the rapid growth of China, but also of South Korea, compared to Western countries. We also explain the difference between bilateral and multilateral collaboration in indicators based on countries' contribution to scientific articles.

Chapter 3 introduces a method to measure the intensity of collaboration between two countries independently of size and relative to all other bilateral relations in a global network. Here, Norway's relations to China and South Korea are studied as part of a global collaboration network which is influenced by the relations other countries as well. Special attention is given to the United States as an important actor. Trends and changes in collaboration intensities and clusters are presented.

Chapters 4 (relations with China) and *5* (relations with South Korea) are the main parts of the report. They present the bilateral collaboration activities in nine major areas of research. In each of these areas, the most active contributing institutions on both sides are identified. The relative importance of each area is measured relative to the two countries' international collaboration profile in general.

Chapter 6 extends the analysis of presented in Chapter 4 by providing more insights into Sino-Norwegian collaboration in the engineering sciences including computer science. The analysis of institutional collaboration is deepened, and the trends and changes in the global context are analysed in an area of research where China now clearly dominates in global research and where there is increasing focus on competition, trade sanctions, self-containment, and security and defence.

Each chapter is summarized at the end and these summaries are presented together in the Summary above.

As a revision of the report published a year ago on *Norway's scientific collaboration with China in a global context* (NIFU Working Paper 2022:1), this report has the following changes:

- Chapter 4 in the previous report on collaboration in Arctic research is not included this time.
- Chapters 1 and 2 in the previous report are now thoroughly revised as *Chapters 1-3* in this report with new data and by including South Korea.
- Chapter 3 in the previous report is published again as *Chapter 4* in this report.
- *Chapters 5 and 6* are published for the first time in this report.

2 The contexts for collaboration

2.1 Globalization and growth

China's Gross Domestic Product has doubled every eight years during the last two decades. Giving strong priority to science, the country's research intensity measured as a percentage of GDP doubled at the same time (OECD). And measured by scientific articles in *Web of Science*, China surpassed the USA as the largest contributor to international scientific journals after 2018.

South Korea's Gross Domestic Product has almost tripled during the last two decades. The country's research intensity measured as a percentage of GDP was already well above the European average in 2001 and has more than doubled since then, making South Korea one of the most research-intensive countries in the world (OECD). In terms of scientific output in *Web of Science*, South Korea has grown from the size of Sweden in 2001 to the size of Spain in 2021.

The rapid growths of China and South Korea in the global science system is important for the understanding of trends in scientific collaboration. The general growth and globalization of science in the same period is also important as a background.

2.1.1 The growth within *Web of Science*

A total of 831,000 scientific articles were published in the year 2001 and indexed by *Web of Science* with authors' addresses linked to countries. As seen in Figure 2.1, there has been a considerable growth since then. Almost 2.4 million such articles have been indexed with the publication year 2021. Two factors may explain the decline in 2022, the previous and partly continuing pandemic, and the fact that the indexing for Web of Science of articles from the most recent year always continues into the following year. The relative importance of the factors can only be determined later in 2023. In this report, we will add the most recent year 2022 to our analysis only in cases where we look at relative shares of articles. Figures presenting trends with absolute numbers will be limited to the time series 2001-2021.

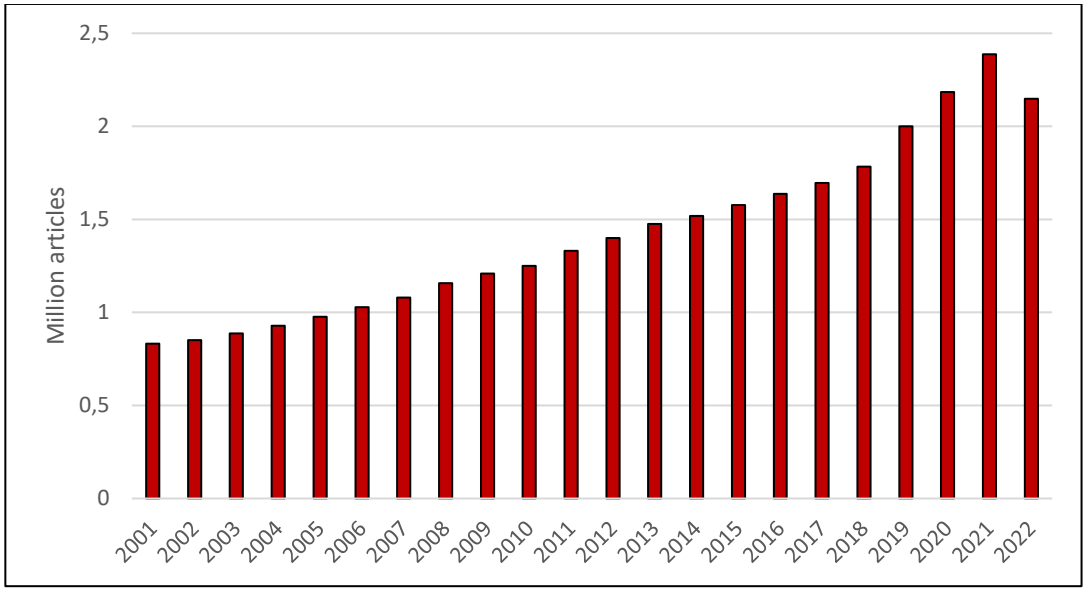

Figure 2.1. The number of scientific articles (in millions) indexed in *Web of Science* by publication year 2001-2022.

The observed growth within *Web of Science* is partly due to an increasing number of journals being indexed. This number increased from 9,200 in 2001 to 13,400 in 2021. The average annual volume of scientific articles in the journals also increased from 90 to 160 articles per year. Both growth factors indicate an *external* growth and change in the market of scientific journals. The main market change is that Article Processing Charges (APC) have been added to subscriptions as a second business model (Zhang et al., 2022). The strongest effect is seen after most countries adopted an Open Access policy since 2018. Examples of the new business model are the three largest scientific journals indexed in 2021. They did not exist in 2000 and are now published with unforeseen annual volumes: *Scientific Reports* was indexed in 2021 with 23,200 articles, *PLOS One* with 15,500 articles, and *Sustainability* with 12,900 articles.

The growth of the market of international journals also reflects the globalization and growth of the scientific system itself. Three factors are often mentioned as explanations for this development:

- Increasing research intensity measured as a percentage of GDP, particularly in emerging economies.
- Increasing international collaboration and mobility in science.
- Internationalization of scientific publishing.

These factors are important for understanding the global context for the development of scientific collaboration with China and South Korea in each bilateral relation. Another factor to consider is that the growth rates differ among countries. The following sections provide a closer look at these national differences

2.1.2 The rapid growths of China and South Korea

One of the clearest changes in the global science system during the last two decades is China's rapid growth to become the world's largest contributing country to international scientific journals. As seen in Figure 2.2, China took over the role of USA after 2018. The size of China within *Web of Science* was comparable to the size of Canada back in 2001. China surpassed the UK to become the second largest country already in 2006.

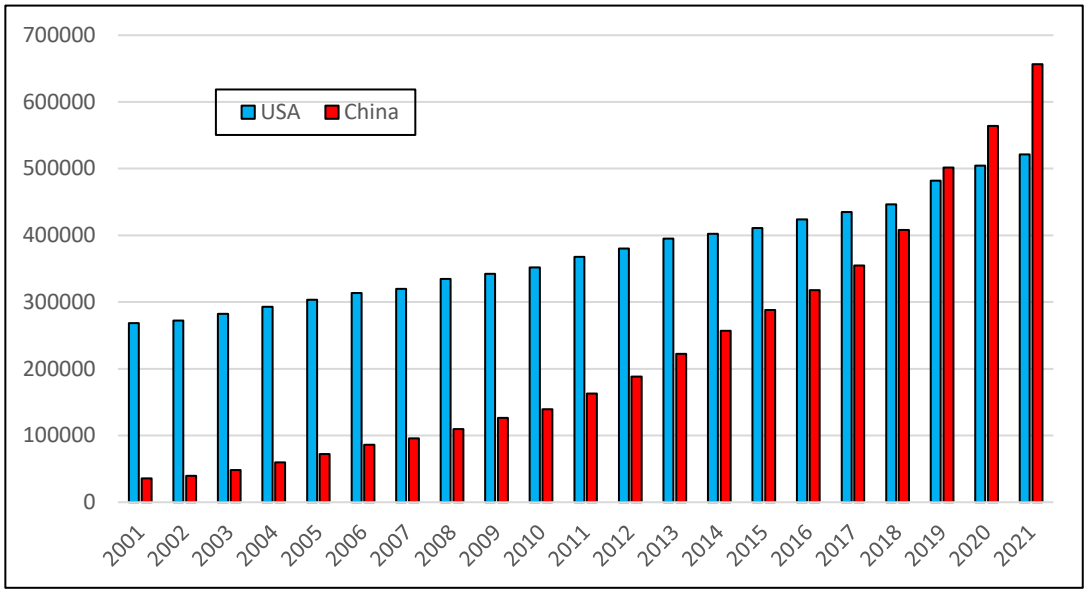

Figure 2.2. The number of scientific articles in *Web of Science* contributed to by China and USA per publication year 2001-2021.

As we shall see below, the trend in the scientific production of USA is typical for Western countries. Sweden follows this typical pattern of growth at a lower rate. Figure 2.3 compares the trend for South Korea with that of Sweden. The two countries had a comparable output in 2001. By 2021, South Korea had a more than twice as large output in *Web of Science*.

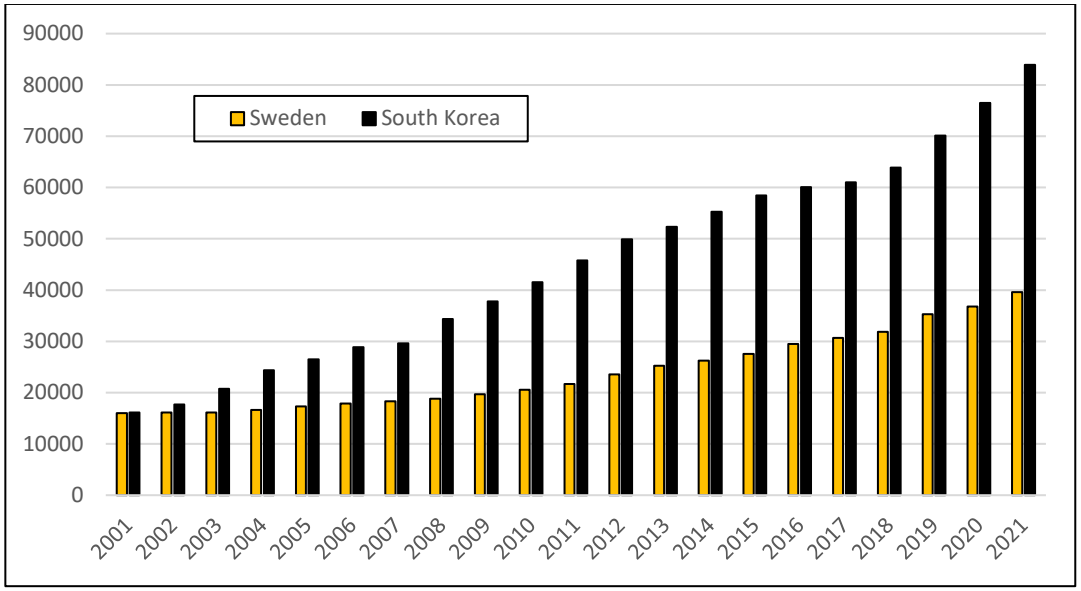

Figure 2.3. The number of scientific articles in *Web of Science* contributed to by South Korea and Sweden per publication year 2001-2021.

One of the factors that may explain the two Asian countries' more rapid growth within Web of Science was mentioned above: The growth of the economies combined with rapidly increasing investments in science. Another factor is the strong incentives to publish in journals indexed by Web of Science. This phenomenon, named "SCI worship" in China (the original name of Web of Science was the Science Citation Index), has for many years influenced research evaluation, staff employment, career promotion, awards, university and disciplinary rankings, and funding in China (Zhang & Sivertsen, 2020). Even individual cash incentives for WoS publications have been widespread (Quan, Chen & Shu, 2017). Similar performance-based incentives have been running at Korean universities (Kim & Bak, 2015).

To further compare the growths of China and South Korea with that of other countries, we will use percentage shares of scientific articles within Web of Science as the indicator. For each year, the number of scientific articles a country has contributed to is divided by the global total of articles in Web of Science. This indicator implies that countries may have overlapping shares in articles that more than one country contributed to. We will return below to an analysis of articles based on international collaboration.

Figure 2.4 compares China to five other large countries within Web of Science. China stands out with an extraordinary growth rate. The traditional large research countries have decreasing shares, except India where the share is moderately increasing. The increases of China and India are typical for emerging economies and show that the globalization of science is observable in international scientific journals.

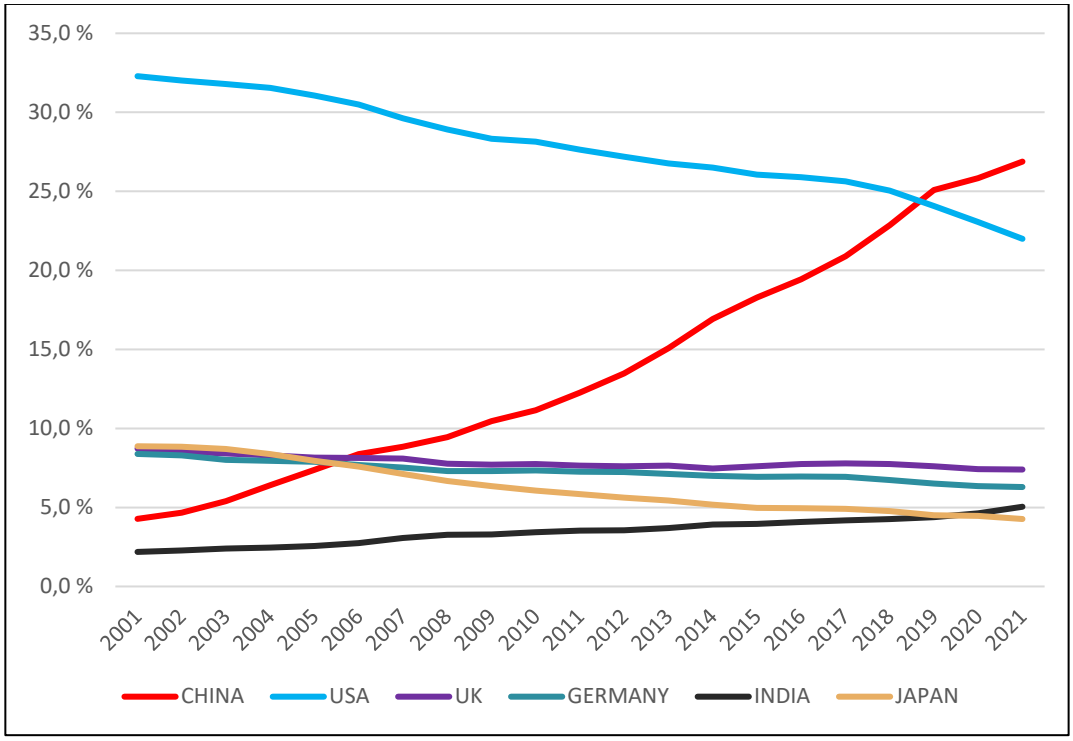

Figure 2.4. Six large contributing countries to articles in *Web of Science* and their percentage share of the global total per year 2001-2020.

Figure 2.5 shows the trends for five other Asian countries including South Korea. All five have increasing shares in the first of the two decades. In the last decade, the global share of South Korea is stabilized while it is reduced for Taiwan.

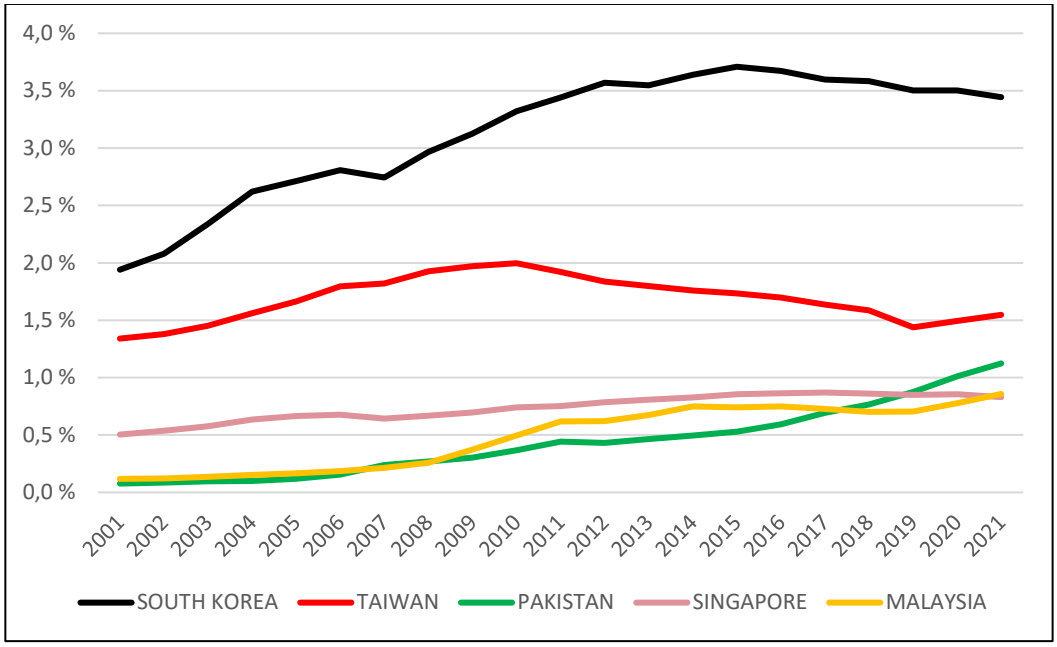

Figure 2.5. Five other Asian contributing countries to articles in *Web of Science* and their percentage share of the global total per year 2001-2020.

We already saw that Germany's share has been decreasing. Figure 2.6 shows that the share is also decreasing or stable for the Netherlands, Switzerland, Sweden, and Finland. The share of Denmark increased between 2009 and 2017 and decreased thereafter. Norway stands out with increasing shares during the whole period.

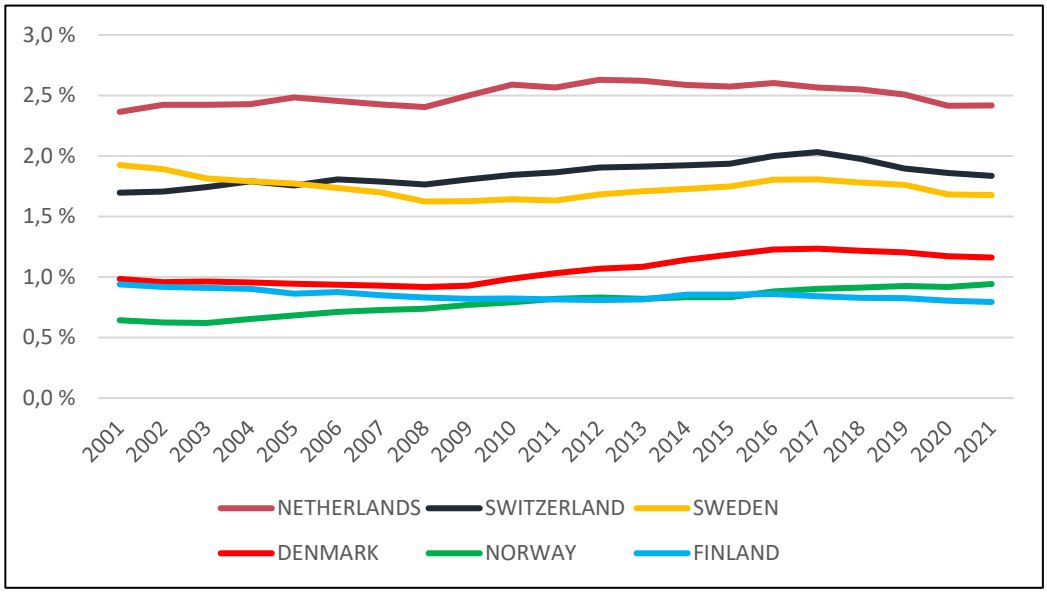

Figure 2.6. Four Scandinavian countries and two other European countries contributing to articles in *Web of Science* and their percentage share of the global total per year 2001-2020.

With China's extraordinary growth in science during the last two decades to become a major contributor to global science, all countries can expect China to have become a major collaborator in science as well. However, the degree to which this is true varies among countries, as we shall see in section 2.3.

2.2 Increasing scientific influence

While the number of scientific publications indicate trends in R&D activity, citations can be used for indicators of the global scientific influence and impact of this activity. According to the Norwegian annual report on science and innovation indicators (See *Figure 6b* in Norges forskningsråd, 2021), China now ranks among the most influential countries, well over the average for all countries, also over Norway, and now at the same level as the USA in field-normalized citation impact, an indicator of influence on the scientific literature of the world. China has climbed on this indicator at almost the same rate as the scientific production, starting from a position much lower than most other countries twenty years ago (See *Figure 3* in Schneider & Norn, 2023). South Korea has also climbed considerably on the same indicator, but reaching the average of all countries, not the same high level as China. At the same time, the USA has lost its former higher position in citation impact over all other countries.

One should note that this indicator of scientific influence is not independent of scientific production. China is not only producing more highly cited articles; the country also has a much larger share of the citing articles.

2.3 The degree of international collaboration in articles

Some scientific articles have authors with affiliations in only one country. Other articles have co-authors in two or more countries. The latter category has had a relative increase as a percentage within Web of Science for several decades. In most countries, the share is now over 50 percent. The share is generally higher in small countries than in large countries, indicating that small countries are more dependent on international collaboration to perform research.

We calculated the percentage share of articles with international collaboration among 27 countries during 2001-2020 and selected six countries to represent the results as shown in Figure 2.7. Norway represents the line that could be drawn for all countries in Northern Europe. Switzerland deviates from the European normal by higher shares while the UK and the USA have lower shares as expected for larger countries. South Korea slightly deviates, and China clearly deviates, from this pattern by having lower degrees of international collaboration.

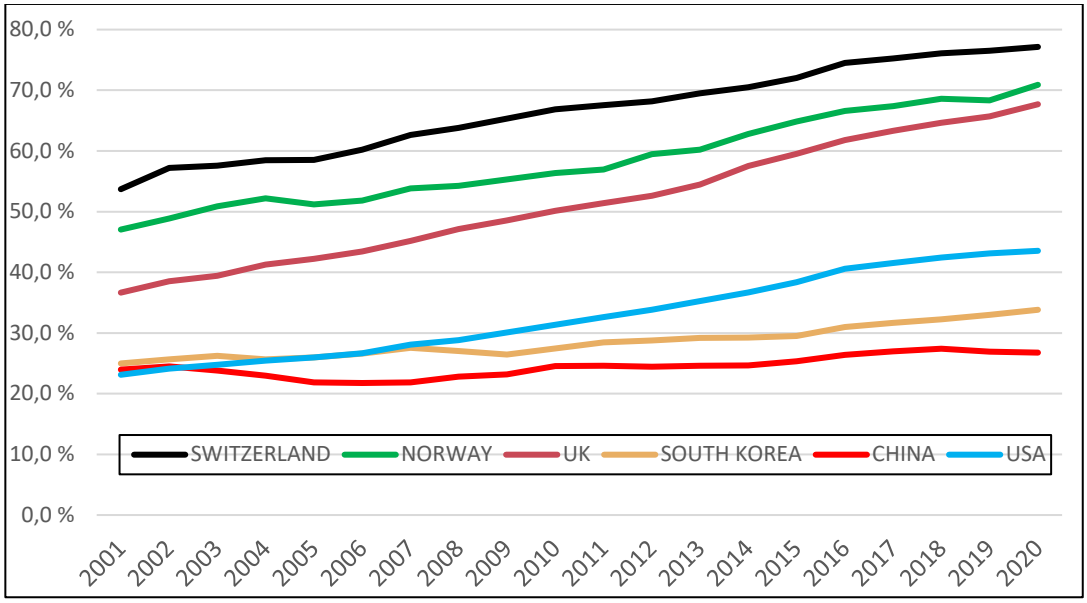

Figure 2.7. Degree of international collaboration measured as the percentage share of articles with co-authors in at least one other country among all articles from the country. Six selected countries with articles published 2001-2020.

The high growth rates already shown in Figures 2.2 and 2.3 are important for the understanding of why the two Asian countries differ from the Western countries. The number of articles with international collaboration increased by five times in both South Korea and Norway between 2001 and 2020. The difference is mainly that South Korea almost doubled its size within Web of Science, thereby rising from a small to a medium-sized scientific country.

China again stands out from all other countries. While the indicator in Figure 2.7 shows an almost stable degree of international collaboration, the number of articles with collaboration between China and other countries was multiplied by 18 between 2001 and 2020. China quickly became the largest country with an expected *lower degree* of international collaboration, but the *volume* of international collaboration increased immensely.

China published more than 400,000 articles in Web of Science *without* international collaboration in 2020. The corresponding number was 27,000 in 2001. The increase is larger than could be expected from the growth and increased research-intensity of the economy. The explanation is that the Chinese research sector was large already in 2001, but the scientific output was mainly published in *domestic scientific journals*. China has now partly moved its scientific production to the international journals covered by *Web of Science*, but domestic publishing is still important and presently being stimulated (Zhang & Sivertsen, 2020).

2.4 Bilateral versus multilateral collaboration

Internationally funded research consortia with global representation of research organizations are increasingly influencing bibliometric statistics based on *Web of Science*. A well-known example is the publications from the CERN laboratory in Switzerland for experiments in particle physics. Their articles are published very frequently (as often as fortnightly), are often very highly cited, and represent up to 3,000 listed authors each time with affiliations in more than 40 countries on all continents, including Norway, China and South Korea.

We will distinguish in this study between articles representing bilateral, trilateral, and multilateral country collaboration. Articles representing bilateral collaboration are interesting because they indicate what we often wish to know about international collaboration in research: To what extent are researchers in the two countries selecting each other for international collaboration? Articles representing trilateral or multilateral collaboration may depend more on third-party influences, but these types of collaboration can also be important for the stabilization and growth of bilateral relations in times when they are challenged (see section 3.3.1 below).

We illustrate the distinctions between the three types of international collaboration in *Figure 2.8* using Norway in the publication year 2020 and its relations to the five other countries in Figure 2.7 for the example. They are ranked in Figure 2.8 according to the share of articles with bilateral collaboration.

China stands out in Norway's profile with large shares of articles resulting from bilateral collaboration. The shares are also relatively high for USA and Sweden. Collaboration with South Korea, on the other hand, is in 72 percent of the cases based on multilateral collaboration. (The high share of multilateral collaboration with Switzerland is due to CERN and other large infrastructures located in the country.) In this respect, the China and South Korea differ as collaboration partners for Norway. Closeness (for Sweden) and the frequency of collaboration (see China in Figure 2.10 below) seem to influence the tendency to collaborate bilaterally compared to multilaterally. Double affiliations of researchers in the two countries may explain large shares of bilateral collaboration. A fourth possibility is the influence of bilateral research programmes aimed at reinforced collaboration between two countries.

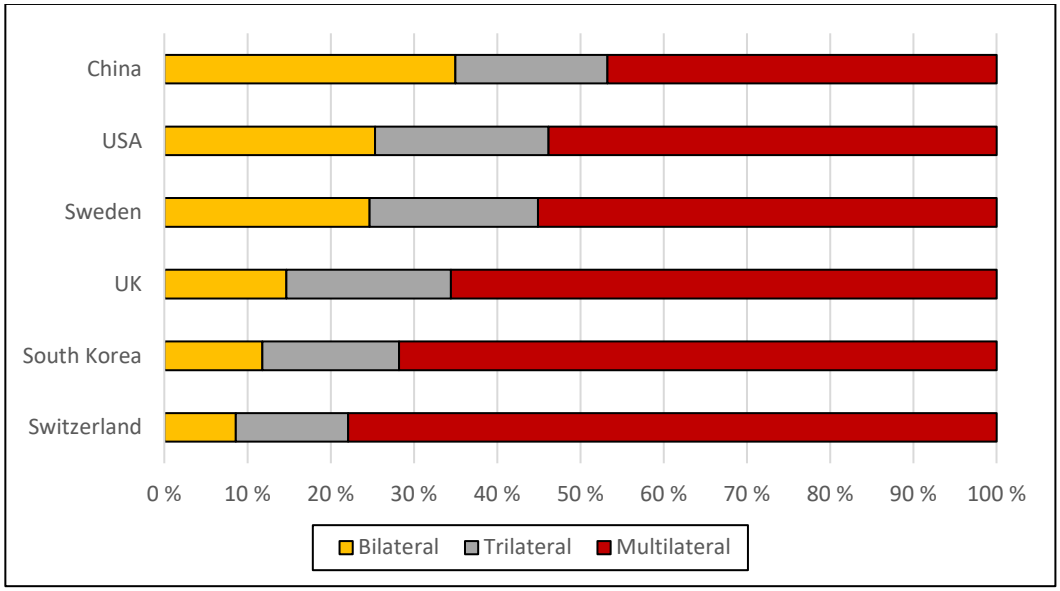

Figure 2.8. The number of collaboration articles with Norway in 2020 with a distinction between articles with evidence of bilateral, trilateral, and multilateral collaboration among countries. The countries are ranked according to the number of articles with bilateral collaboration.

2.5 Summary

The number of articles indexed in Web of Science has tripled up to 2.4 million annually during the last twenty years. The growth reflects increasing research intensity measured as a percentage of GDP, particularly in emerging economies. The growth also reflects increasing international collaboration and mobility in science as well as the internationalization of scientific publishing. Within this global context, partly reflecting these general factors, but also because of internal policy changes, China has grown outstandingly to become the world's largest contributor to indexed scientific articles. South Korea has grown as well compared to Western countries and is now one of the world's most research-intensive nations. For these reasons, Norwegian research collaboration with the two countries can be expected to increase over time.

The collaboration with China is to a higher degree of based on bilateral collaboration (only Norway and China are represented in the article's authors' addresses) while the collaboration with South Korea is to a high degree based on multilateral collaboration involving other countries as well.

3 Collaboration clusters and intensities

3.1 Measuring the relative intensity of collaboration

Figures 3.1-3 on the next page show the five largest collaborating countries from the perspective of each of the three countries China, South Korea, and Norway. Country size evidently influences collaboration frequencies. USA is a large collaboration partner for all three countries. However, the importance of collaboration with USA, relative to collaboration with other countries, seems to differ among the three countries. This difference cannot simply be grasped by comparing the rank of USA within each country or the numbers of collaboration articles with USA. Country size influences the picture we get by the simple measurement in Figures 3.1-3.

This chapter will therefore be based on *size-independent* measures to calculate the *relative intensity of collaboration* between two countries, that is, relative to the activity in the other bilateral relations in the global network. A size-independent indicator of relative collaboration intensity (Luukkonen, Persson & Sivertsen, 1992) is widely used today in governmental advice, e.g., by the US National Science Board (2019) in its *Science & Engineering Indicators* report. We recently modified the indicator to become more mathematically consistent (Fuchs, Rousseau & Sivertsen, 2021). The relative intensity of collaboration (RIC) between country x and country y is calculated by using this formula:

> *RICxy = (Cxy/Cx)/(Cy-Cxy/Cw), where Cxy is the number of articles with collaboration between x and y, Cx is the total number of articles with international collaboration in which x is involved within the whole network, Cy is the total number of articles with international collaboration in which y is involved within the whole network, and Cw is the sum total of articles with international collaboration in the whole network.*

We will apply the formula on a matrix of collaboration frequencies among the 40 largest science producing countries (see section 1.2.3 above). We will measure the intensities in three different years, 2012, 2017, and 2022, to detect changes over time. The perspectives of four countries will be compared: Norway, China, South Korea, and USA. USA is included because of the differences observed in Figures 3.1-3.

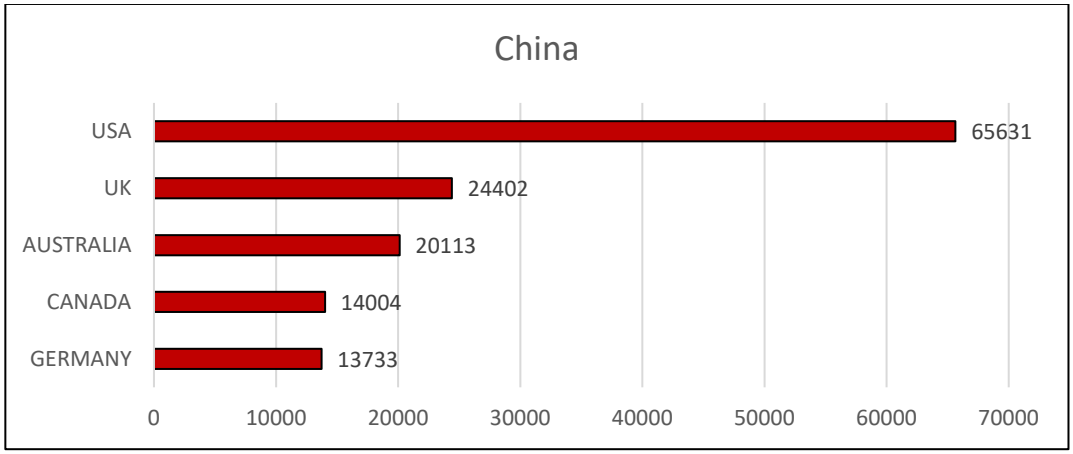

Figure 3.1. Chinas's five largest collaboration partners in 2021.

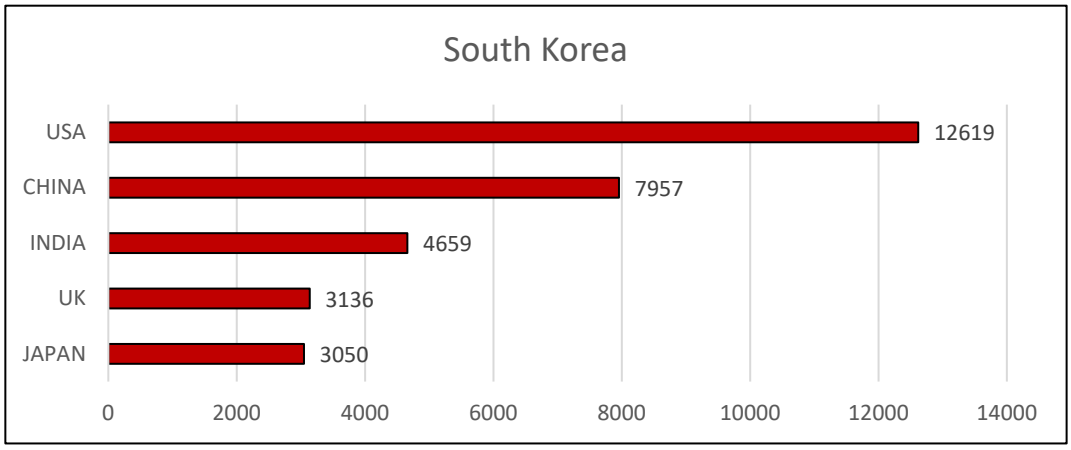

Figure 3.2. South Korea's five largest collaboration partners in 2021.

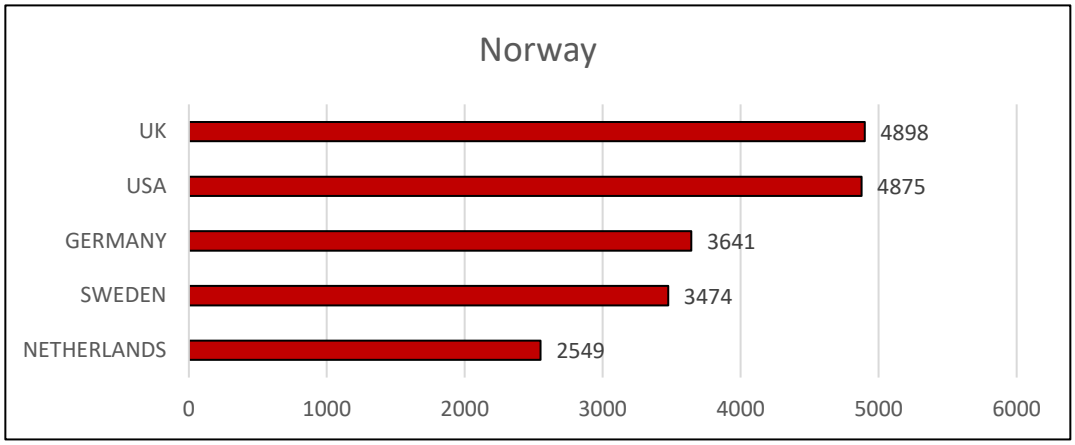

Figure 3.3. Norway's five largest collaboration partners in 2021.

If more countries were included in the comparison used in the three figures above, Norway would rank number 30 in China's list with 2,087 collaboration articles in 2021. With the same number of articles, China ranks number ten in Norway's list. Norway would rank number 34 in South Korea's list with 515 collaboration

articles in 2021. With the same number of articles, South Korea ranks number 28 in Norway's list. These numbers also illustrate the need for a size-independent indicator of collaboration intensity that takes the activity in the whole network into consideration.

3.1.1 The relative intensities of Norway's relations

The relative collaboration intensities of Norway's relations are shown in Figure 3.4. Collaboration is most intense in the relations to the other Nordic countries and the other European countries. The intensities are low in the relations to all Asian countries, including China and South Korea. The relation to USA also has a low intensity. We will have a closer look at the fluctuations between 2012 and 2022 in section 3.3 below.

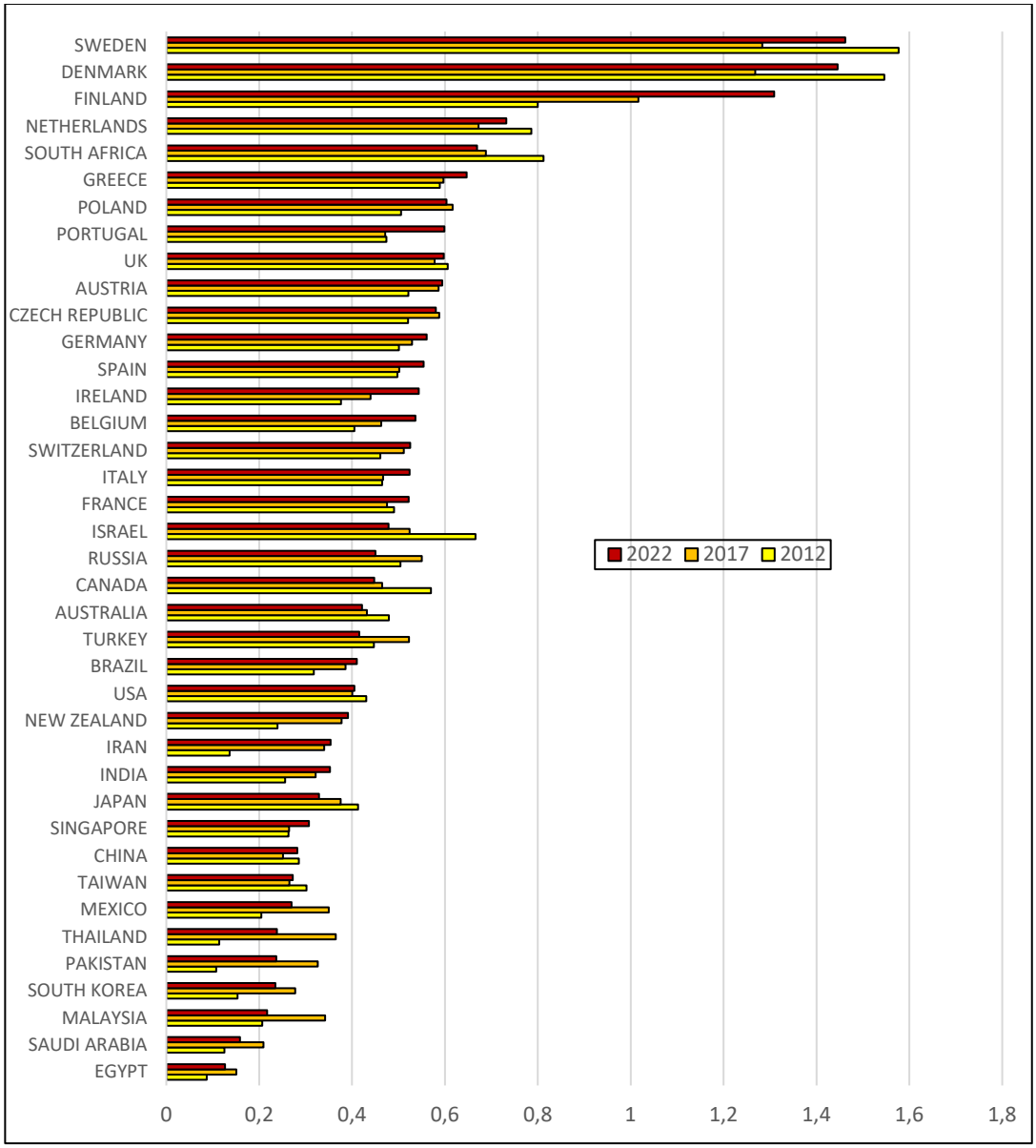

Figure 3.4. Relative collaboration intensities in Norway's bilateral relations 2012-2022. The countries are ranked according to the intensity in 2022.

3.1.2 The relative intensities of China's relations

The relative collaboration intensities of China's relations are shown in Figure 3.5. Collaboration is most intense in the relations to the other Asian countries, including South Korea, and to large English-speaking countries, particularly USA and Australia. The intensity is low in the relation to Norway, lower than to the other Nordic countries. We will have a closer look at the fluctuations between 2012 and 2022 in section 3.3 below.

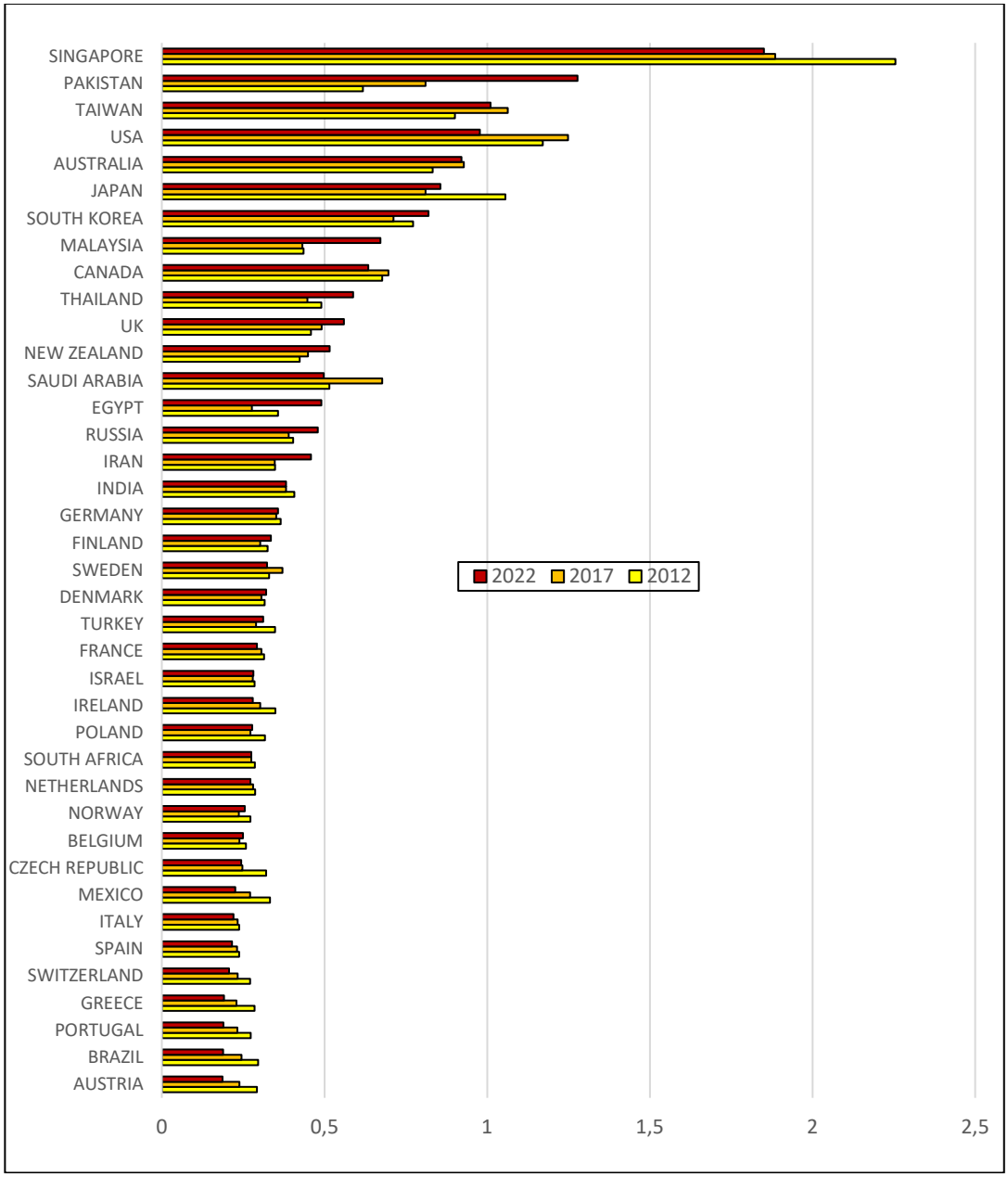

Figure 3.5. Relative collaboration intensities in China's bilateral relations 2012-2022. The countries are ranked according to the intensity in 2022.

3.1.3 The relative intensities of South Korea's relations

The relative collaboration intensities of South Korea's relations are shown in Figure 3.6. Collaboration is most intense in the relations to the other Asian countries, including China, and to USA. The intensity is low in the relation to Norway and the other Nordic and European countries. We will have a closer look at the fluctuations between 2012 and 2022 in section 3.3 below.

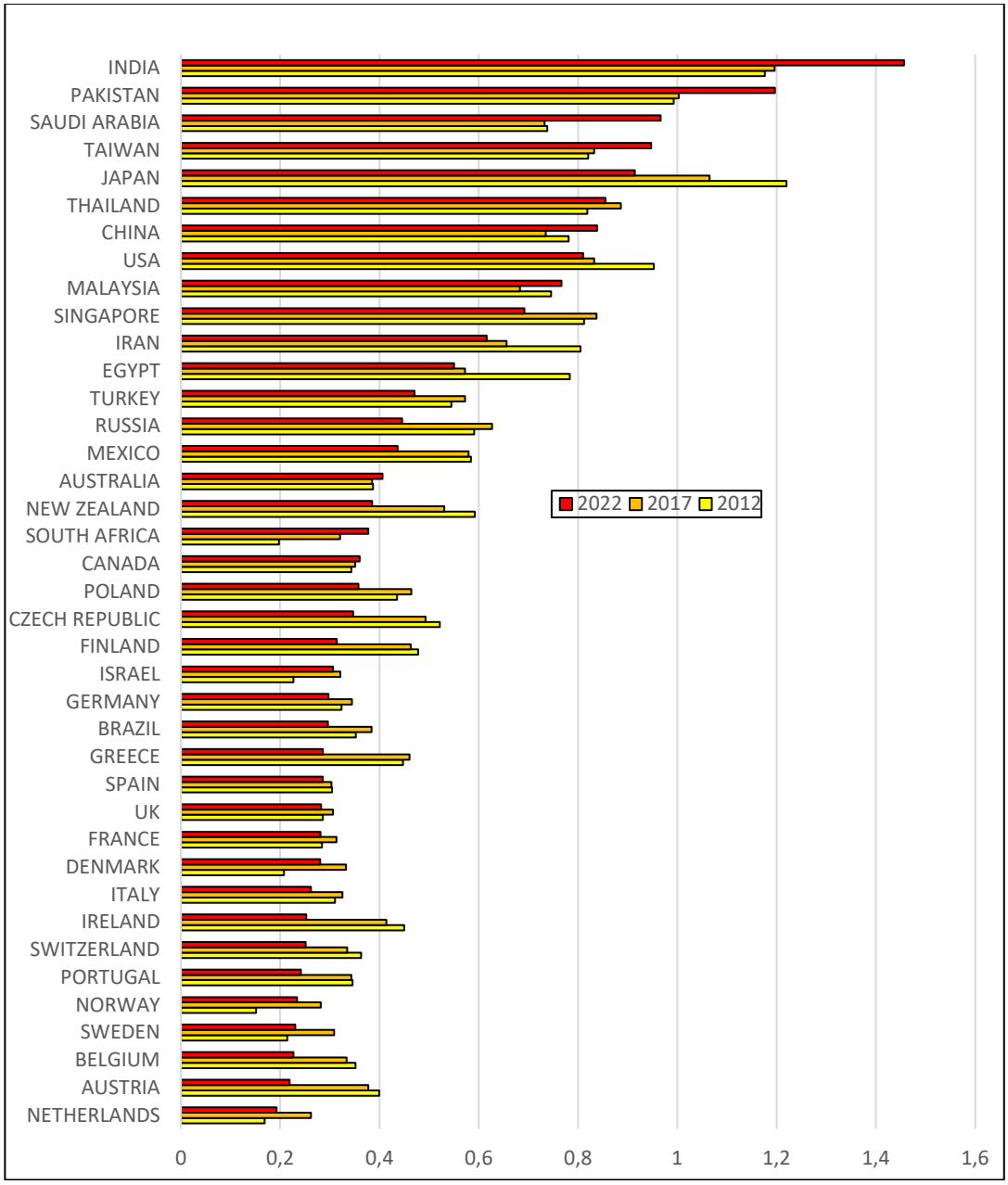

Figure 3.6. Relative collaboration intensities in South Korea's bilateral relations 2012-2022. The countries are ranked according to the intensity in 2022.

3.1.4 The relative intensities of USA's relations

The relative collaboration intensities of USA's relations are shown in Figure 3.6. Collaboration is most intense in the relations to China, Canada, and South Korea. the other Asian countries, including China, and to USA. The intensity is low in the relations to Norway and other small European countries. We will have a closer look at the fluctuations between 2012 and 2022 in section 3.3 below.

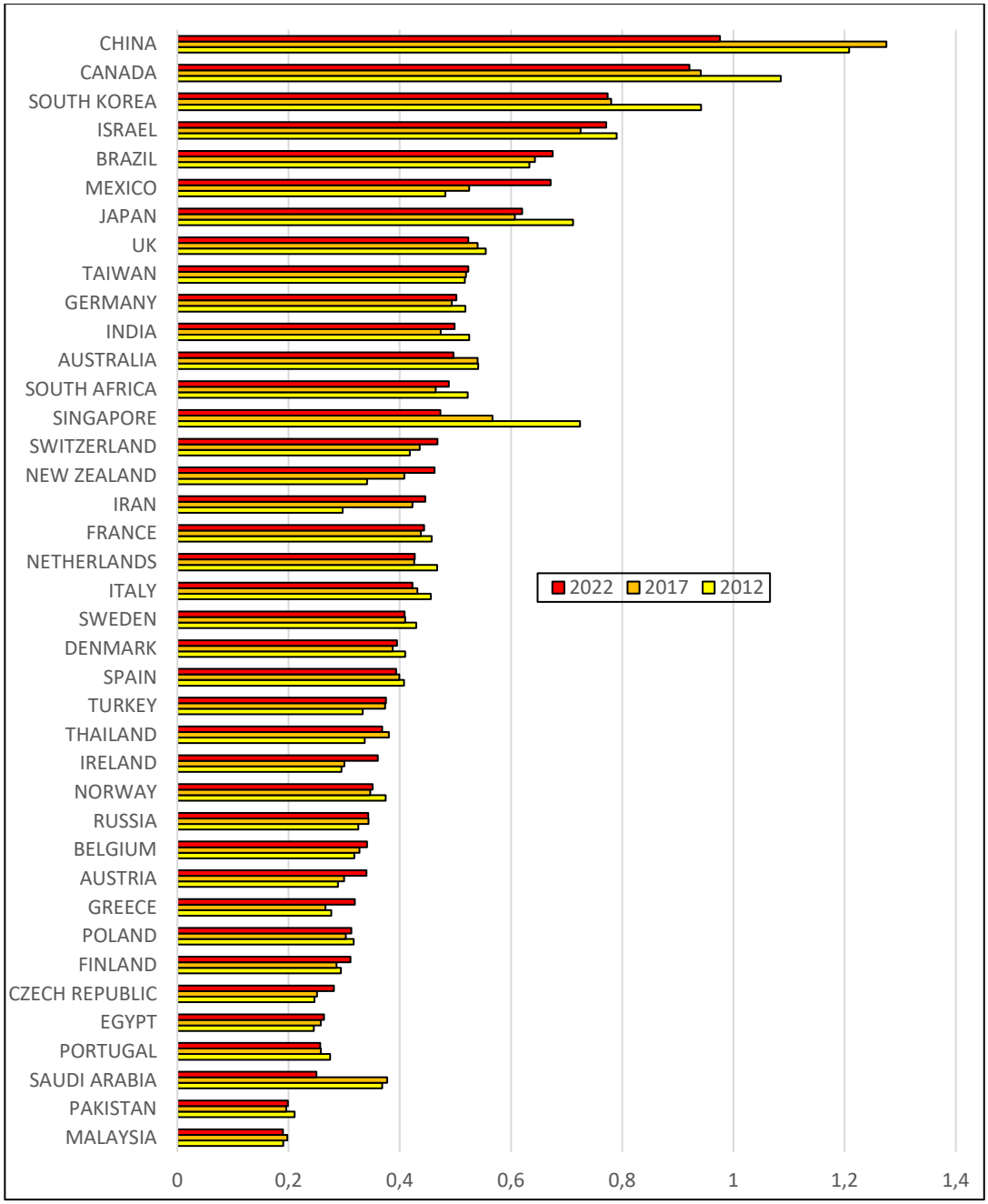

Figure 3.7. Relative collaboration intensities in USA's bilateral relations 2012-2022. The countries are ranked according to the intensity in 2022.

3.2 Global clusters

Norway has relatively little collaboration with China and South Korea when the sizes of the three countries in the global network of scientific collaboration activity is considered. Norway's collaboration profile is dominated by the other Nordic and European countries. In general, the engagement with Asian countries is relatively low for Norway.

China and South Korea collaborate intensively with each other and with other Asian countries. In addition, collaboration with USA has high relative intensity. We also saw in Figures 3.1-2 that their collaboration activity with USA is high also in absolute numbers. China differs from South Korea by having high intensity of collaboration with other English-speaking countries as well: Australia, Canada, UK, and New Zealand. This pattern is probably due to student and researcher mobility in China's relations.

In general, we observe a European cluster of collaboration where Norway is mostly involved. This cluster can be contrasted with a cluster of close collaboration between North America, Australia, and East-Asia. There is also an emerging cluster of increasing collaboration within and throughout Asia. China and South Korea have major roles in the two latter clusters.

Recent years have seen increasing tensions between science policies advocating openness and globalization on the one hand, and foreign policies much more focused on competition, trade sanctions, self-containment, and security and defence on the other. Taking the latter perspective of foreign policies, the clusters of global collaboration presented above so far represent a paradox. It is difficult to recognise the borders of defence alliances in the pattern. USA and China are the world's major collaboration partners in science while the intensity is low between USA and most NATO countries. China has intense collaboration with Asian countries with NATO ties such as Japan, South Korea, and Taiwan.

3.3 Trends and changes in the intensities

International collaboration in science is usually without abrupt changes. It normally follows the general trend of increasing globalization in research. Geographical and cultural closeness or distance, as well as multinational organizations and funding sources, also seem to play a role. However, some of the changes in collaboration intensity that were revealed in the analysis above may represent political influences. We will comment on two of them before we summarize more general trends seen in Figures 3.4-7 above.

3.3.1 Changes in Norway's relations to China and South Korea

Figure 3.8 shows China's share in the total of articles with international collaboration that four Scandinavian countries were engaged in year by year between 2012 and 2022. The increasing relative importance of China in international scientific collaboration was the same for the four countries until 2014 and followed the general growth of China in science production. The increase for Norway then halted for four years until it resumed in 2017 without reaching the same level as for the

other Scandinavian countries. This continued difference between the Scandinavian countries was also reflected in Figure 3.5 above showing the relative intensities from the perspective of China. Norway is less engaged in scientific collaboration with China than the other Nordic countries are.

The evident explanation seems to be China's unilateral decision to close official relations and collaboration with Norway after the Nobel Peace Prize was awarded to Liu Xiaobo in 2010 (Sverdrup-Thygeson, 2017). The relations were restored in 2016, among them the bilateral programme for collaboration in science. The revitalization of collaboration in higher education and science was marked by the China-Norway Science Day in Beijing on April 17, 2018. The reason why China's reaction in 2010 is not traceable in the diagram before in 2013-14, is that it may take 2-4 year from a research project is started until it is published. We also observe that collaboration did not disappear, the increase was only halted. Multilateral collaboration involving third parties may be the stabilizing factor.

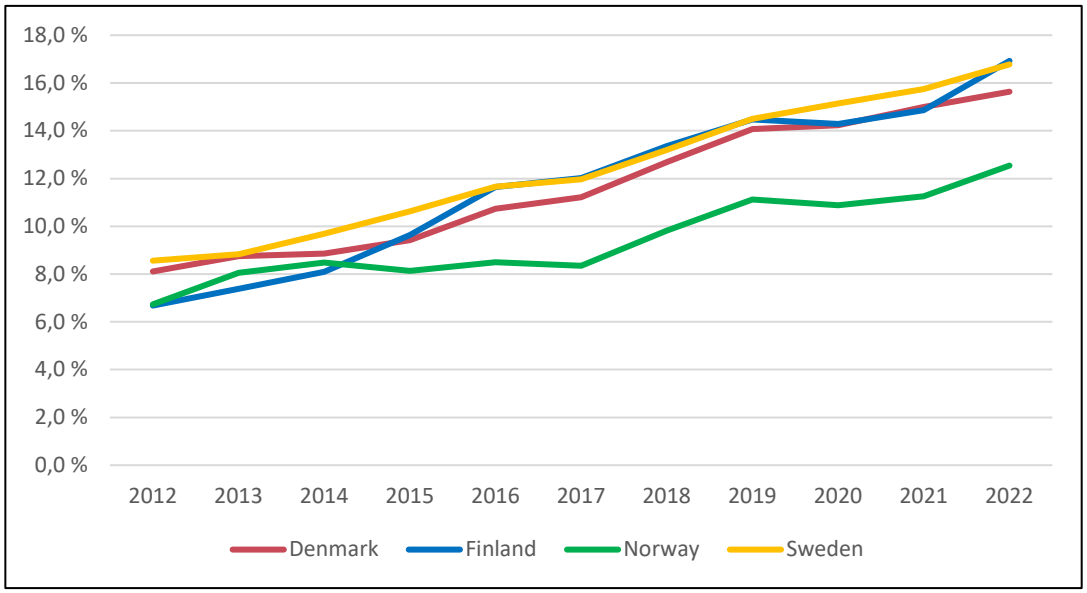

Figure 3.8. Articles in collaboration with China as a percentage of all articles with international collaboration from four Scandinavian countries in 2012-2022.

The trends in Figure 3.8 can be compared to Figure 3.9 showing trends in collaboration between the Nordic countries and South Korea. The trends for Denmark and Sweden resemble the growth and stagnation of South Korea in Figure 2.5 above. There is a stagnation in the trend for Norway in the same period as with China, but South Korea has grown in Norway's collaboration profile the last five years reaching the same level as for Denmark and Sweden. As also seen in Figure 3.6 above, Finland collaborates relatively more with South Korea than the other Nordic countries do, but the intensity was reduced after 2019.

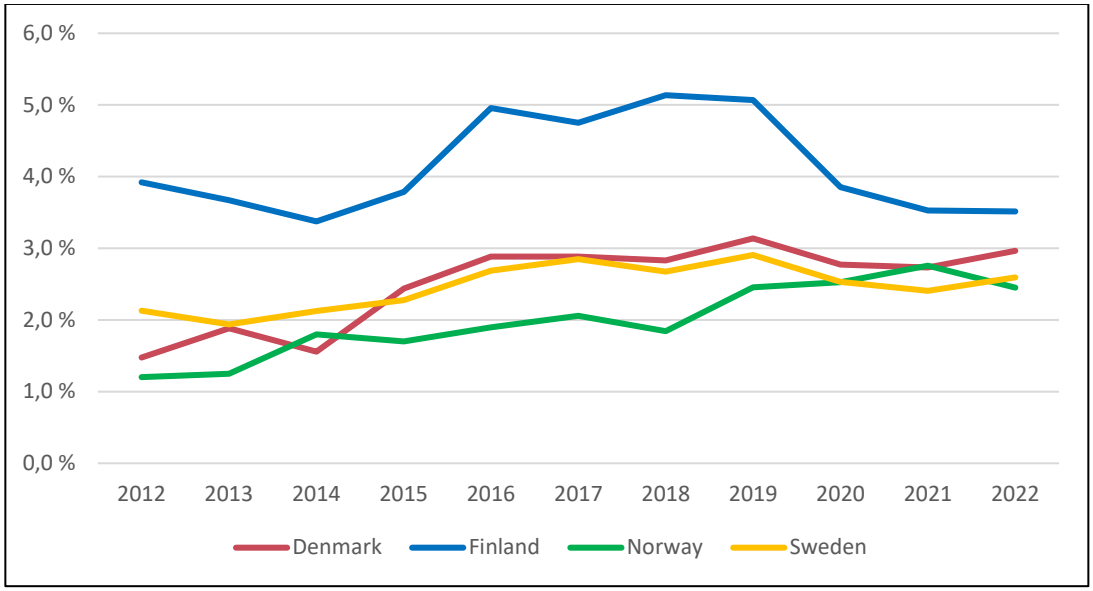

Figure 3.9. Articles in collaboration with South Korea as a percentage of all articles with international collaboration from four Scandinavian countries in 2012-2022.

3.3.2 The rise and fall of Sino-American collaboration

Figures 3.5 and 3.7 showed a mutual increase in relative collaboration intensity between China and USA between 2012 and 2017 and a clear decrease afterwards. This is the most discussed change in the global scientific collaboration pattern in recent years. The two countries are by far the world's largest in science. They are involved in 46 percent of the world's scientific production and the number of articles the American and Chinese researchers co-author is comparable to the total production of the Netherlands or 2,5 times the total production of Norway.

For a more detailed picture of the rise and fall in Sino-American collaboration in science, Figure 3.10 shows the proportions of the collaboration articles in China' relations to USA, UK and South Korea within the total of China's international collaboration articles each year from 2012 to 2022.

Before 2012, the relative share of USA in China's collaboration profile had steadily increased reaching almost 50 percent. Mutually, in USA's collaboration profile, China surpassed the United Kingdom as USA's largest collaboration partner around 2010, and a few years later, USA had twice as much collaboration with China as with the UK. From the perspective of China, figure 3.10 shows a slight decrease in the relation to USA between 2016 and 2019 after which the decline becomes steeper. The cause cannot be the pandemic. The share of the UK and South Korea in China's profile has continued to increase in the same years. The decreased relative intensity of collaborations between China and the USA is more likely to be reflecting the deteriorating relations between the two countries since 2018 (Tang et al., 2021; Zweig, 2021).

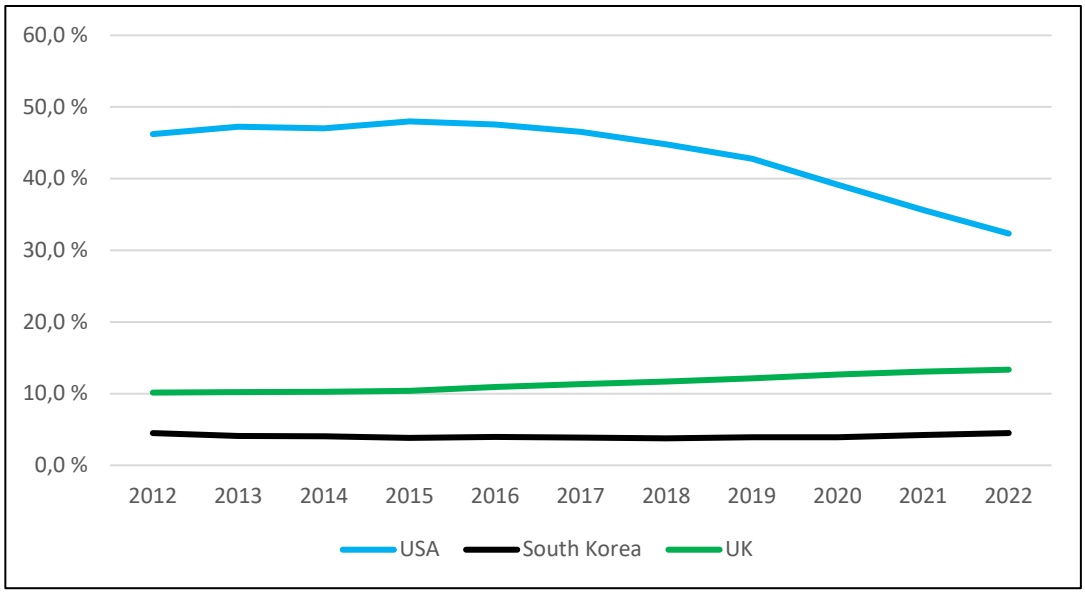

Figure 3.10. China's articles in collaboration with USA, UK, and South Korea as percentages of all of China's articles with international collaboration 2012-2022.

Figure 3.6 above also showed decreasing relative intensity in South Korea's collaboration with USA. A closer picture is given in Figure 3.11. USA has been dominating in the collaboration profile of South Korea. China is gradually becoming a counterweight while USA is clearly declining, and the UK is stable or increasing.

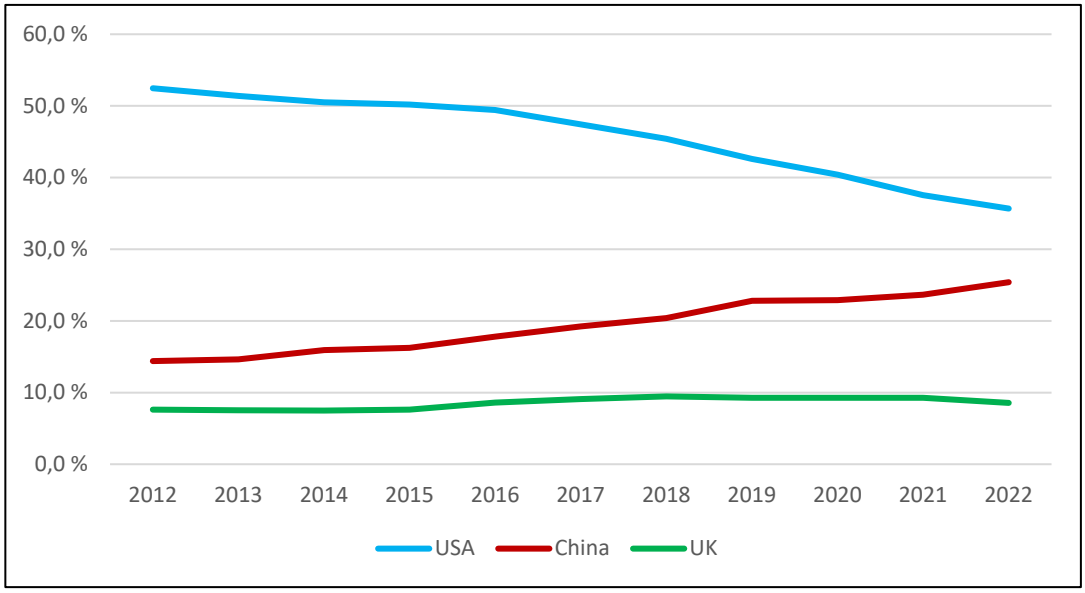

Figure 3.11. South Korea's articles in collaboration with USA, China, and UK as percentages of all of South Korea's articles with international collaboration 2012-2022.

3.4 Summary

The increasing importance of China and South Korea in Norway's international collaboration profile is mainly due to the two countries' rapid growth within global science. Norway has relatively little collaboration with China and South Korea when the sizes of the three countries in the global network of scientific collaboration activity is considered. Norway's collaboration profile is dominated by the other Nordic and European countries. In general, the engagement with Asian countries is relatively low for Norway.

China and South Korea collaborate intensively with each other and with other Asian countries. In addition, collaboration with USA has high relative intensity. China differs from South Korea by having high intensity of collaboration with other English-speaking countries as well: Australia, Canada, UK, and New Zealand. This pattern is probably due to student and researcher mobility in China's relations. China also differs from South Korea by having a decreasing intensity of collaboration with the USA in recent years.

In general, we observe a European cluster of collaboration where Norway is mostly involved. This cluster can be contrasted with a cluster of close collaboration between North America, Australia, and East-Asia. There is also an emerging cluster of increasing collaboration within and throughout Asia. China and South Korea have major roles in the two latter clusters.

4 Norway's relations with China

This chapter is based on an analysis of almost 11,500 scientific articles that were published and indexed in Web of Science in 2001-2021 with authors' addresses in both China and Norway. Half of the articles were published the last five years 2017-2021. Hence, the analysis mainly reflects the more recent research collaboration activities in Sino-Norwegian relations.

Other countries than China and Norway are involved in almost two thirds of the articles. We will separate between articles with different types of collaboration – bilateral, trilateral, and multilateral – throughout the analysis.

As introduced in section 1.2.2, we separate between nine main areas of research based on a classification of journals: Biology, Biomedicine, Chemistry, Computer Science, Environmental Sciences, Health Sciences, Physics, Social Sciences and Humanities (SSH), and Technology.

For a closer look at Sino-Collaboration in technology, with the inclusion of the engineering sciences and computer science, we advise to combine the reading of this chapter with the expanded analysis presented in Chapter 6.

Within each area of research and type of collaboration, this chapter will identify the institutions that most frequently practice Sino-Norwegian collaboration in each of the countries. The most frequently used journals in each area of research will be listed to indicate the active fields of research more specifically.

4.1 Areas of research and type of collaboration

After allowing for double counting when classifying the articles by main area of research, the sum of analysed articles increases by 30 percent to 15,000. Within this number, the categories have different sizes, as shown in *Figure 4.1* where we also distinguish between three types of collaboration.

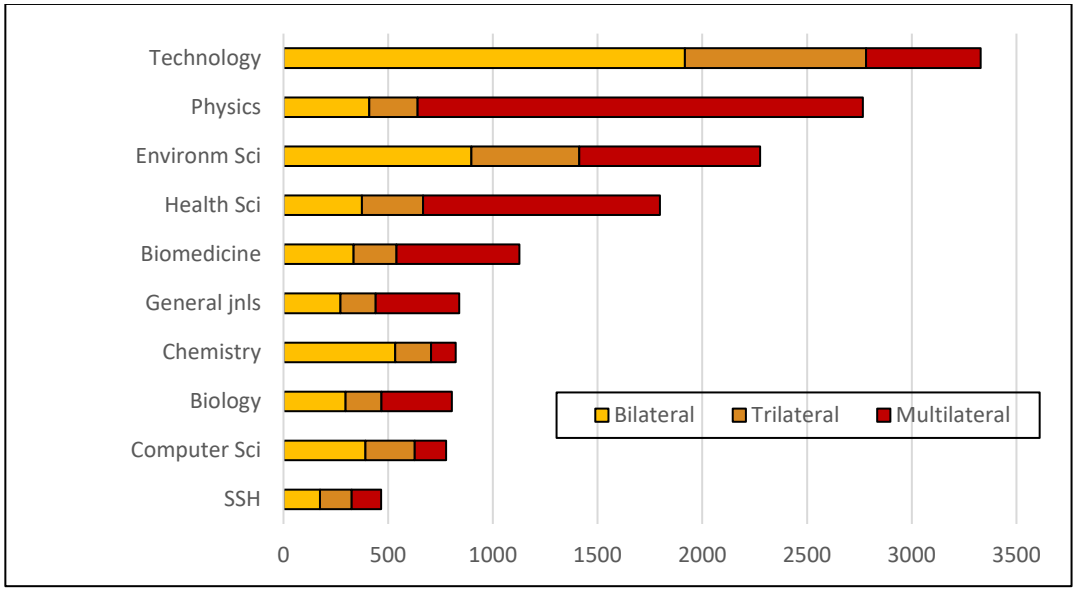

Figure 4.1. The number in articles with Sino-Norwegian collaboration 2001-2021 in each of ten categories and with a distinction between three types of collaboration at country level.

China and Norway often engage in collaboration in Physics and the Health Sciences, but this engagement is mostly driven by multinational collaboration. On the other hand, Technology, Environmental Sciences, Chemistry, and Computer Science represent main areas with more bilateral and trilateral collaboration. Collaboration in these areas is to a higher degree based on a specific mutual interest between Chinese and Norwegian researchers and their institutions.

Sino-Norwegian collaboration in science has a distinct profile when compared to the two countries general research profiles. In *Figure 4.2* below, all the years 2001-2021 are included to make visible the distinct profile of Sino-Norwegian collaboration, as shown in yellow.

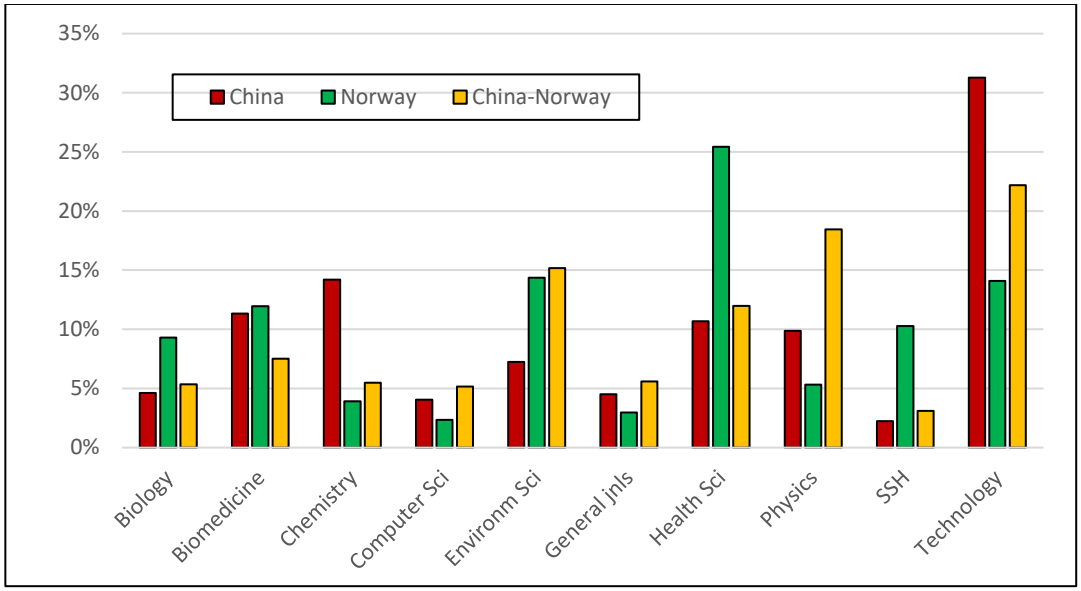

Figure 4.2. The shares of articles with Sino-Norwegian collaboration 2001-2021 in each of ten categories (in yellow) compared to the similar distribution when all articles from each of the countries in the same period are considered.

Biomedicine stands out as a major area of research where there is less collaboration than could be expected from the relative activity in each of the countries. The opposite is the case for Physics and Computer Science, where there is more collaboration than expected from the perspective of both countries. There is high collaboration activity in the Environmental Sciences, which is strong in Norway's profile, and in Technology, which is strong in China's profile. Collaboration in Biology, Chemistry, Health Sciences, and Social Sciences and Humanities is not influenced by high activity in one of the countries.

When combining Figures 4.1 and 4.2, we observe that Environmental Sciences, Technology and Computer Science are the areas of research with high relative collaboration intensity within mainly the bilateral and trilateral types of collaboration. Below, we will present the areas of research in an order of importance according to these criteria.

Figure 4.3 shows that in the same three main areas, Environmental Sciences, Technology and Computer Science, we find the strongest revitalization of collaboration after 2017. Biology is another area with strong increase, although the number of articles is lower.

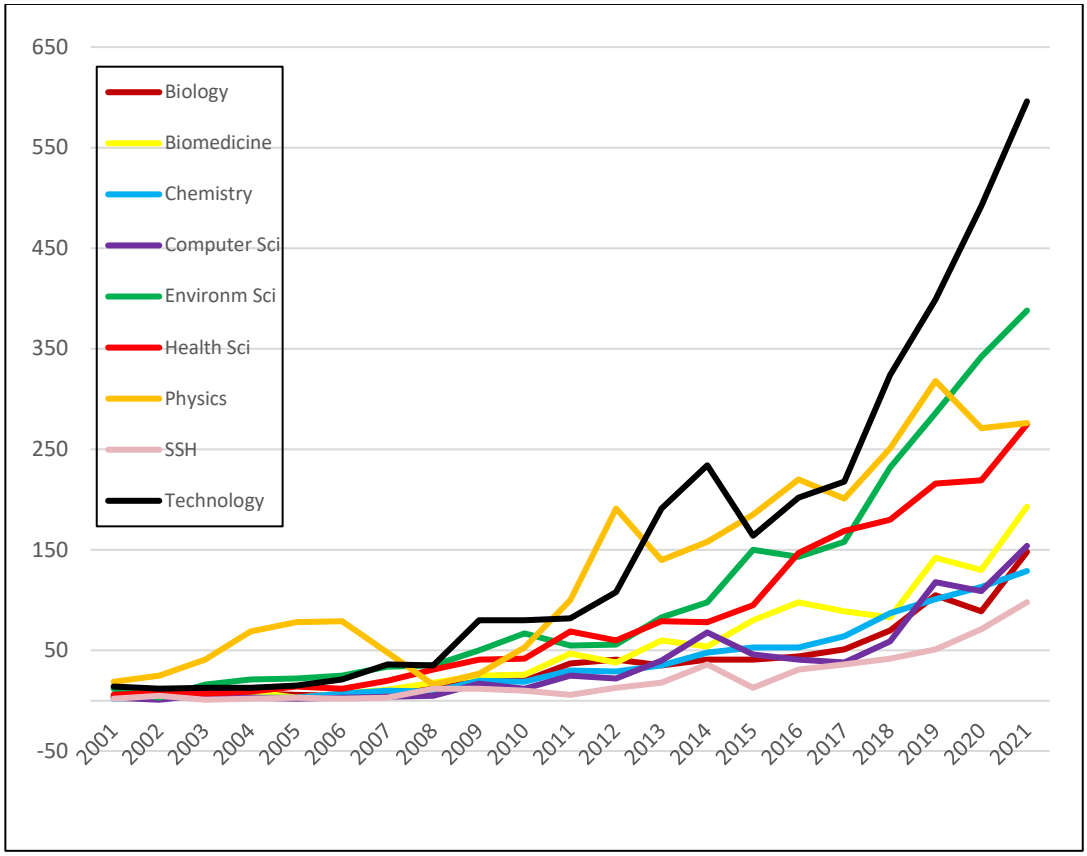

Figure 4.3. Number of articles with Sino-Norwegian collaboration 2001-2021 in nine major areas of research.

4.1.1 Contributing research sectors on the Norwegian side

The universities and other higher education institutions in Norway are the most frequent Norwegian partners in published research from Sino-Norwegian collaboration. This is shown in *Figure 4.4*. The independent research institutes are also active in the collaboration, particularly in biology, environmental sciences, and computer science. (We chose to classify the Bjerknes Centre for Climate Research and its affiliated organizations in Bergen as belonging to the higher education sector, which might underestimate the contribution of the institute sector to the collaboration in environmental sciences.) The contribution of research in the health sector is as expected significant in Biomedicine and the Health Sciences. There are small contributions from the corporate sector in all areas of research. But the contribution of this sector to research collaboration might be underestimated in our data since this sector's research is often not published.

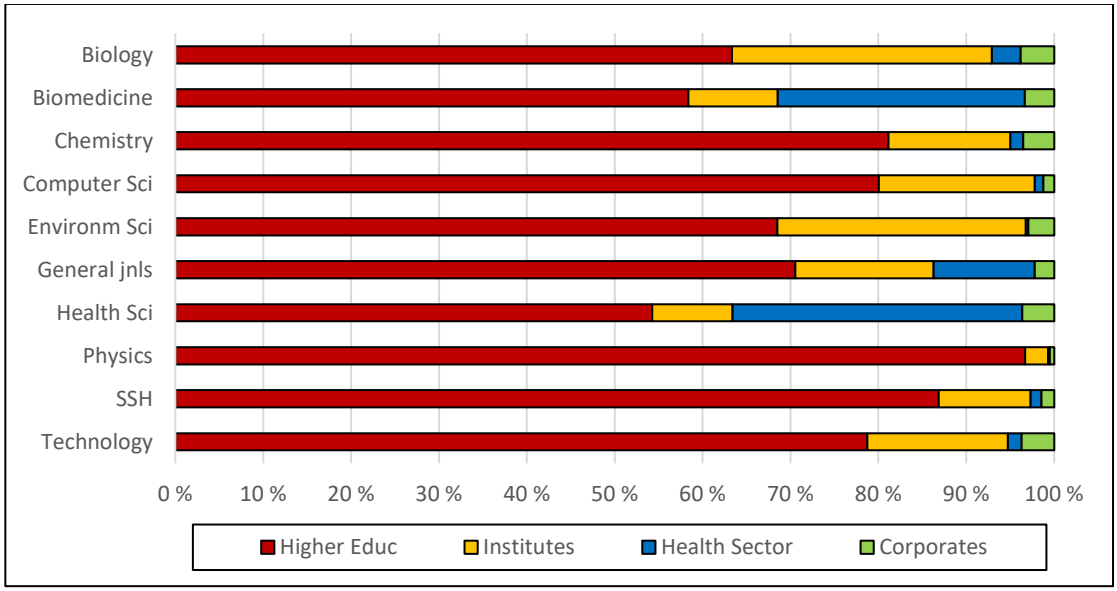

Figure 4.4 Articles with Sino-Norwegian collaboration 2001-2021 in nine major areas of research. Shares between four sectors of research on the Norwegian side.

In the following, we will have a closer look at the most frequent journals and collaborating institutions in Sino-Norwegian research collaboration in each of nine major areas of research (excluding the category General Journals). We present the areas of research in the order or relative importance for the bilateral relation as found in the analysis above. The underlying data represent scientific articles with author addresses in both China and Norway published 2001-2021 and indexed in Web of Science.

4.2 Collaboration in nine major areas of research

4.2.1 Environmental sciences

The analysis of Sino-Norwegian collaboration in this area of research is based on 2,276 articles published 2001-2021. Of these, 898 are based on bilateral collaboration. In 515 articles with trilateral collaboration, USA, UK, Germany, Sweden, Australia, and Canada are the six most frequent third partners. France replaces Sweden among the six most frequent partners in 863 articles with multilateral collaboration.

The most frequent journals that have published articles from Sino-Norwegian collaboration in the Environmental Sciences are listed in *Figure 4.5*. Specialized journals in climate research and marine research and engineering are present are present among more general journals representing geophysics and environmental science. Hydrological engineering also seems to be a focused area of frequent collaboration.

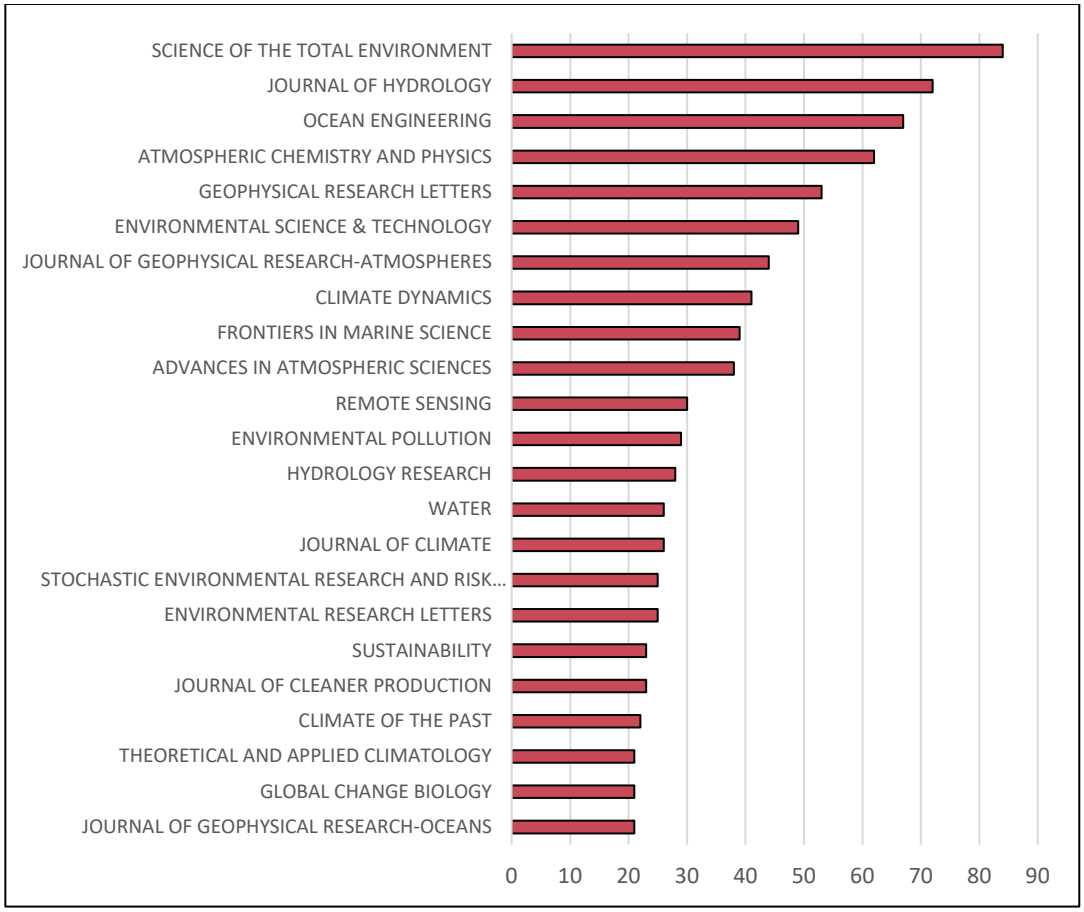

Figure 4.5. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in the Environmental sciences.

The most active partners on the Norwegian side in the Environmental sciences are University of Bergen (Geophysical institute, Bjerknes Centre for Climate Research, Nansen Environmental and Remote Sensing Centre) and University of Oslo (particularly Department of Geosciences). The three other major universities in the sciences are active: Norwegian University of Science and Technology, UiT - the Arctic University of Norway, and Norwegian University of Life Sciences. Several independent institutes are important for collaboration in this area of research: Norwegian Institute for Water Research (NIVA), CICERO - Center for International Climate Research, Norwegian Institute for Air Research (NILU), Norwegian Meteorological Institute, Institute for Marine Research, Norwegian Institute of Bioeconomy Research (NIBIO), Norwegian Polar Research Institute, Norwegian Geotechnical Institute (NGI), Geological Survey of Norway (NGU), and Norwegian Institute for Natural Research (NINA).

On the Chinese side, a major partner is the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences. Some of this collaboration is with two centres hosted by IAP, the Climate Change Research Center (CCRC) and the Nansen-Zhu International Research Center (NZC). The latter was founded in

collaboration with the above-mentioned partners in Bergen. Several other CAS institutes are active partners as well: Institute of Geology and Geophysics, Guangzhou Institute of Geochemistry, Institute of Geographical Sciences and Natural Resources Research, Nanjing Institute of Geography and Limnology, Institute of Tibetan Plateau Research, and the Research Center for Eco-Environmental Sciences.

Another major Chinese partner is the State Key Laboratory of Water Resources and Hydropower Engineering Science at Wuhan University. Two other state laboratories are also active: The State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering at Hohai University, and the State Key Laboratory of Estuarine and Coastal Research at East China Normal University.

The most active other universities are the University of the Chinese Academy of Sciences, Peking University, the China University of Geosciences in Wuhan, Tsinghua University, Beijing Normal University, and Nanjing University.

After going through the material, we see that there are in fact three fields of research that we have analysed under the umbrella 'Environmental sciences', each of them with a high collaboration activity supported by mutual interest and the most important institutions on both sides: 1) environmental sciences based on geophysical research, particularly in climate research, 2) marine science and engineering, and 3) hydrological engineering.

4.2.2 Technology

The analysis of Sino-Norwegian collaboration in this area of research is based on 3,329 articles published in 2001-2021. Of these, 1,917 are based on bilateral collaboration. In 865 articles with trilateral collaboration, USA, UK, Sweden, Australia, Singapore, and Germany are the six most frequent third partners. Italy and France replace Sweden and Singapore among the six most frequent partners in 547 articles with multilateral collaboration.

The most frequent journals that have published articles from Sino-Norwegian collaboration in Technology are listed in *Figure 4.6*. The profile represents industrial and marine engineering, materials science, and environmental engineering, the latter with overlap towards environmental sciences, see above. There is also overlap with information technology, see Computer science below.

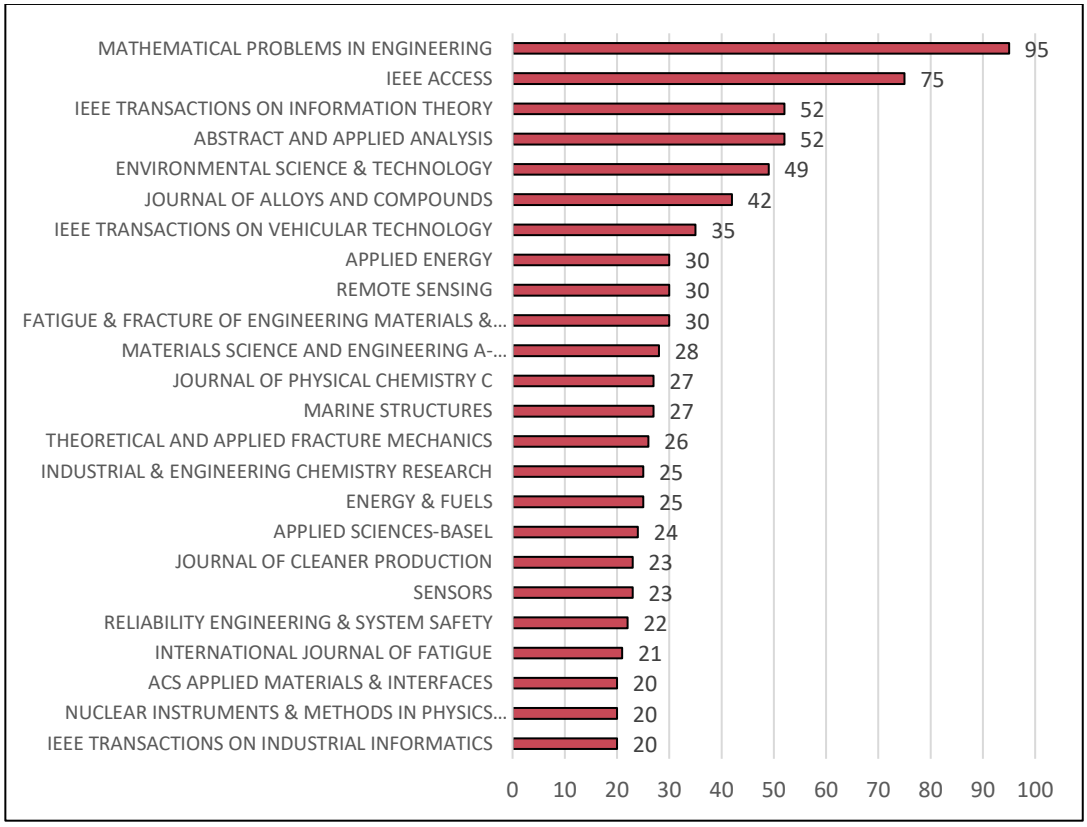

Figure 4.6. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Technology.

The two major partners on the Norwegian side are the Norwegian University of Science and Technology (NTNU) and several divisions of SINTEF. Other institutes are active as well: Simula Research Laboratory, Simula Metropolitan Center for Digital Engineering, Norwegian Geotechnical Institute (NGI), and Institute for Energy Technology (IFE).

The other most active universities are University of Oslo, University of Agder, University of Bergen, University of Stavanger, and University of South-Eastern Norway.

Corporate research in Norway is also involved: Equinor, Super Radio AS, DNV GL, and Marintek.

Major actors on the Chinese side are the State Key Laboratory of Chemical Engineering at East China University of Science and Technology, and the State Key Laboratory of Ocean Engineering at Shanghai Jiao Tong University. Active are also the College of Engineering at Bohai Univ, the School of Automation of Guangdong University of Technology, Harbin Institute of Technology, and Nanjing University of Science and Technology, Chongqing University, Wuhan University of Technology, University of Science and Technology Beijing, and Jiangsu University of Science & Technology.

4.2.3 Computer science

The analysis of Sino-Norwegian collaboration in this area of research is based on 776 articles published 2001-2021. Of these, 392 are based on bilateral collaboration. In 234 articles with trilateral collaboration, UK, USA, Singapore, Canada, Australia, and France are the six most frequent third partners. Taiwan and Germany replace Singapore and France among the six most frequent partners in 150 articles with multi-lateral collaboration.

The most frequent journals that have published articles from Sino-Norwegian collaboration in Computer science are listed in *Figure 4.7*. The profile represents both industrial applications and applications in telecommunication.

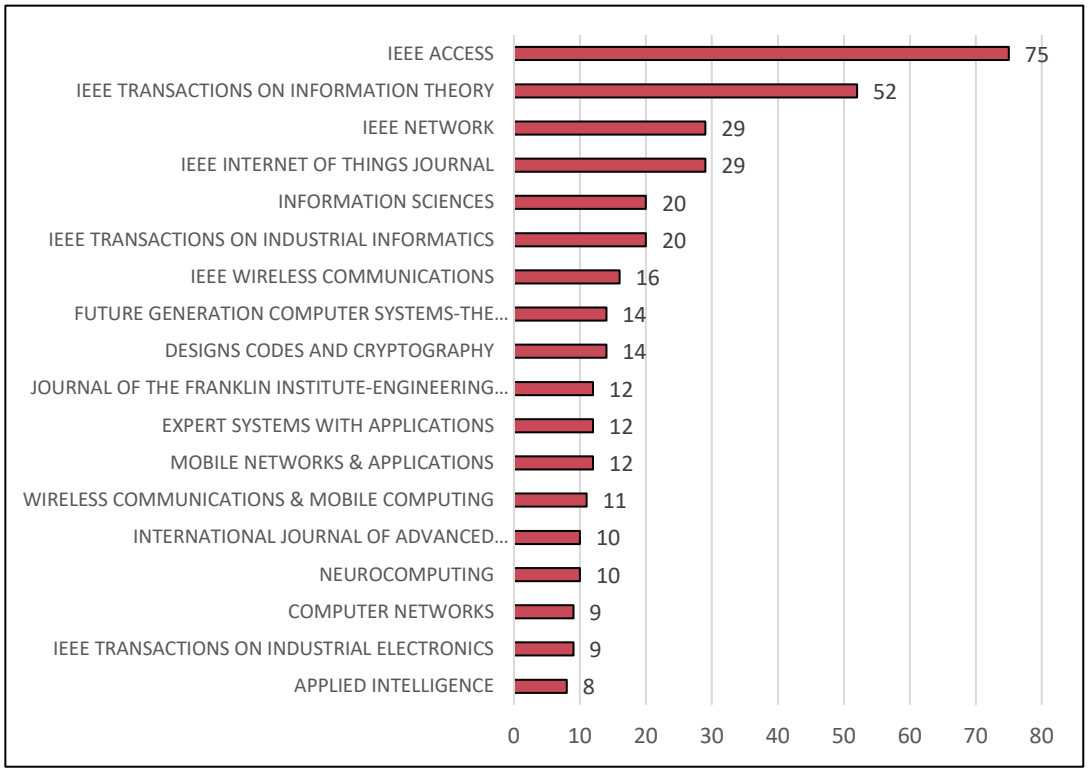

Figure 4.7. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Computer science.

The two major partners on the Norwegian side are the Norwegian University of Science and Technology (NTNU) and University of Oslo. The other most active universities are University of Agder, University of Bergen, Western Norway University of Applied Sciences and University of Stavanger. Simula Research Laboratory and Simula Metropolitan Center for Digital Engineering are also active.

The major actor on the Chinese side is Harbin Institute of Technology. Otherwise, as in Norway, universities dominate in the collaboration: Macau University of Science & Technology, Guangdong University of Technology, University of

Electronic Science and Technology of China, Hubei University, Nanjing University of Science and Technology, and Shandong University of Science & Technology.

4.2.4 Physics

The analysis of Sino-Norwegian collaboration in this area of research is based on 2,766 articles published 2001-2021. Of these, only 410 are based on bilateral collaboration. In 230 articles with trilateral collaboration, USA, Sweden, UK, Germany, Italy, and Australia are the six most frequent third partners. France and Russia replace Sweden and Australia among the six most frequent partners in 2,126 articles with multilateral collaboration, which Sino-Norwegian collaboration in this area of research is dominated by.

The most frequent journals that have published articles from Sino-Norwegian collaboration in Physics are listed in *Figure 4.8*. The profile is dominated by high-energy physics, but astrophysics and applied physics are represented as well.

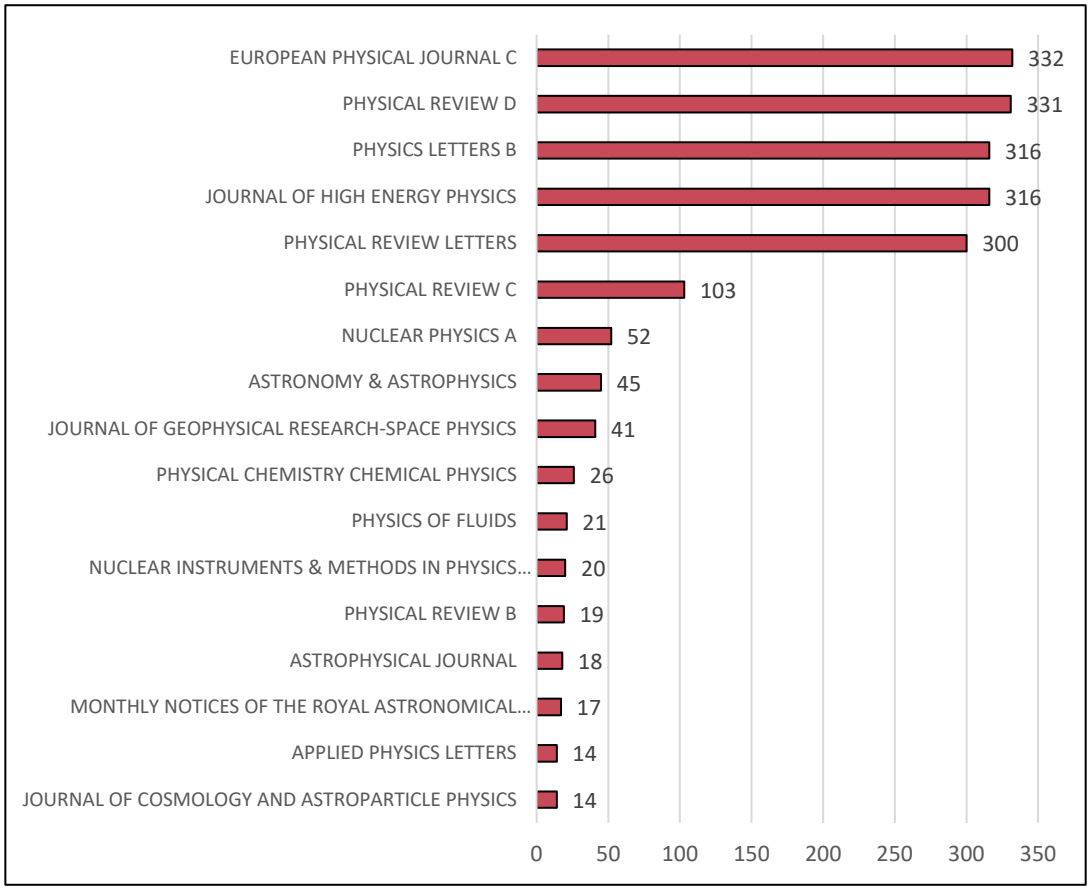

Figure 4.8. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Physics.

Five universities are the major partners on the Norwegian side: University of Bergen, University of Oslo, University of South-Eastern Norway, Western Norway University of Applied Sciences, and Norwegian University of Science and Technology.

The major actors on the Chinese side are the Institute for High Energy Physics and the China Institute of Atomic Energy of the Chinese Academy of Sciences, as well as the Department of Physics at Nanjing University. Departments of Physics at other universities are active as well: University of Science and Technology of China, University of Hong Kong, Chinese University of Hong Kong, Shandong University, Hong Kong University of Science & Technology, Tsinghua University, University of the Chinese Academy of Sciences, and Central China Normal University in Wuhan.

4.2.5 Chemistry

The analysis of Sino-Norwegian collaboration in this area of research is based on 822 articles published 2001-2021. Of these, as many as 533 are based on bilateral collaboration. In 171 articles with trilateral collaboration, Sweden, USA, Denmark, UK, Germany, and Italy are the six most frequent third partners. France replaces Italy among the six most frequent partners in 118 articles with multilateral collaboration.

The most frequent journals that have published articles from Sino-Norwegian collaboration in Chemistry are listed in *Figure 4.9*. The profile is focused on materials science and physical chemistry.

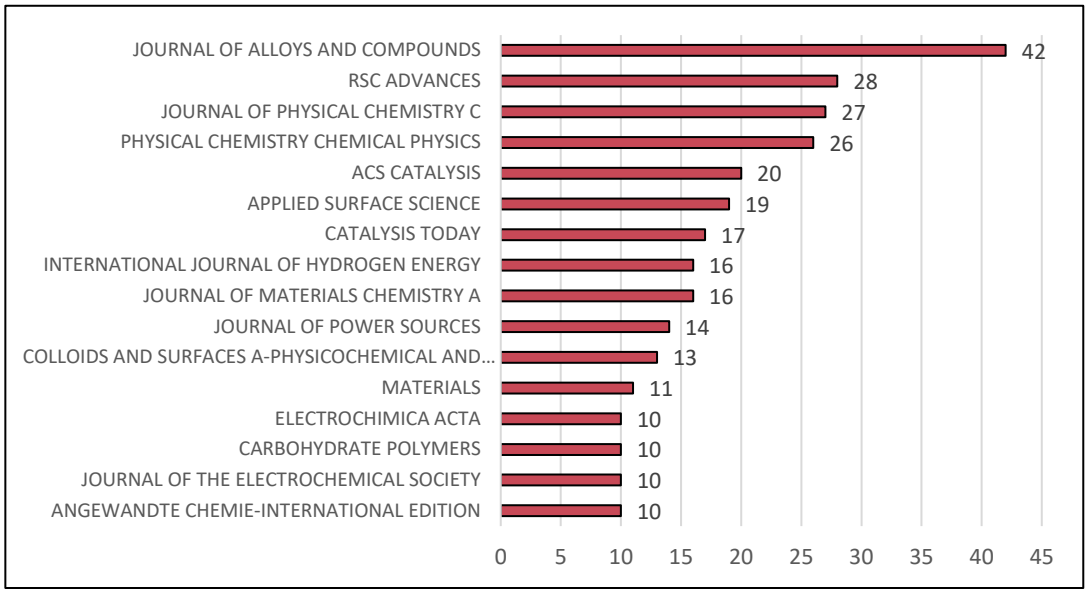

Figure 4.9. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Chemistry.

SINTEF and four universities are the major partners on the Norwegian side: Norwegian University of Science and Technology, University of Oslo, University of Bergen, and University of South-Eastern Norway.

The major actor on the Chinese side is the State Key Laboratory of Chemical Engineering, East China University of Science and Technology. Other frequent collaborators are Sichuan Agricultural University, Jiaxing University, China University of Petroleum, Central South University, and Jiangsu University.

4.2.6 Biology

The analysis of Sino-Norwegian collaboration in this area of research is based on 804 articles published 2001-2021. Of these, 296 are based on bilateral collaboration. In 172 articles with trilateral collaboration, USA, Germany, UK, Finland, Denmark, and Sweden are the six most frequent third partners. France, Australia, and Canada replace the other Nordic countries among the six most frequent partners in 118 articles with multilateral collaboration.

The most frequent journals that have published articles from Sino-Norwegian collaboration in Biology are listed in *Figure 4.10*. The profile is clearly focused on the characteristic Norwegian orientation in biology: Marine biology and fisheries research.

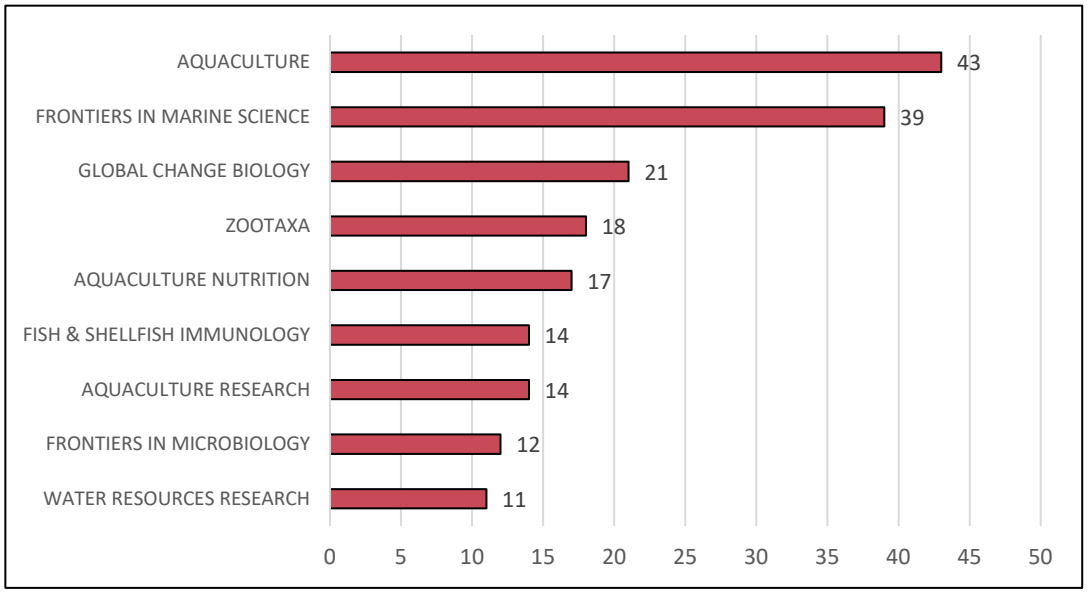

Figure 4.10. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Biology.

The five largest universities in Norway are major actors on the Norwegian side: University of Oslo, University of Bergen, Norwegian University of Life Sciences, Norwegian University of Science and Technology, and UiT - The Arctic University

of Norway. However, research institutes are also major contributors: Institute for Marine Research, NIBIO, Norwegian Institute for Natural Research, Norwegian Institute for Water Research, and Nofima.

The Feed Research Institute of the Chinese Academy of Agricultural Sciences is an active partner on the Chinese side. Several institutes of the Chinese Academy of Sciences also contribute: Institute of Zoology, Kunming Institute of Botany, Institute of Oceanology, Institute of Microbiology, Institute of Applied Ecology, and Chengdu Institute of Biology. Among the universities, the main partners are the College of Life Sciences at Nankai University, The School of Life Sciences at Sun Yat-sen University, and the College of Life Sciences at Hainan Normal University.

4.2.7 Biomedicine

The analysis of Sino-Norwegian collaboration in this area of research is based on 1,126 articles published 2001-2021. Of these, 335 are based on bilateral collaboration. In 204 articles with trilateral collaboration, USA, UK, Denmark, Sweden, Netherlands, and Australia are the six most frequent third partners. Germany and Canada replace Denmark and the Netherlands among the six most frequent partners in 587 articles with multilateral collaboration.

The most frequent journals that have published articles from Sino-Norwegian collaboration in Biomedicine are listed in *Figure 4.11*. The profile is mostly focused on human biology and genetics, and on oncology, but marine biology is also represented here.

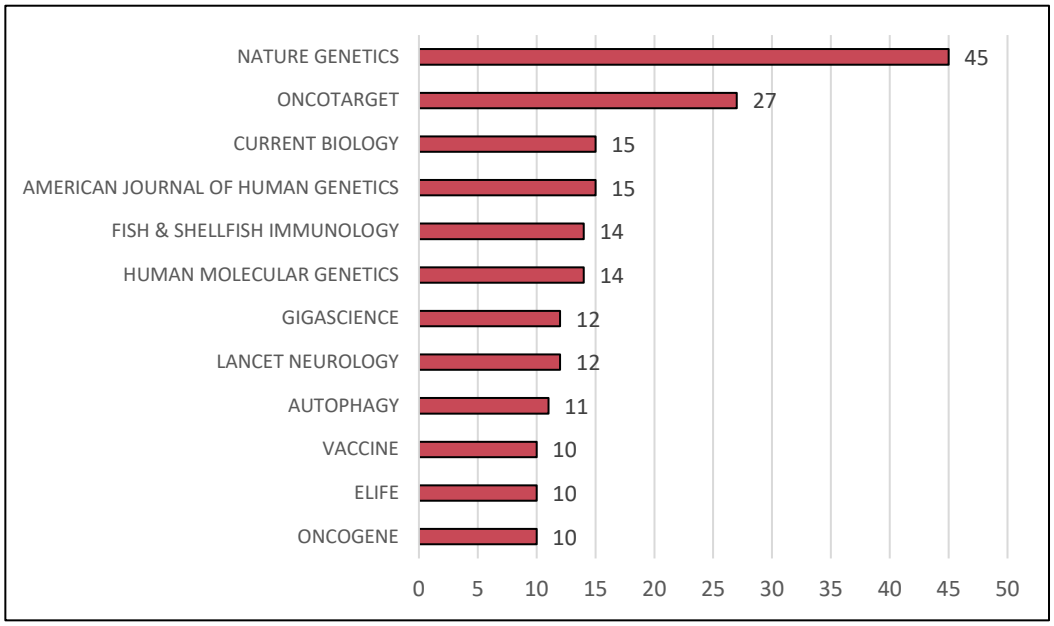

Figure 4.11. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Biomedicine.

The major actors on the Norwegian side are the university hospitals and universities in Oslo, Bergen, Trondheim, and Tromsø. In addition, Institute for Marine Research in Bergen and the National Public Health Institute contribute.

Major partners on the Chinese side are the Medical Schools and the affiliated hospitals of Zhengzhou University, Shandong University, Shanghai Jiao Tong University, and Peking University. In addition, there are several contributions from the Shanghai Cancer Institute and from BGI Shenzhen life sciences company (formerly Beijing Genomics Institute).

4.2.8 Health sciences

The analysis of Sino-Norwegian collaboration in this area of research is based on 1,797 articles published 2001-2021. Of these, 375 are based on bilateral collaboration. In 291 articles with trilateral collaboration, USA, UK, Sweden, Denmark, Australia, and Canada are the six most frequent third partners. Germany replaces Denmark among the six most frequent partners in 1,131 articles with multilateral collaboration, which is the dominating type of Sino-Norwegian collaboration in this area of research.

The most frequent journals that have published articles from Sino-Norwegian collaboration in the health sciences are listed in *Figure 4.12*. Prestigious general journals dominate, which is as expected in studies based on multilateral collaboration in the health sciences. Oncology is the dominating subdiscipline.

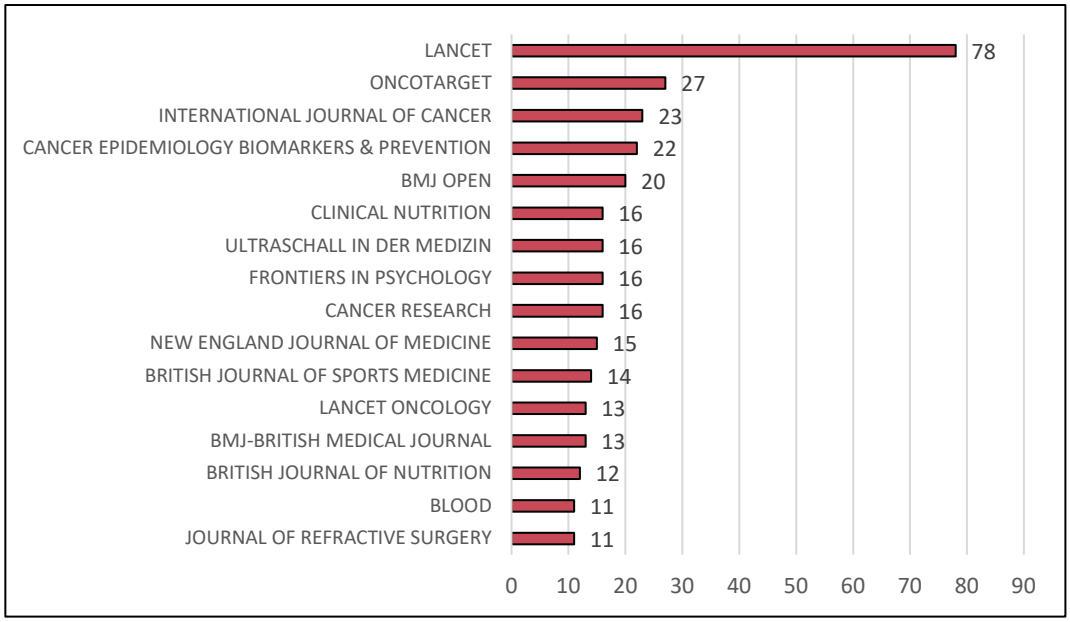

Figure 4.12. The journals that most frequently published articles with Sino-Norwegian collaboration 2001-2021 in Health sciences.

Again, as in biomedicine, the major actors on the Norwegian side are the university hospitals and universities in Oslo, Bergen, Trondheim, and Tromsø. The hospitals in Stavanger and Lillehammer also contribute. In addition, the Cancer Registry of Norway and the Norwegian School of Sports Sciences are active.

Major partners on the Chinese side are the Medical Schools and the affiliated hospitals of Zhengzhou University, Nanjing Medical University, Shandong University, Shanghai Jiao Tong University, Sichuan University, Fudan University, and University of Hong Kong. In addition, there are several contributions from the Chinese Center for Disease Control and Prevention.

4.2.9 Social sciences and humanities

The analysis of Sino-Norwegian collaboration in these areas of research is based on 467 articles published 2001-2021. Of these, 175 are based on bilateral collaboration. In 151 articles with trilateral collaboration, USA, UK, Israel, Australia, Canada, and the Netherlands are the six most frequent third partners. Germany replaces Israel among the six most frequent partners in 141 articles with multilateral collaboration.

The social sciences and humanities (SSH) are wide areas of research represented with only a limited number of articles in this report. One reason is that Web of Science has limited coverage of scholarly publishing in these areas (Aksnes & Sivertsen, 2019). We also saw in Figure 4.2 above that the relative activity of China is low in the SSH, at least as measured within Web of Science. The relative activity for Norway is much higher but seems not to be prioritized in the Sino-Norwegian relation.

To solve the problem with few articles representing two wide areas of research, we will, instead of presenting just one list of journals, name a few journals per discipline within the SSH. We present the disciplines in descending order of articles in our data and concentrate on those with at least fifteen articles.

Business and Economics dominate in our data with 280 articles. The most frequent journals are INTERNATIONAL JOURNAL OF PROJECT MANAGEMENT, PROJECT MANAGEMENT JOURNAL, and ENERGY POLICY.

Education & Educational Research is also frequent with 46 articles. Most frequent are SCANDINAVIAN JOURNAL OF EDUCATIONAL RESEARCH, INTERNATIONAL JOURNAL OF SCIENCE AND MATHEMATICS EDUCATION, and HIGHER EDUCATION POLICY.

Public Administration is represented with 41 articles. The most frequent journals are TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE, INTERNATIONAL REVIEW OF ADMINISTRATIVE SCIENCES, INTERNATIONAL PUBLIC MANAGEMENT JOURNAL, and HABITAT INTERNATIONAL.

Psychology is represented with 26 articles. The most frequent journals are JOURNAL OF HAPPINESS STUDIES, JOURNAL OF ORGANIZATIONAL BEHAVIOR, PERSONNEL PSYCHOLOGY, APPLIED PSYCHOLOGICAL MEASUREMENT, and ARCHIVES OF SEXUAL BEHAVIOR.

Geography is represented with 21 articles. The most frequent journals are GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS, INTERNATIONAL JOURNAL OF GEOGRAPHICAL INFORMATION SCIENCE, TRANSACTIONS IN GIS, and EUROPEAN PLANNING STUDIES.

Information Science & Library Science is represented with 15 articles. The most frequent journals are JOURNAL OF KNOWLEDGE MANAGEMENT, SCIENTOMETRICS, and JOURNAL OF GEOGRAPHICAL INFORMATION SCIENCE.

The main actors on the Norwegian side of Sino-Norwegian collaboration in the SSH are University of Oslo, Norwegian University of Science & Technology, BI Norwegian Business School (BI), University of Stavanger, University of Bergen, University of Agder, Norwegian School of Economics (NHH), CICERO - Center for International Climate Research, Oslo Metropolitan University, and Nordic Institute for Studies in Innovation, Research and Education (NIFU).

The main actors on the Chinese side are City University of Hong Kong, Tsinghua University, Zhejiang University, Renmin University, University of Hong Kong, Chinese University of Hong Kong, Beijing Normal University, and Wuhan University.

4.3 Summary

By using three criteria to assess the relative importance of an area of research in Sino-Norwegian scientific collaboration, we could rank them in this order:

1. Environmental sciences
2. Technology
3. Computer science
4. Physics and Chemistry
5. Biology
6. Biomedicine and Health Sciences
7. Social Sciences and Humanities

We find three fields of research under the umbrella Environmental sciences which stand out with high collaboration activity that seems to be organized and supported in mutual interest between the most important institutions on both sides: 1) environmental sciences based on geophysical research, particularly in climate research, 2) marine science and engineering, and 3) hydrological engineering.

Technology and computer science reflect the priorities and strengths in the research profile of China as compared to the rest of the world. There is a Norwegian 'mark' on what seems to be the common interests in these areas of research:

marine engineering, materials science, and environmental engineering within technology, and telecommunications within computer science.

Chinese science is traditionally strong in the physical sciences, less strong in the life sciences. The strengths of China are mirrored in the collaboration with Norway. There is much collaboration in physics and astrophysics, but this interaction is mostly mediated by multilateral collaboration, e.g., in high energy physics. Bilateral collaboration is relatively more important in chemistry where we observe a focus on materials science and physical chemistry.

Biology includes the sciences of bioproduction in our analysis. The activity in the Sino-Norwegian relation is not high, but the profile in biology is clearly focussed on the characteristic Norwegian orientation: Marine biology and fisheries research.

In most of the areas of research mentioned so far, the universities play a major role on the Norwegian side, but the research institutes are also important in some fields of research. As we turn to biomedicine and the health sciences, the Norwegian hospitals are also active collaboration partners. However, a large part of this collaboration with China is mediated by multilateral consortia and projects. Also, the strengths of Norwegian research in these areas are not mirrored in China.

The social sciences and humanities are areas of research without much collaboration between China and Norway. China is less active than Norway in journals covering these areas in Web of Science. The collaboration with Norway is dominated by studies in business and economics.

5 Norway's relations with South Korea

A total of 2,842 scientific articles were published and indexed in Web of Science in 2001-2022 with authors' addresses in both South Korea and Norway. Half of the articles were published during the last five years 2018-2022.

Other countries than South Korea and Norway are involved in almost 90 percent of the articles. We will distinguish between articles with four types of collaboration:

– *Bilateral:* Only Norway and South Korea are involved (280 articles)
– *Trilateral:* A third country is involved as well (469 articles)
– *Multilateral:* Two or more other countries are involved (972 articles)
– *Global:* More than 30 addresses in a high number of countries (1,112 articles)

The latter type with global collaboration will be excluded in most of the analysis to better characterize scientific collaboration between the two countries. To indicate the research profile of the articles with global collaboration, Figure 5.1 shows the most frequent journals they are published in.

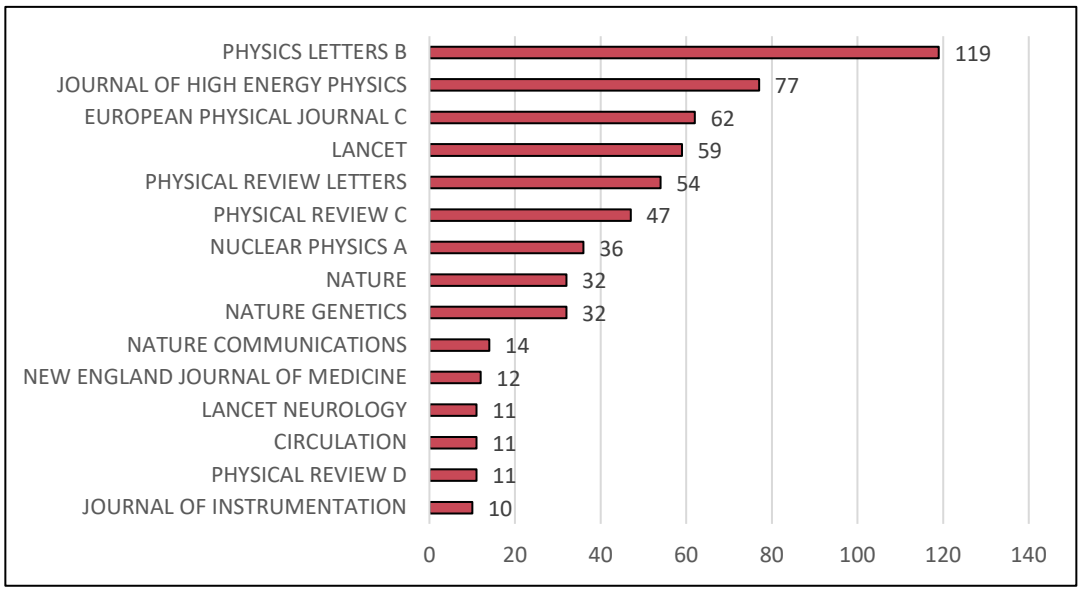

Figure 5.1. The most frequent journals publishing articles based on global collaboration in which South Korea and Norway contribute together.

The profile of articles with global collaboration is dominated by the main outlets from the large multinational facilities for nuclear physics and astrophysics, and from medical research based on global multicentre organization.

5.1 Nine main areas of research

As introduced in section 1.2.2, we separate between nine main areas of research based on a classification of journals: Biology, Biomedicine, Chemistry, Computer Science, Environmental Sciences, Health Sciences, Physics, Social Sciences and Humanities (SSH), and Technology.

Within each area of research and type of collaboration, we will identify the institutions that most frequently collaborate in each of the countries. The most frequently used journals or subject category of journals in each area of research will be listed to indicate the active fields of research more specifically.

After allowing for double counting when classifying the articles by main area of research, the sum of analysed articles increases by 25 percent to 3,542. Within this number, the categories have different sizes, as shown in *Figure 5.2* where we also distinguish between the four types of collaboration.

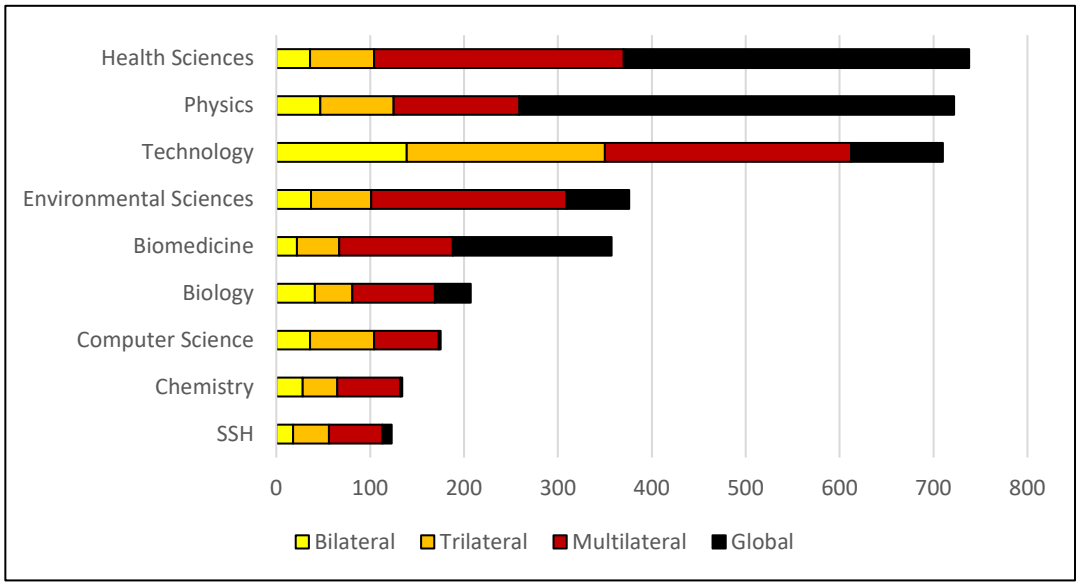

Figure 5.2. The number in articles with Korean-Norwegian collaboration 2001-2022 in each of nine categories and with a distinction between three types of collaboration at country level.

Collaboration in Physics and the Health Sciences is mostly driven by participation in multinational and global collaboration. Technology and Computer Science represent main areas with relatively more bilateral and trilateral collaboration. Collaboration in these areas may to a higher degree reflect a specific mutual interest between Korean and Norwegian researchers and their institutions.

5.2 Research profiles

Korean-Norwegian collaboration in science has a distinct profile when compared to the two countries' general research profiles. In *Figure 5.3* below, all the years 2001-2022 are included to make visible the distinct profile of Korean-Norwegian collaboration, as shown in yellow.

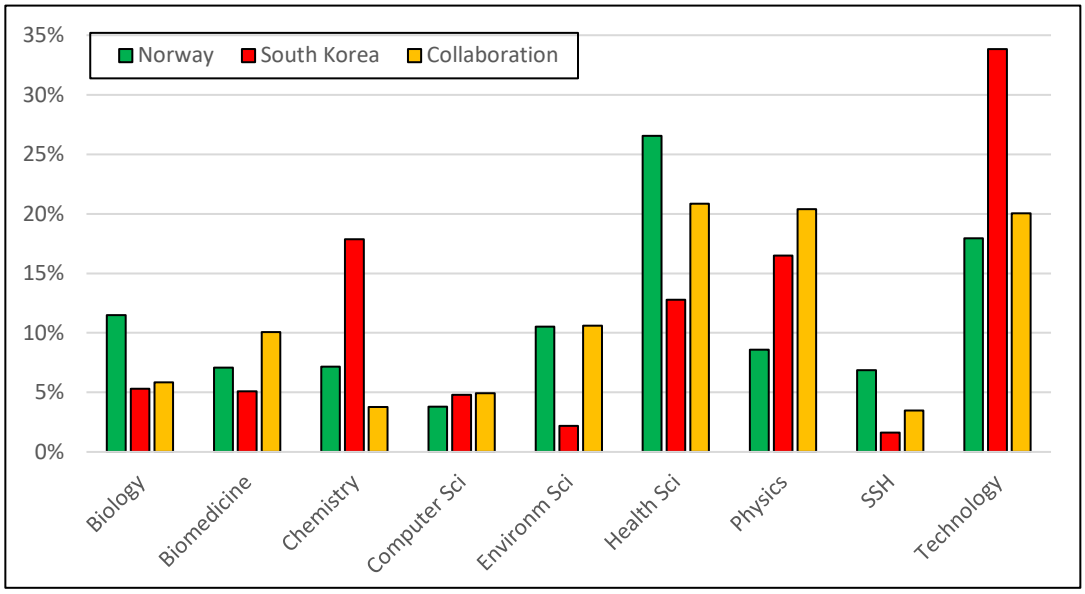

Figure 5.3. The shares of articles with Korean-Norwegian collaboration 2001-2022 in each of nine categories (in yellow) compared to the similar distribution when all articles from each of the countries in the same period are considered.

Chemistry stands out as a major area of research where there is less collaboration than could be expected from the relative activity in each of the countries. The opposite is the case for Physics, Biomedicine, and Computer Science, where there is more collaboration than expected from the perspective of both countries. There is high collaboration activity in the Environmental Sciences, the Health Sciences, and Social Sciences and Humanities, which are strong in Norway's profile, and in Technology, which is strong in South Korea's profile. Collaboration in Biology is not influenced by high activity in Norway.

When combining Figures 5.2 and 5.3, we observe that Environmental Sciences, Technology, and Computer Science are the areas of research with high relative collaboration intensity within mainly the bilateral and trilateral types of collaboration. Below, we will present the areas of research in an order of importance according to these criteria.

Figure 5.4 shows that collaborations in Technology and Computer Science have had the sharpest increases recently. Health Sciences, Physics, and Environmental Sciences have had more stable increases during the last decade to dominate the

collaboration profile. What seems to be decreases in 2022 are due to the delay of indexing in *Web of Science.*

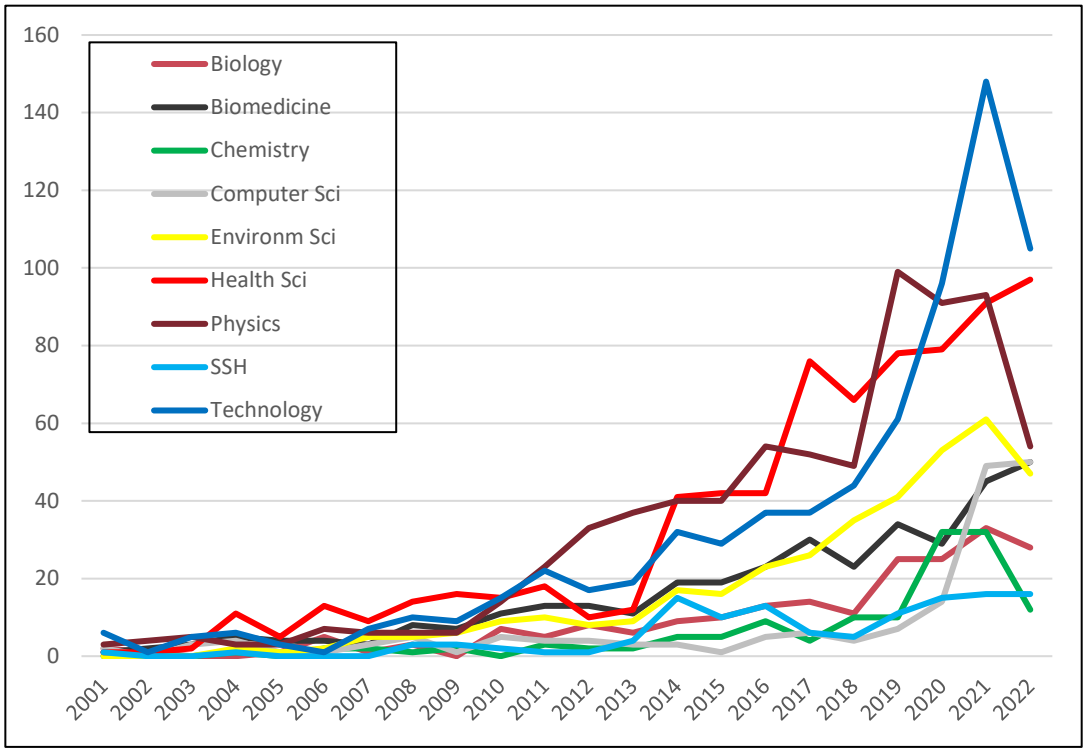

Figure 5.4. Number of articles with Korean-Norwegian collaboration 2001-2022 in nine major areas of research.

5.2.1 Contributing research sectors on the Norwegian side

Figure 5.5 shows the shares of four Norwegian research sectors in the contributions to collaboration with South Korea in each area of research. Articles with global collaboration are not included in this analysis.

The universities and other higher education institutions in Norway are the most frequent Norwegian partners in published research from Korean-Norwegian collaboration. The independent research institutes are also active in the collaboration, particularly in Biology, Environmental Sciences, and Social Sciences and Humanities. The contribution of research in the health sector is, as expected, significant in Biomedicine and the Health Sciences. There are small contributions from the corporate sector in all areas of research. But the contribution of this sector to research collaboration might be underestimated in our data since this sector's research is often not published.

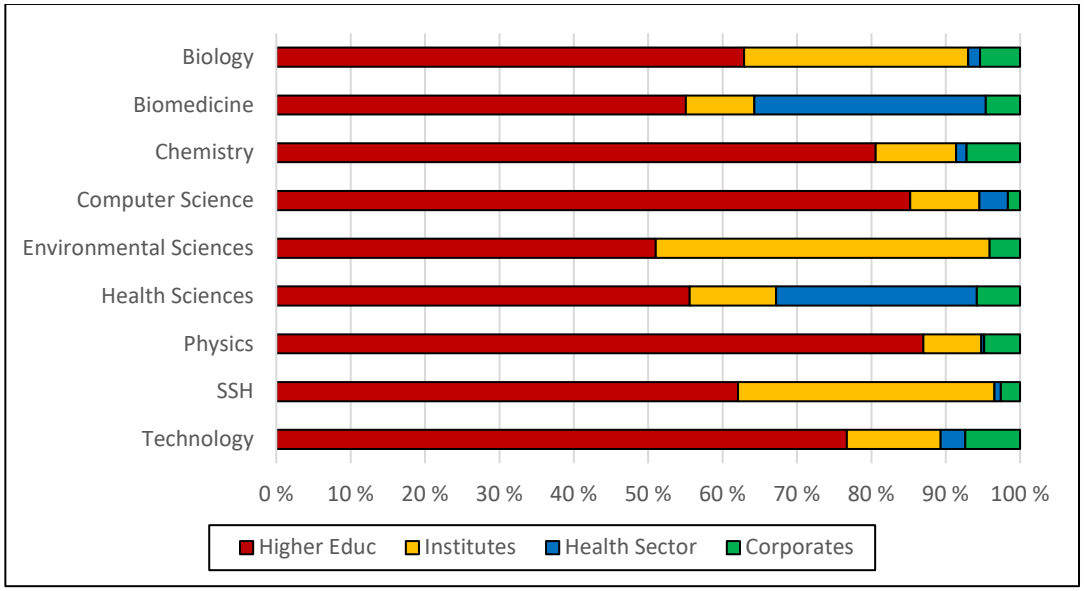

Figure 5.5. Articles with Korean-Norwegian collaboration 2001-2022 in nine major areas of research. Shares between four sectors of research on the Norwegian side.

5.3 Collaboration in nine major areas of research

In the following, we will have a closer look at the most frequent collaborating institutions in South Korea and Norway and the research profile of the collaboration in each of the nine major areas of research. We present the areas of research in the order of relative importance for the bilateral relation as found in the analysis above. The underlying data represent 1,730 scientific articles with author addresses in both South Korea and Norway that were published 2001-2022. Articles with global collaboration are not included.

5.3.1 Technology

A total of 710 articles were published in 2001-2022 with Korean-Norwegian collaboration in Technology. Of these, 139 are based on bilateral collaboration. In 211 articles with trilateral collaboration, USA, India, Pakistan, and China are the most frequent third partners. UK and Germany replace Pakistan among the most frequent partners in 262 articles with multilateral collaboration. 98 articles with global collaboration are not included in the further analysis.

The distribution of the collaboration articles by subcategories of journals in Technology is shown in *Figure 5.6*. The subcategory *Science & Technology – General* represents articles in general journals such as *Nature*, *Science*, *Nature Communications*, *Scientific Reports* and *PLOS One*.

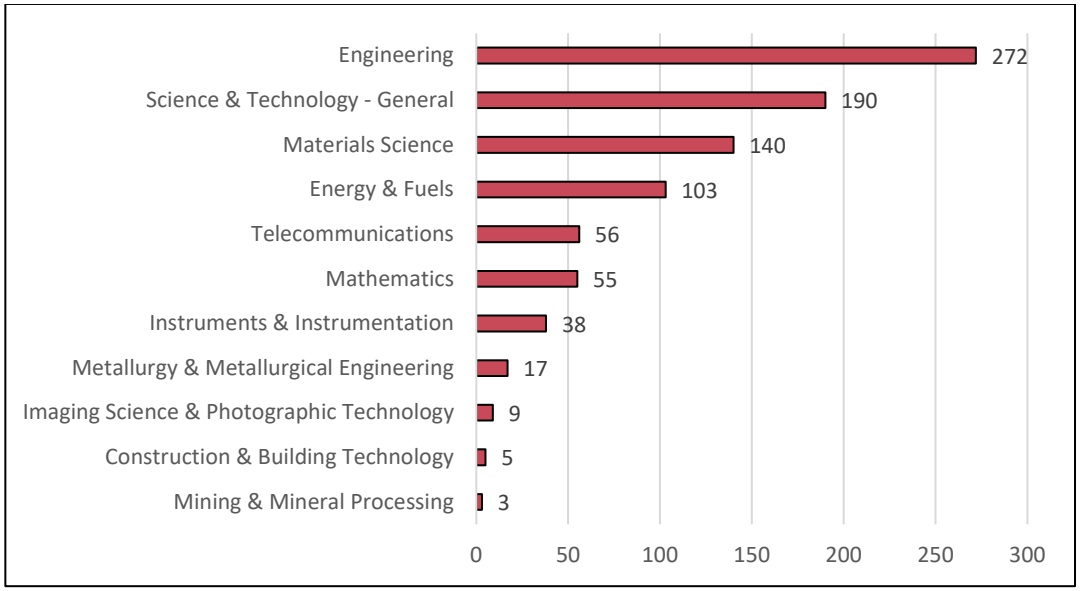

Figure 5.6. Korean-Norwegian collaboration 2001-2022 by subcategories in Technology.

The major partners on the Norwegian side are the Norwegian University of Science and Technology (NTNU), University of Oslo, University of Stavanger, and Western Norway University of Applied Sciences. SINTEF, Bjerknes Centre for Climate Research, Norwegian Geotechnical Institute (NGI), and Simula Research Laboratory are the most active among the institutes. The main corporate actors are Equinor and DNV GL.

The major collaborating institutions in South Korea are listed in *Figure 5.7*.

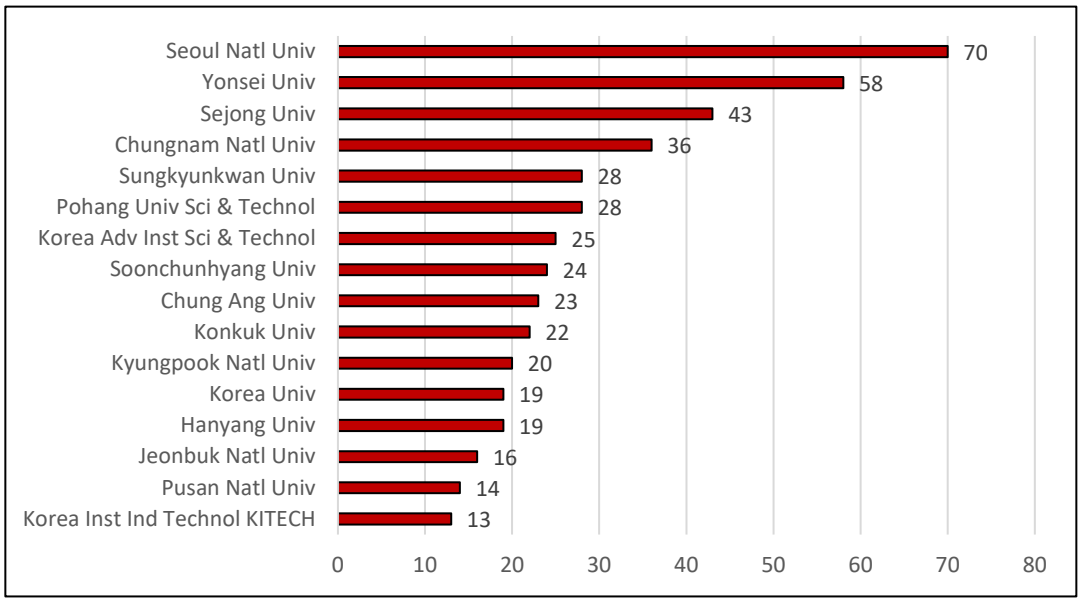

Figure 5.7. The Korean institutions that most frequently collaborate in Technology.

5.3.2 Environmental Sciences

A total of 376 articles were published in 2001-2022 with Korean-Norwegian collaboration in Environmental Sciences. Of these, 37 are based on bilateral collaboration. In 64 articles with trilateral collaboration, USA (24 articles), China (8), and Germany (7) are the most frequent third partners. USA, UK, Germany, and Japan are the most frequent partners in 208 articles with multilateral collaboration. 67 articles with global collaboration are not included in the further analysis.

The distribution of the collaboration articles by subcategories in Environmental Sciences is shown in *Figure 5.8*.

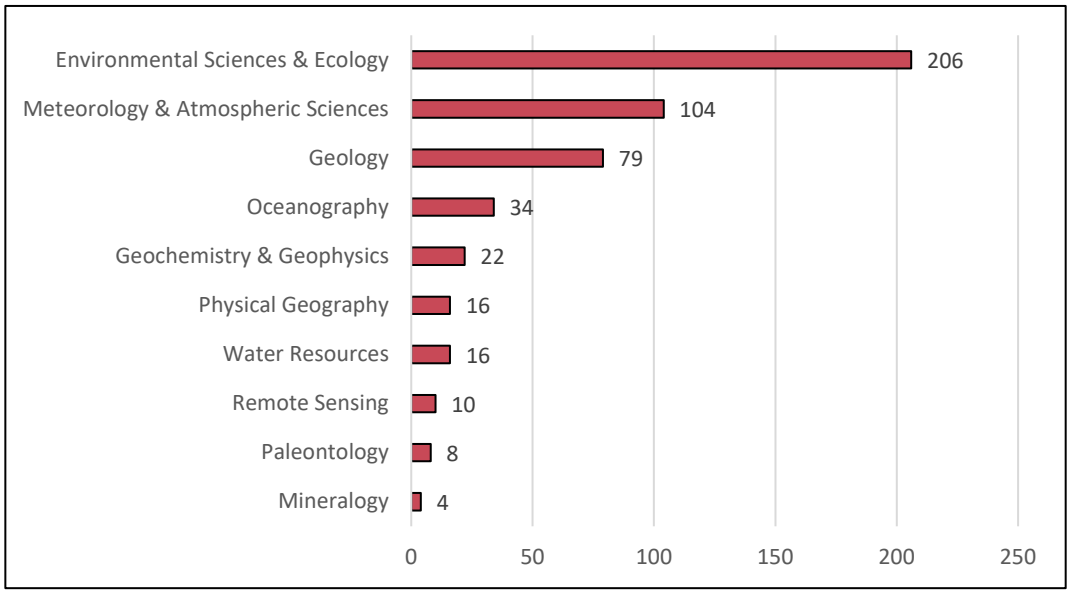

Figure 5.8. Korean-Norwegian collaboration 2001-2022 by subcategories in Environmental Sciences.

The major partners on the Norwegian side are University of Oslo, Norwegian Institute for Air Research (NILU), and Bjerknes Centre for Climate Research. The most active other universities are Norwegian University of Science and Technology (NTNU), UiT Arctic University of Norway, and University of Bergen. Other active institutes are Norwegian Meteorological Institute, Norwegian Polar Institute, and Institute for Marine Research.

The major collaborating institutions in South Korea are listed in *Figure 5.9*.

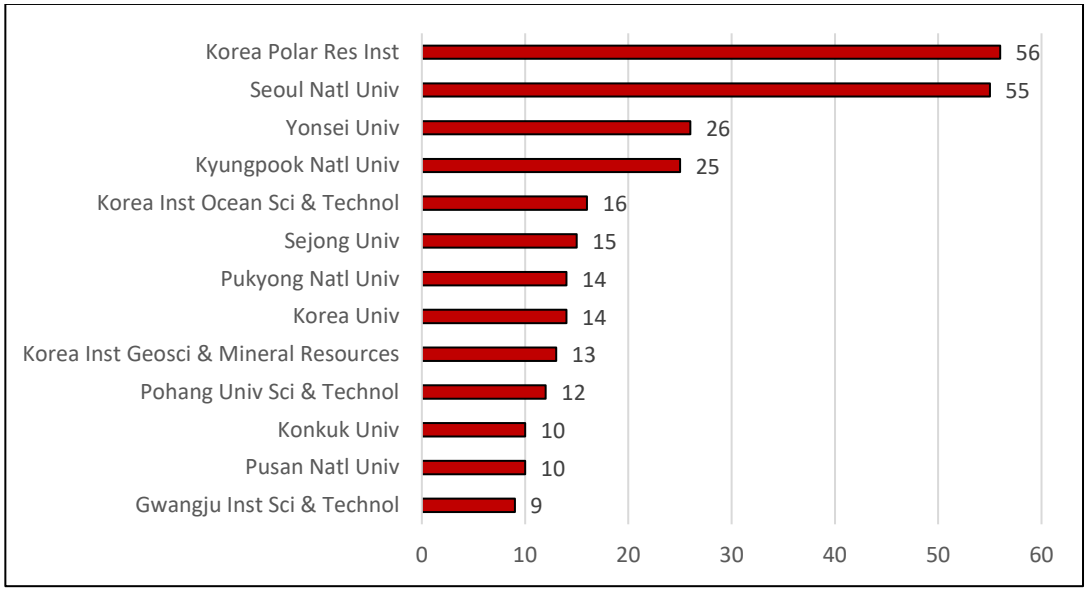

Figure 5.9. The Korean institutions that most frequently collaborate in Environmental Sciences.

5.3.3 Computer Science

A total of 175 articles were published in 2001-2022 with Korean-Norwegian collaboration in Computer Science. Of these, 36 are based on bilateral collaboration. In 68 articles with trilateral collaboration, Pakistan (15 articles), India (14), and Canada (8) are the most frequent third partners. Pakistan, USA, and China are the most frequent partners in 69 articles with multilateral collaboration. 2 articles with global collaboration are not included in the further analysis.

Most articles in Computer Science are only in one subcategory. To indicate the research orientations, we instead show the most frequent journals in *Figure 5.10*.

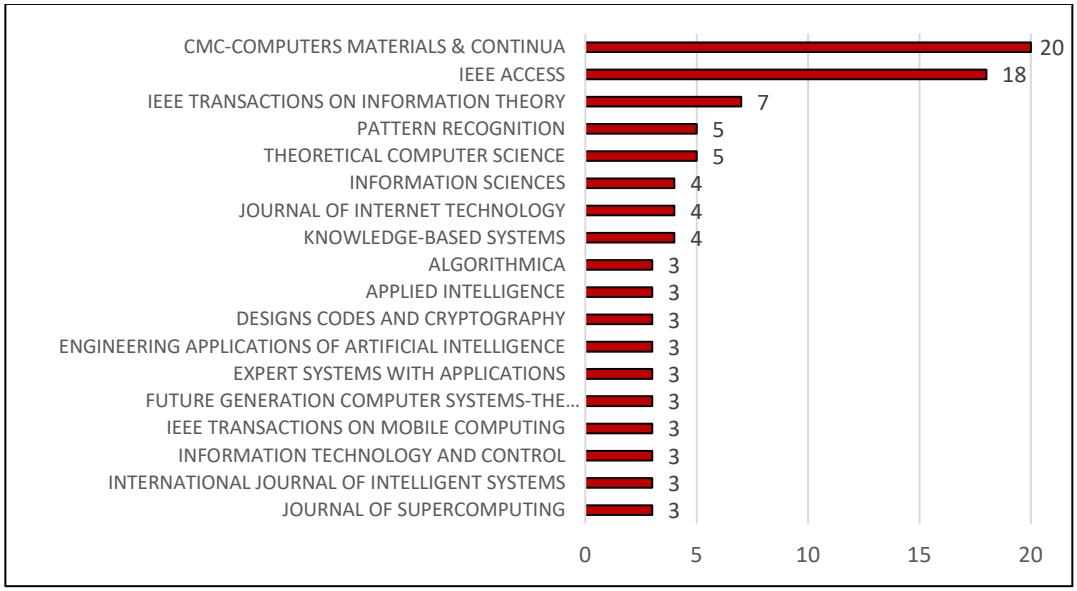

Figure 5.10. Korean-Norwegian collaboration 2001-2022: The most frequent journals in Computer Science.

The major partners on the Norwegian side are Noroff School of Technology and Digital Media, Norwegian University of Science and Technology (NTNU), Western Norway University of Applied Sciences, University of Oslo, and University of Bergen. Western Norway Research Institute and Simula Research Lab are most frequent among the institutes.

The major collaborating institutions in South Korea are listed in *Figure 5.11*.

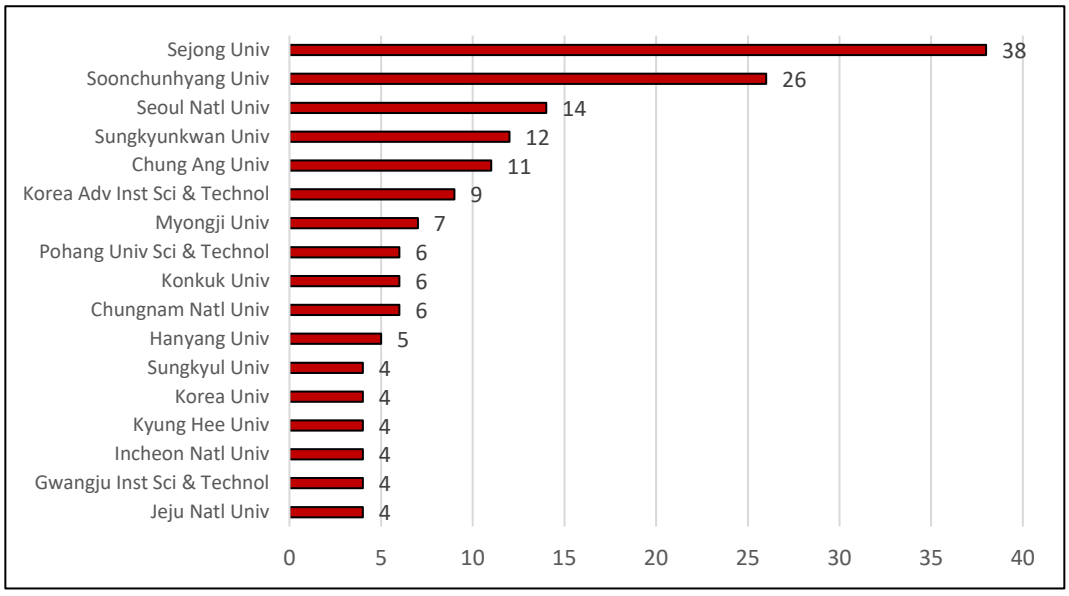

Figure 5.11. The Korean institutions that most frequently collaborate in Computer Science.

5.3.4 Physics

A total of 722 articles were published in 2001-2022 with Korean-Norwegian collaboration in Computer Science. Of these, only 47 are based on bilateral collaboration. In 78 articles with trilateral collaboration, India (23 articles), USA (9), Russia (8), China (6) and France (6) are the most frequent third partners. Germany, USA, UK, China, and France are the most frequent partners in 134 articles with multilateral collaboration. 463 articles with global collaboration are not included in the further analysis.

Most of the articles in Physics are in only two subcategories, Physics (621) and Astronomy & Astrophysics (204). To indicate the research orientations, we instead show the most frequent journals in *Figure 5.12*. Even with the exclusion of articles with global collaboration, the profile is influenced by the large multinational infrastructures for research in nuclear physics and in astrophysics.

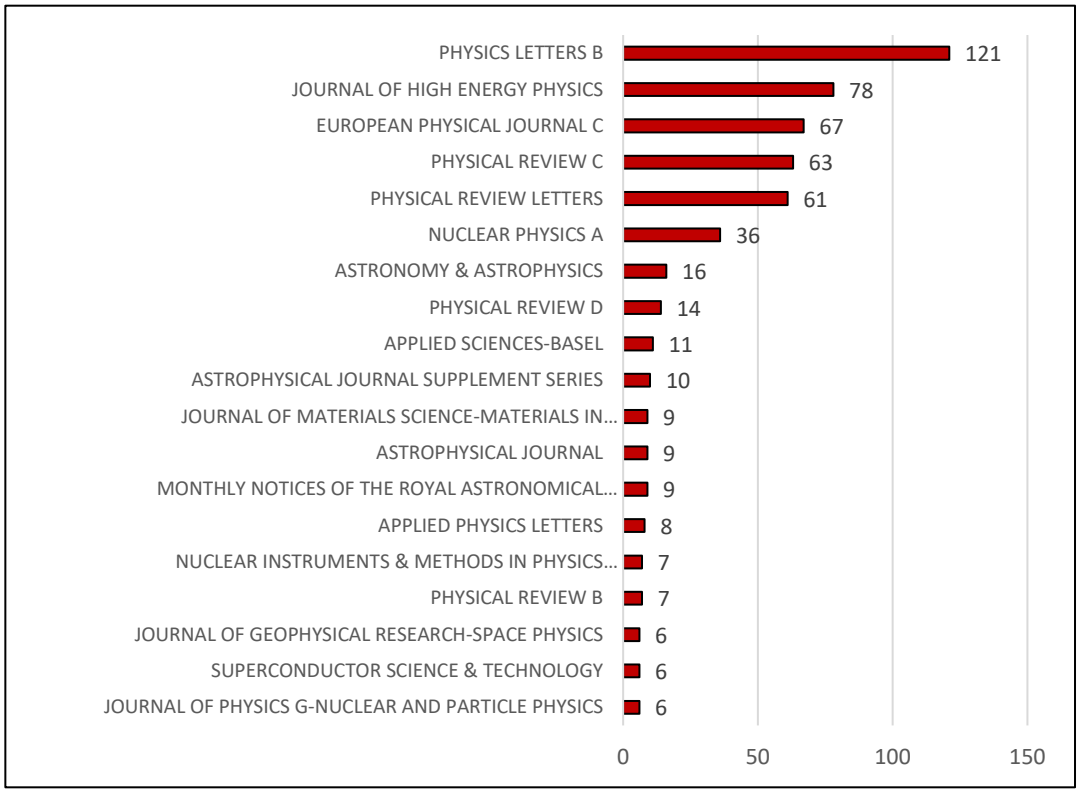

Figure 5.12. Korean-Norwegian collaboration 2001-2022: The most frequent journals in Physics.

The major partners on the Norwegian side are University of Oslo, Norwegian University of Science and Technology (NTNU), Western Norway University of Applied Sciences, and University of Bergen. Institute for Energy Technology and SINTEF are most frequent among the institutes.

The major collaborating institutions in South Korea are listed in *Figure 5.13*.

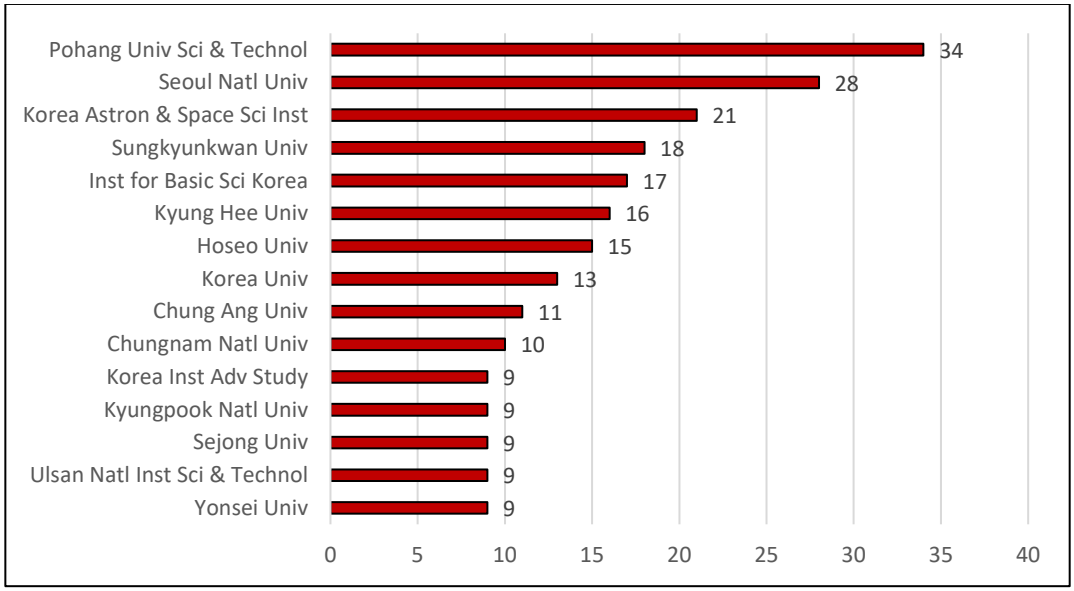

Figure 5.13. The Korean institutions that most frequently collaborate in Physics.

5.3.5 Health Sciences

A total of 736 articles were published in 2001-2022 with Korean-Norwegian collaboration in Health Sciences. Of these, only 36 are based on bilateral collaboration. In 68 articles with trilateral collaboration, USA (52 articles), Australia (4), and Denmark (3) are the most frequent third partners. USA, UK, Australia, and Japan are the most frequent partners in 266 articles with multilateral collaboration. 368 articles with global collaboration are not included in the further analysis.

The most frequent subcategories of journals are shown in *Figure 5.14*.

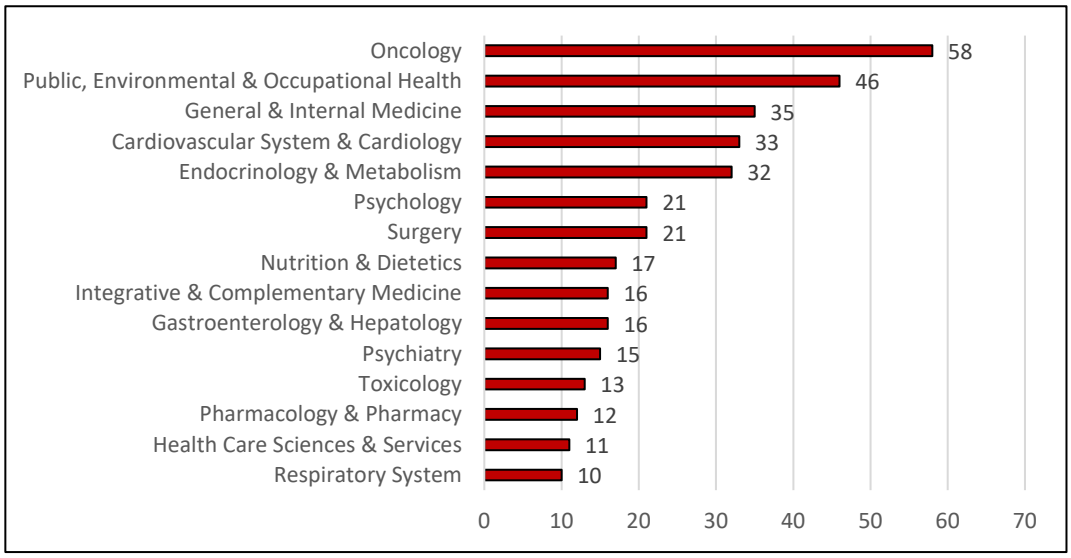

Figure 5.14. Korean-Norwegian collaboration 2001-2022: The most frequent journal subcategories in Health Sciences.

The major partners on the Norwegian side are University of Oslo, Oslo University Hospital, UiT Arctic University of Norway, and University of Bergen. The Norwegian Institute for Public Health is the main actor among the institutes while Laerdal Medical contributes from the corporate sector.

The major collaborating institutions in South Korea are listed in *Figure 5.15*.

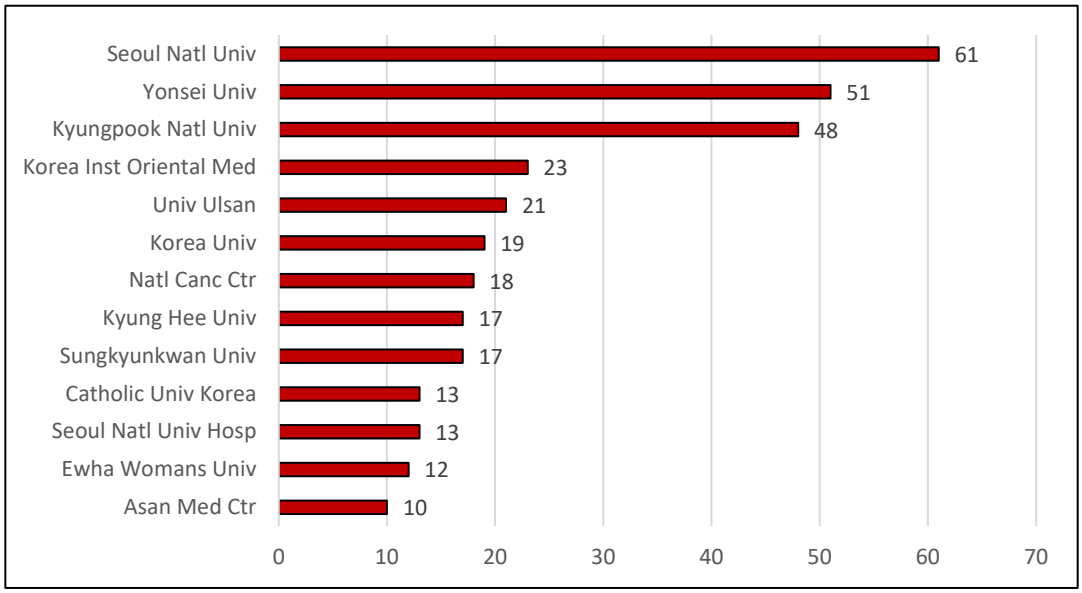

Figure 5.15. The Korean institutions that most frequently collaborate in Health Sciences.

5.3.6 Biomedicine

A total of 357 articles were published in 2001-2022 with Korean-Norwegian collaboration in Biomedicine. Of these, only 22 are based on bilateral collaboration. In 45 articles with trilateral collaboration, USA (30 articles), Sweden (2), and Japan (3) are the most frequent third partners. USA, Germany, UK, Canada, and France are the most frequent partners in 121 articles with multilateral collaboration. 169 articles with global collaboration are not included in the further analysis.

The most frequent subcategories of journals are shown in *Figure 5.16*.

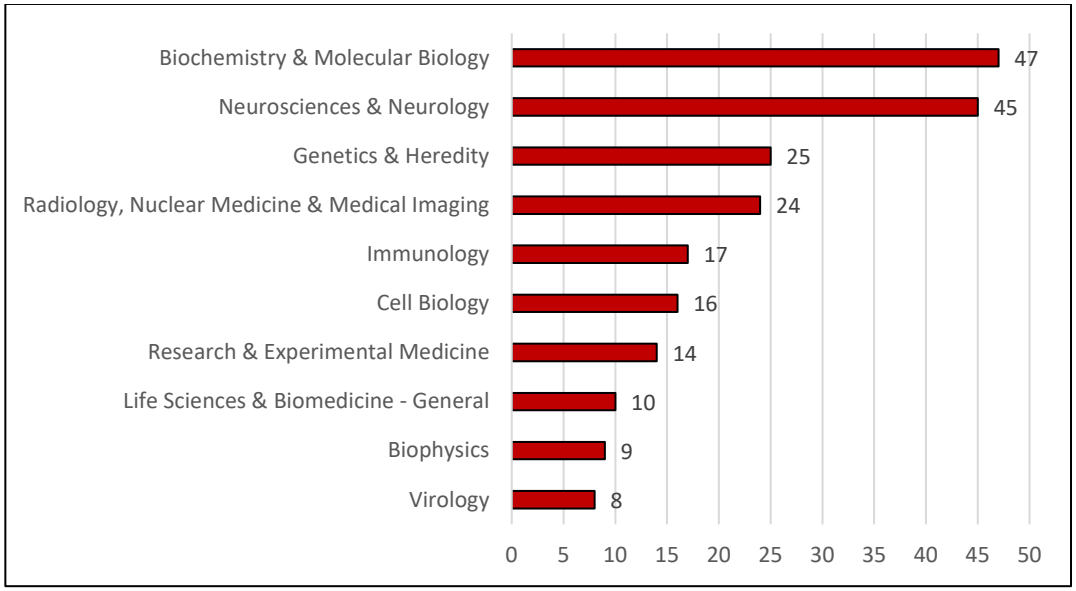

Figure 5.16. Korean-Norwegian collaboration 2001-2022: The most frequent journal subcategories in Biomedicine.

The major partners on the Norwegian side are University of Oslo, Oslo University Hospital, Norwegian University of Science and Technology (NTNU), and University of Bergen.

The major collaborating institutions in South Korea are listed in *Figure 5.17*.

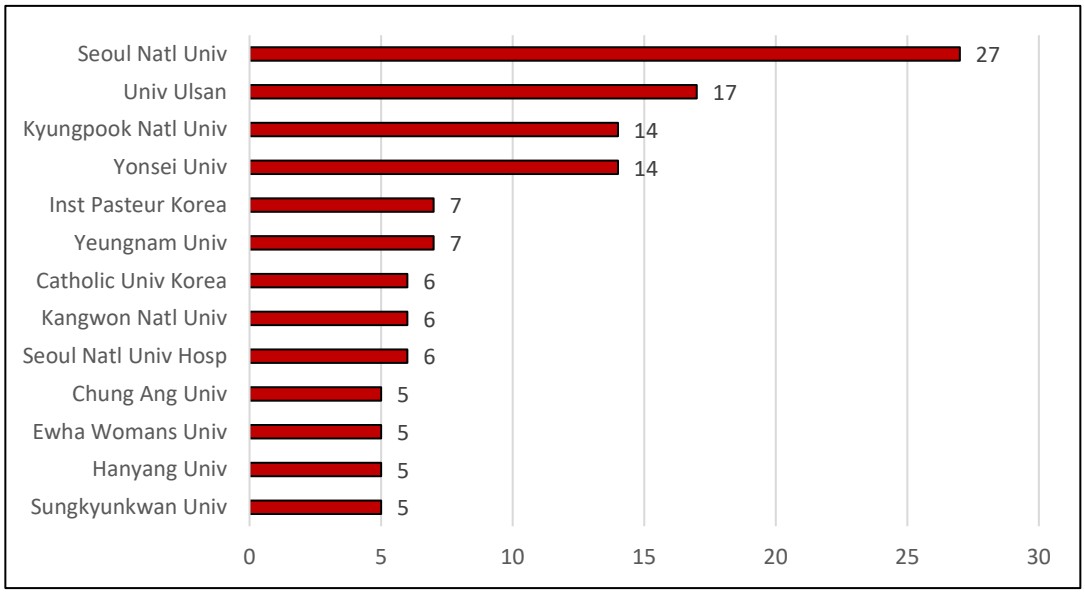

Figure 5.17. The Korean institutions that most frequently collaborate in Biomedicine.

5.3.7 Biology

A total of 207 articles were published in 2001-2022 with Korean-Norwegian collaboration in Biology. Of these, 41 are based on bilateral collaboration. In 40 articles with trilateral collaboration, USA (14 articles), India (6), and UK (5) are the most frequent third partners. USA, Germany, UK, Japan, and Australia are the most frequent partners in 88 articles with multilateral collaboration. 38 articles with global collaboration are not included in the further analysis.

The most frequent subcategories of journals are shown in *Figure 5.18*.

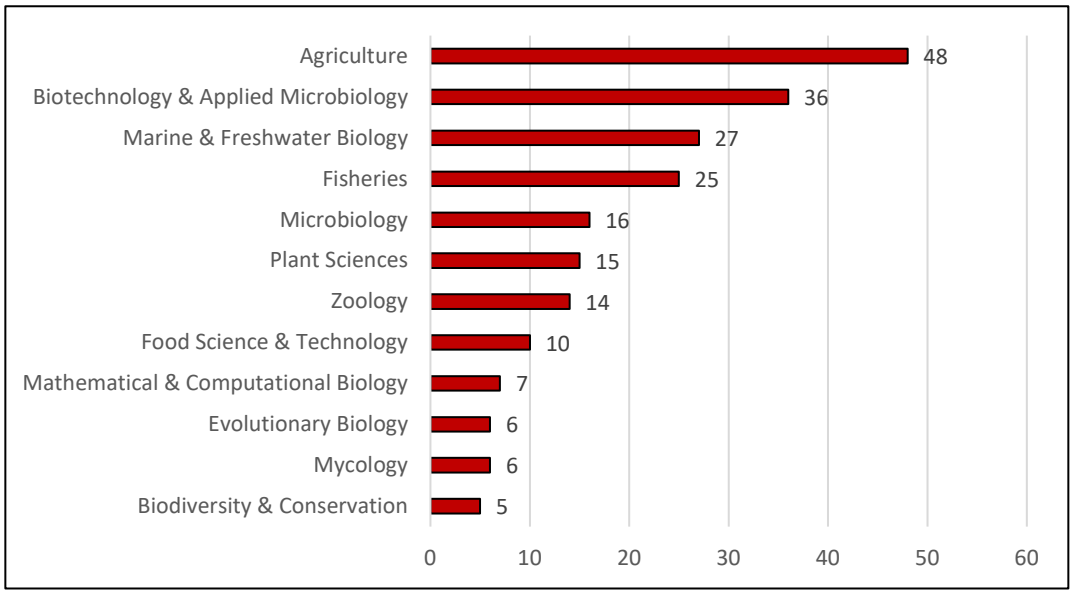

Figure 5.18. Korean-Norwegian collaboration 2001-2022: The most frequent journal subcategories in Biology.

The major partners on the Norwegian side are University of Stavanger, UiT Arctic University of Norway, University of Oslo, University of Bergen, and Norwegian University of Science and Technology (NTNU). The most active institutes are Institute for Marine Research and Norwegian Institute of Bioeconomy Research.

The major collaborating institutions in South Korea are listed in *Figure 5.19*.

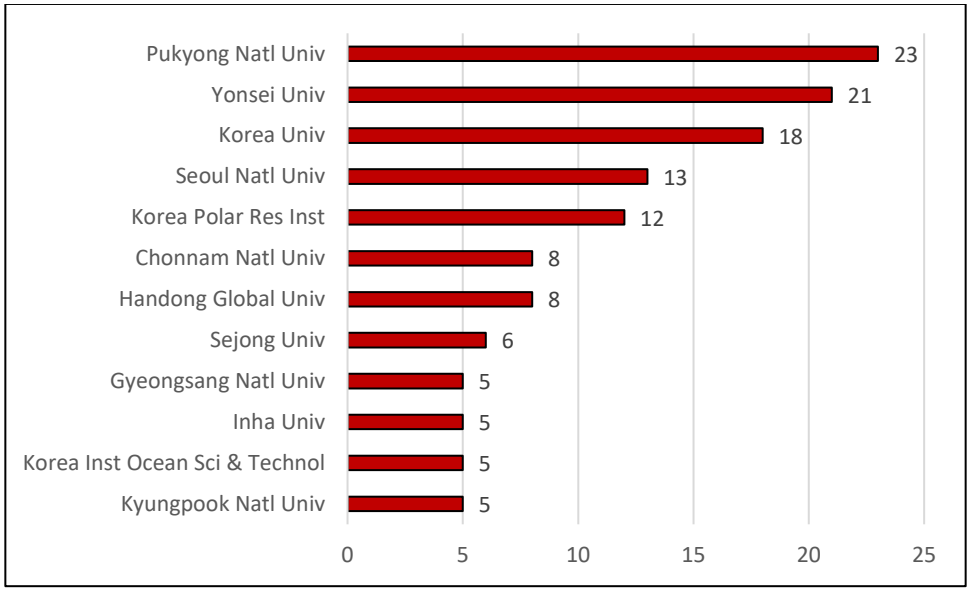

Figure 5.19. The Korean institutions that most frequently collaborate in Biology.

5.3.8 Chemistry

A total of 134 articles were published in 2001-2022 with Korean-Norwegian collaboration in Chemistry. Of these, 28 are based on bilateral collaboration. In 37 articles with trilateral collaboration, India (11 articles), USA (6), and Pakistan (4) are the most frequent third partners. India, USA, Germany, and China are the most frequent partners in 67 articles with multilateral collaboration. 2 articles with global collaboration are not included in the further analysis.

The most frequent journals are shown in *Figure 5.20*.

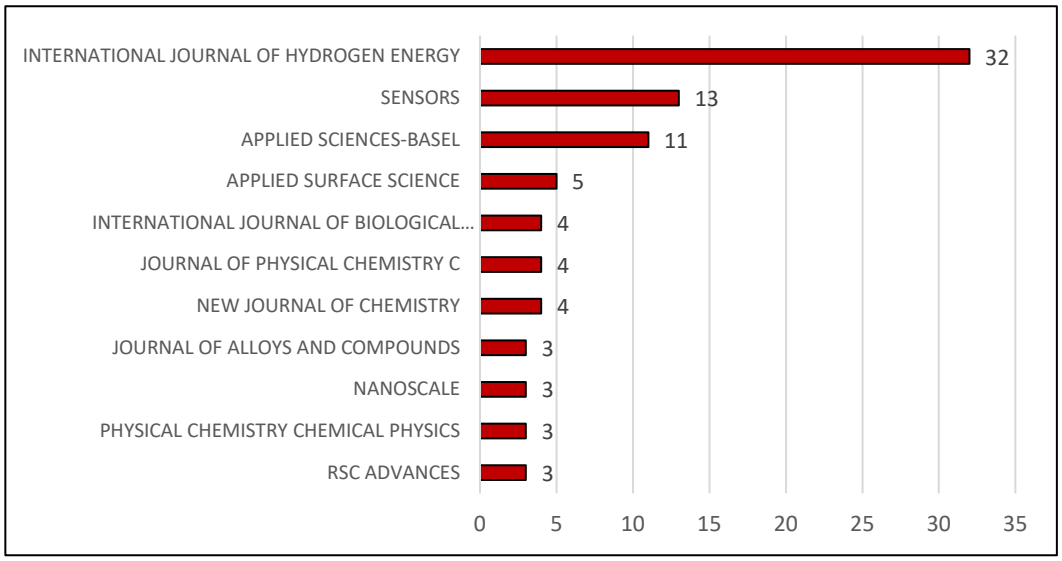

Figure 5.20. Korean-Norwegian collaboration 2001-2022: The most frequent journals in Chemistry.

The major partners on the Norwegian side are Norwegian University of Science and Technology (NTNU), University of Oslo, University of Stavanger, and Western Norway University of Applied Sciences. The most active institutes are SINTEF and Institute for Energy Technology.

The major collaborating institutions in South Korea are listed in *Figure 5.21*.

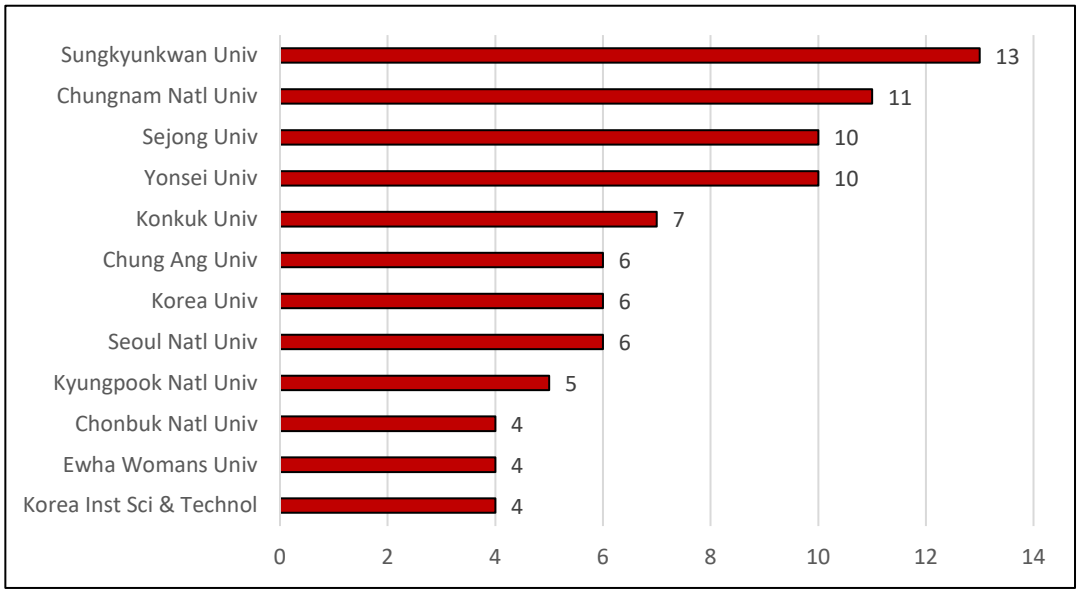

Figure 5.21. The Korean institutions that most frequently collaborate in Chemistry.

5.3.9 Social sciences and humanities

A total of 123 articles were published in 2001-2022 with Korean-Norwegian collaboration in the Social Sciences and Humanities. Of these, 18 are based on bilateral collaboration. In 38 articles with trilateral collaboration, USA (17 articles), UK (7), and China (6) are the most frequent third partners. The same three countries are the most frequent partners in 57 articles with multilateral collaboration. 10 articles with global collaboration are not included in the further analysis.

The most frequent journal categories are shown in *Figure 5.22*.

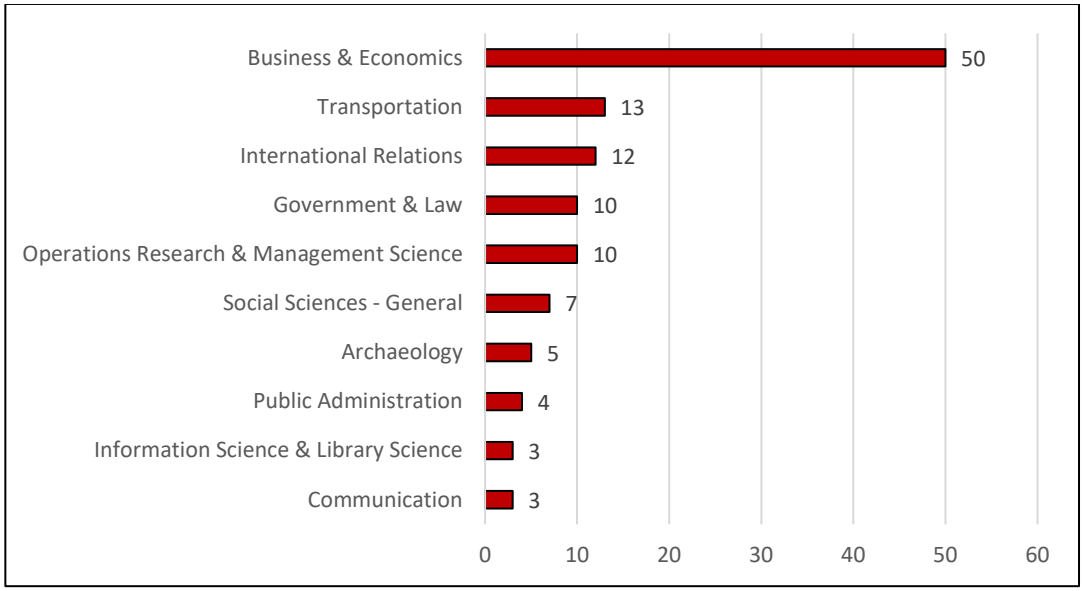

Figure 5.22. Korean-Norwegian collaboration 2001-2022: The most frequent journal categories in Social Sciences and Humanities.

The major partners on the Norwegian side are Norwegian University of Science and Technology (NTNU), University of Oslo, UiT Arctic University of Norway, Norwegian School of Economics, and BI Norwegian Business School. The most active institute is Norwegian Institute of Bioeconomy Research.

The major collaborating institutions in South Korea are listed in *Figure 5.23*.

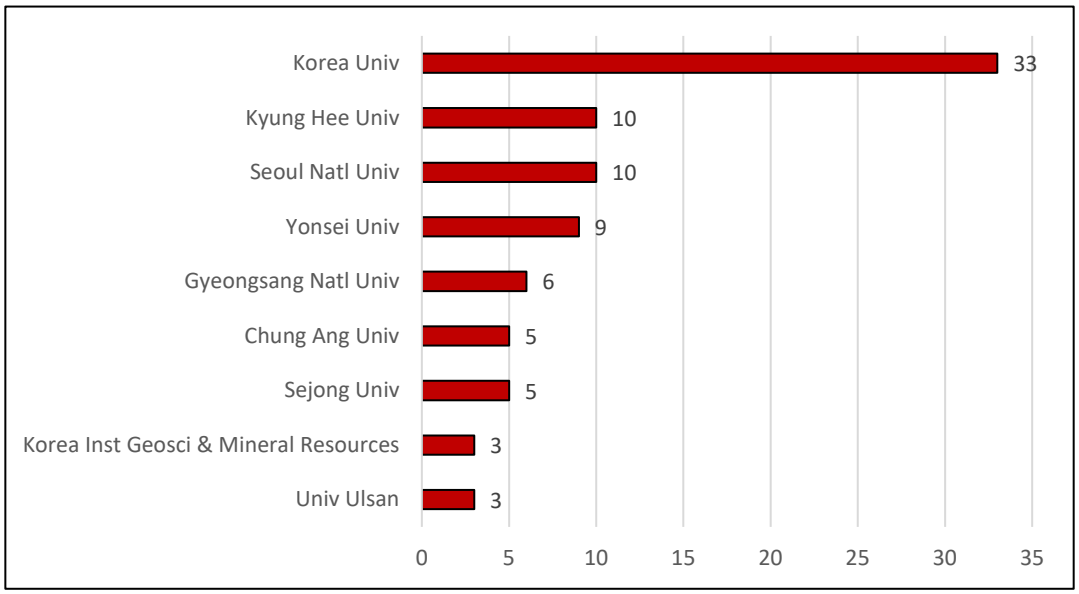

Figure 5.23. The Korean institutions that most frequently collaborate in Social Sciences and Humanities.

5.4 Summary

The role of South Korea in Norway's international collaboration is increasing and now represents 2.5 percent of all articles with international collaboration. A total of 2,842 scientific articles were published and indexed in Web of Science in 2001-2022 with authors' addresses in both countries. Half of the articles were published during the last five years 2018-2022. The collaboration is mostly multilateral. Other countries than South Korea and Norway are involved in almost 90 percent of the articles.

Collaboration in Physics and the Health Sciences is mostly driven by participation in multinational and global collaboration. Environmental Sciences, Technology, and Computer Science represent main areas with relatively more bilateral and trilateral collaboration. Collaboration in these areas may to a higher degree reflect a specific mutual interest between Korean and Norwegian researchers and their institutions. Collaborations in Technology and Computer Science have had the sharpest increases recently.

6 Sino-Norwegian collaboration in technology

Our previous report on *Norway's scientific collaboration with China in a global context* (NIFU Working Paper 2022:1) included a separate chapter with a special focus on arctic research. For this new report, we were asked to instead include a separate chapter providing more insights into the global context of Sino-Norwegian collaboration in technological science.

We summarized in chapter 4 above (and in the previous report) that, among nine main areas of research, technological science and computer science rank second and third after environmental sciences when considering the mutual importance of collaboration between Norway and China. This is mainly due to the strengths of technological science and computer science in the research profile of China. Furthermore, the profile of Sino-Norwegian collaboration in these two areas of research has a Norwegian 'mark' on what seems to be the common interests: marine engineering, materials science, and environmental engineering within technology, and telecommunications within computer science.

We will include computer science as part of technology in this chapter because we find overlapping journals and collaborating institutions in the two categories. We have redefined and renewed the dataset as explained below in section 6.1. On this basis, we will combine and expand the analysis of institutional collaboration presented in sections 4.2.2 (Technology) and 4.2.3 (Computer science). More importantly, we will perform the same type of global context analysis as in chapter 2 and 3, but this time with a special focus on collaboration in technology, an area of research where China clearly dominates in global research and where there is increasing focus on competition, trade sanctions, self-containment, and security and defence.

6.1 Data and methods

The analysis is based on a completely new dataset covering the years 2001-2022. Searches were limited to the journal categories "Engineering" and "Computer Science" in Web of Science. By deduplicating articles from journals that appear in both categories, we got:

- 4,3 million articles from all countries
- 1,2 million articles from China
- 28,200 articles from Norway
- 2,886 articles with affiliations in both China and Norway

The methods are the same as presented in sections 1.2 and 3.1. Articles with Sino-Norwegian collaboration were downloaded for further analysis of institutional collaboration. Macro analysis was based on search statistics.

To indicate the research profile of the new dataset with some examples, *Figure 6.1* shows the most frequent journals that have published the articles with Sino-Norwegian collaboration. Note that *Ocean Engineering* appeared in the major area Environmental sciences in chapter 4, not in Technology. This is an indication of the increased relevance of the new dataset.

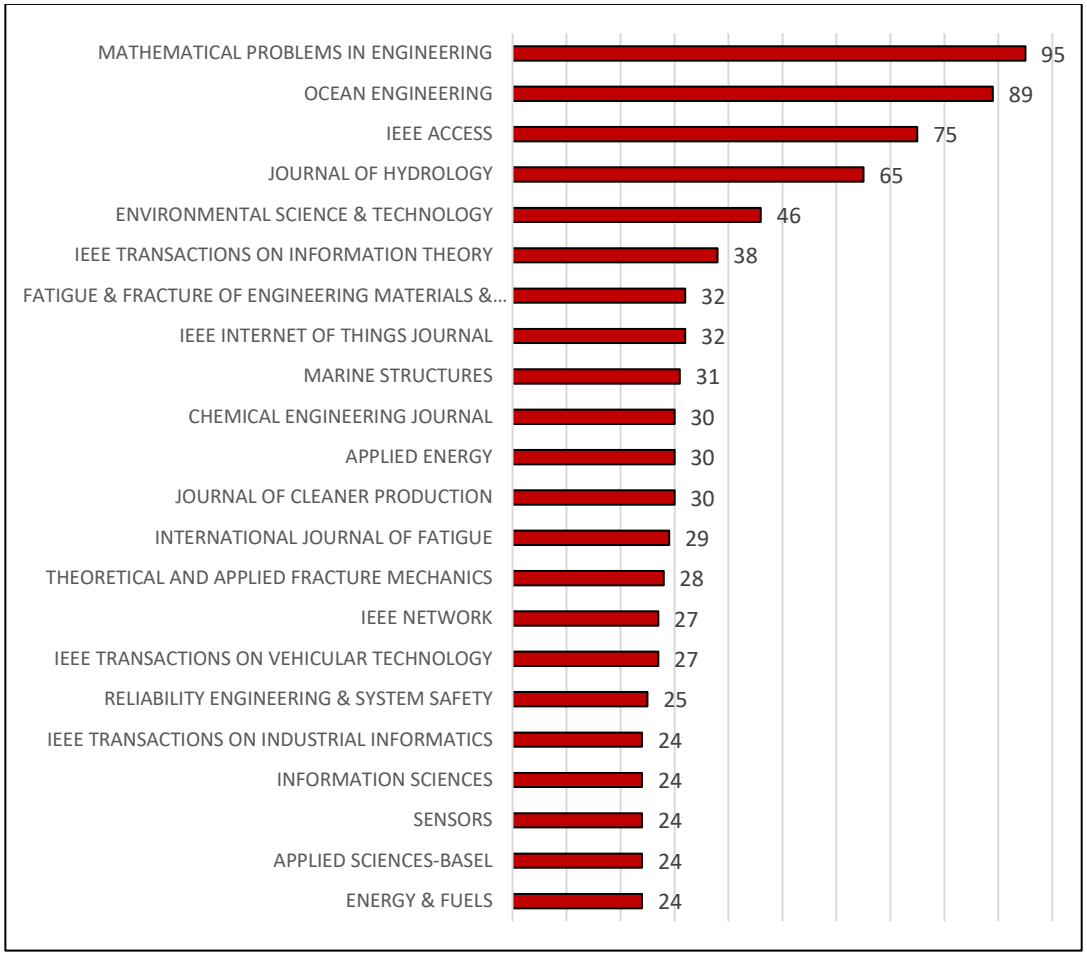

Figure 6.1. The most frequent journals in the dataset of 2,886 articles with combined affiliations in China and Norway.

6.2 The domination of China in the technological sciences

Figure 2.2 in chapter 2 above showed that China took over the role of the USA as the major contributing country to journals in *Web of Science* after 2018. *Figure 6.2* shows that the same thing happened six years earlier in the technological sciences. China now contributes to almost half of the world's articles while the share of the USA is steeply decreasing towards ten percent.

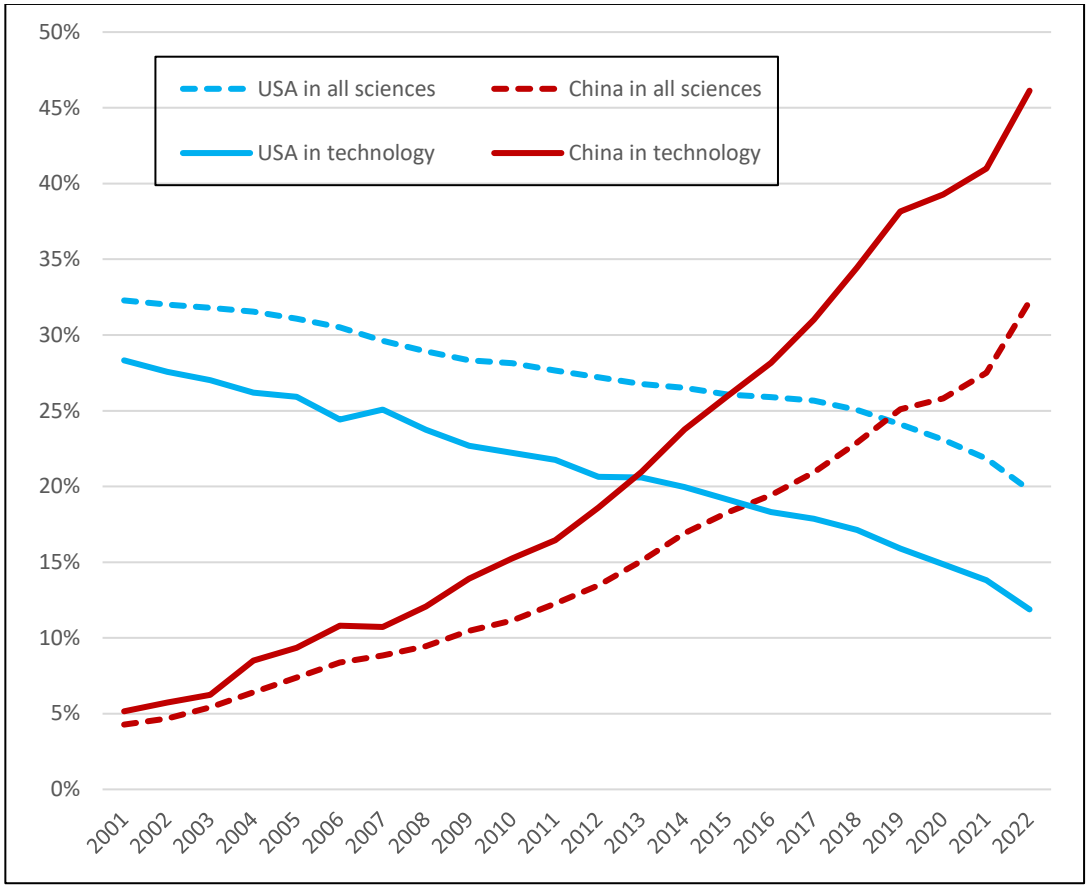

Figure 6.2. World shares in percentages for China and the USA in the global production of scientific articles in all sciences combined and within technology only.

As we shall see below in section 6.4, China has recently been surpassed the USA and the Nordic countries as Norway's major collaboration partner in the technological sciences. Before we arrive at this more local perspective, we will observe some changes in the collaboration patterns among the major countries performing technological research.

6.3 Changes in the collaboration among major countries

As seen in chapter 3 covering all sciences combined, China and the USA are the major collaboration partners in science, however with a decreasing intensity recently. The technological sciences are no exception, as seen in *Figure 6.3*. Here, we compare the trends in collaboration between the two countries by including the third largest country contributing to international collaboration in technological research, United Kingdom.

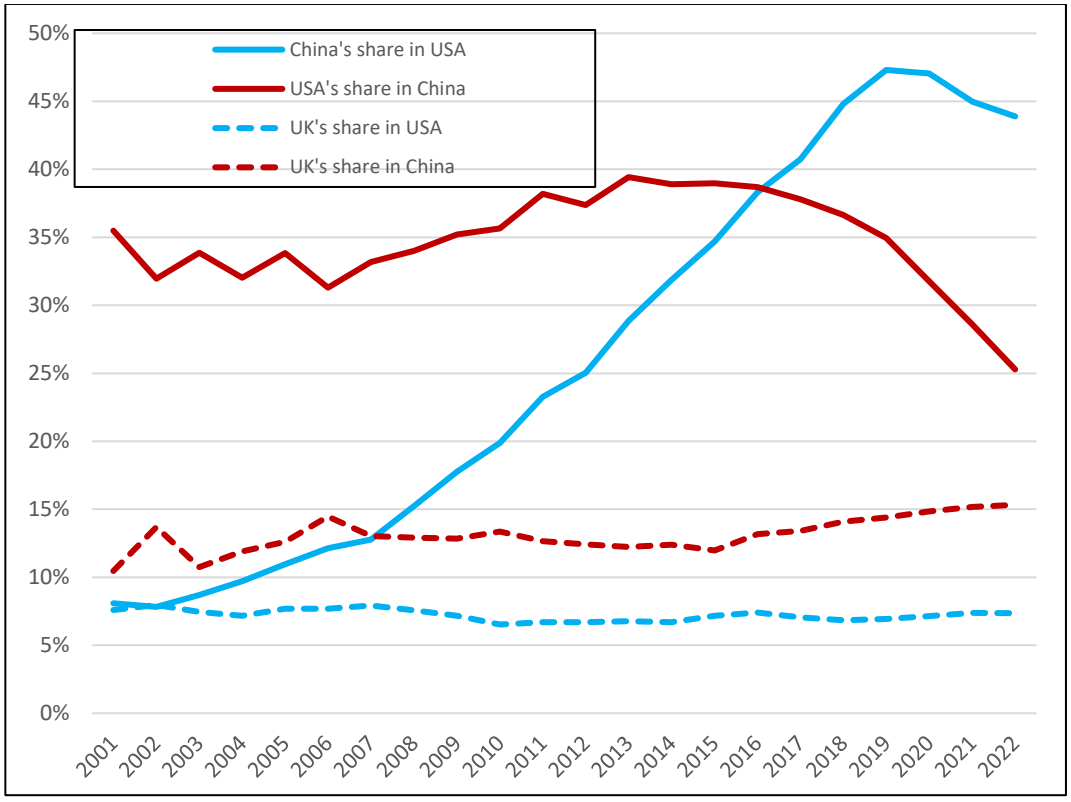

Figure 6.3. The share of China in the USA's articles with international collaboration in technology, and vice versa, compared to the share of the United Kingdom in the collaboration articles from both countries.

China's share in the USA's total number of articles with international collaboration has rapidly increased with the growth of China as a contributor to the technological sciences. In 2018, almost half of the articles with international collaboration had co-authors in China, indicating a high collaboration intensity within the network of global relations. However, from 2018 the trend clearly changed: The share of China decreased while the shares of other large countries in technological research increased (not shown here): Canada, South Korea, Australia, and India (mostly due to the rapidly growing research activity in India's technological research). The share of the UK remained stable, as shown in the Figure.

The share of the USA in China's articles with international collaboration was stable or increasing during the growth of China as a contributing country until 2016. The dramatic decrease in recent years can be compared to the increased share of the UK in China's collaboration pattern. It has also increased in the relations to other large countries in technological research (not shown here): Australia, South Korea, and Germany. There has been a general decline from 30 percent to 23 percent in the share of China's articles with international collaboration between 2016 and 2022, meaning that most of the recent growth in publication output is based on domestic research activity. However, this does not explain the

shift of collaboration intensity from the relation to the USA over to other Western countries.

The recent clear decrease in collaboration activity is mainly in the bilateral relation between China and the USA. It is probably not caused by the pandemic (when comparing to the relations to the UK), but, as observed in section 3.3.2 above, more likely to be influenced by the deteriorating relations between the two countries since 2018 (Tang et al., 2021; Zweig, 2021).

With this decrease, the mutual dependency of the two countries is not balanced anymore. *Figures 6.4 and 6.5* show the twelve most important collaboration partners for China and the USA in the most recent year 2022. The criterium for importance is size, the number of articles with evidence of collaboration. In addition, we add the indicator of relative intensity of collaboration (RIC) as explained in section 3.1. This indicator is size-independent and measures the intensity of collaboration in bilateral relations relative to the activity in the other bilateral relations in the global network, including all the relations of the two countries. One could say it is an indicator of 'preference'. Values over 0.5 (the average) indicate preference over other countries. In a bilateral relation, the values cannot be below 0.5 on one side and above on the other, but the values can be different and provide different rankings of countries from the perspective of each of the countries.

There is only one indication that China is more dependent on the USA than vice versa: The scale of the RIC is higher for China (up to 1.8), indicating that the USA has a more balanced global collaboration pattern throughout the world while China is more focused on its own region and the world's English-speaking countries. There are other indications that the USA is more dependent on China. China has the highest RIC in the USA's relations, and it is slightly higher than on China's side. China has more collaboration and higher intensity than the USA in all other bilateral relations, including Canada and the UK. Also, by simply comparing the number of collaboration articles, China has the more balanced collaboration profile towards third countries.

Noteworthy is also the lack of indications that the collaboration profiles of the two countries follow the borders of defence alliances. The USA seems not to prioritize collaboration with NATO members or Asian NATO friends in an area of research which is strongly relevant for security. Although the downward trend in USA-China collaboration since 2018 indicates a certain geopolitical effect, general collaboration patterns in science seem to counter defence alliances. Perhaps mercantilism more than international agreements about security concerns explains the decrease in collaboration intensity that we detected in section 6.2?

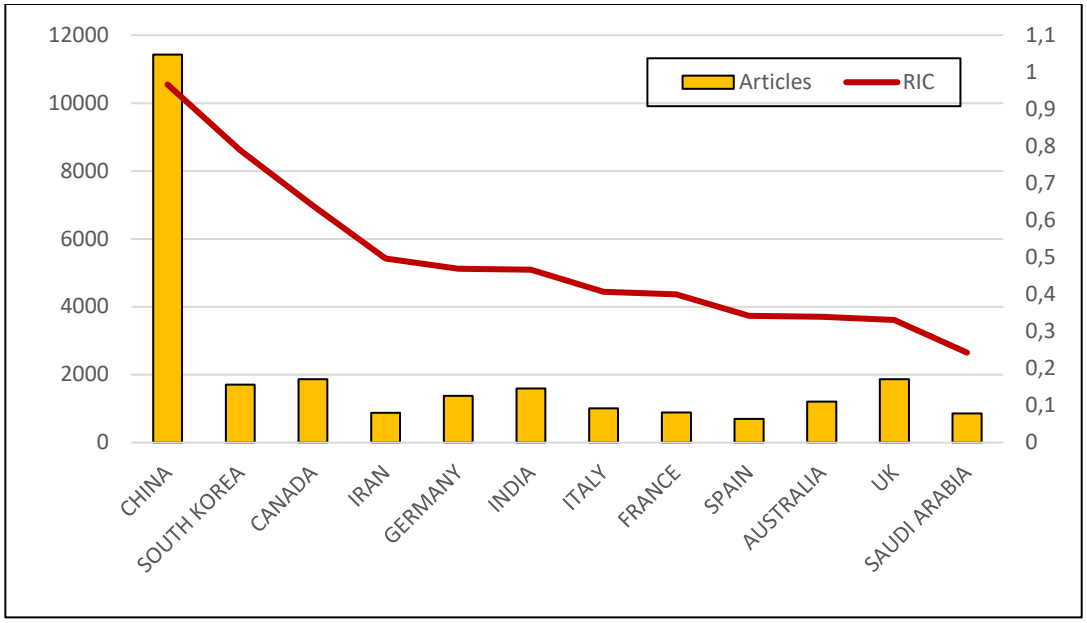

Figure 6.4. The 12 countries with the largest number of collaboration articles in technology with the USA in 2022, ranked by the relative intensity of collaboration (RIC) in each relation.

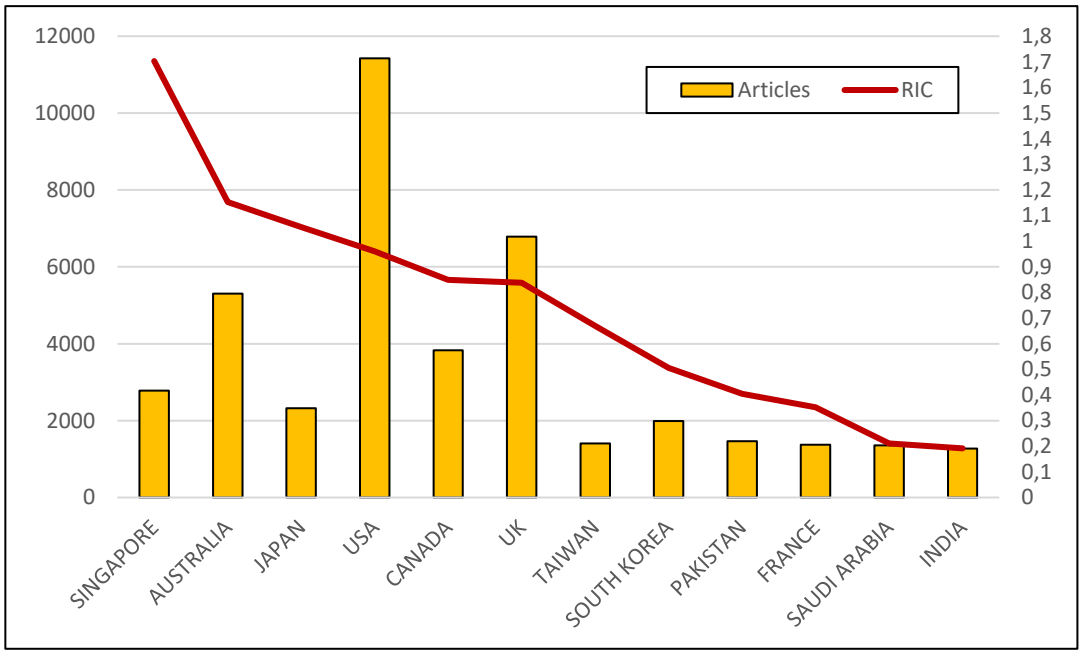

Figure 6.5. The 12 countries with the largest number of collaboration articles in technology with China in 2022, ranked by the relative intensity of collaboration (RIC) in each relation.

6.4 Sino-Norwegian collaboration in a global context

We start by presenting the most recent picture of Norway's most important collaborating countries in the same manner as above with China and the USA. Figure 6.6 shows the 12 countries with the largest number of collaboration articles in technology with Norway in 2022, ranked by the relative intensity of collaboration. China is clearly the largest collaboration partner now, and the relative intensity is higher than in the relations to the UK and the USA.

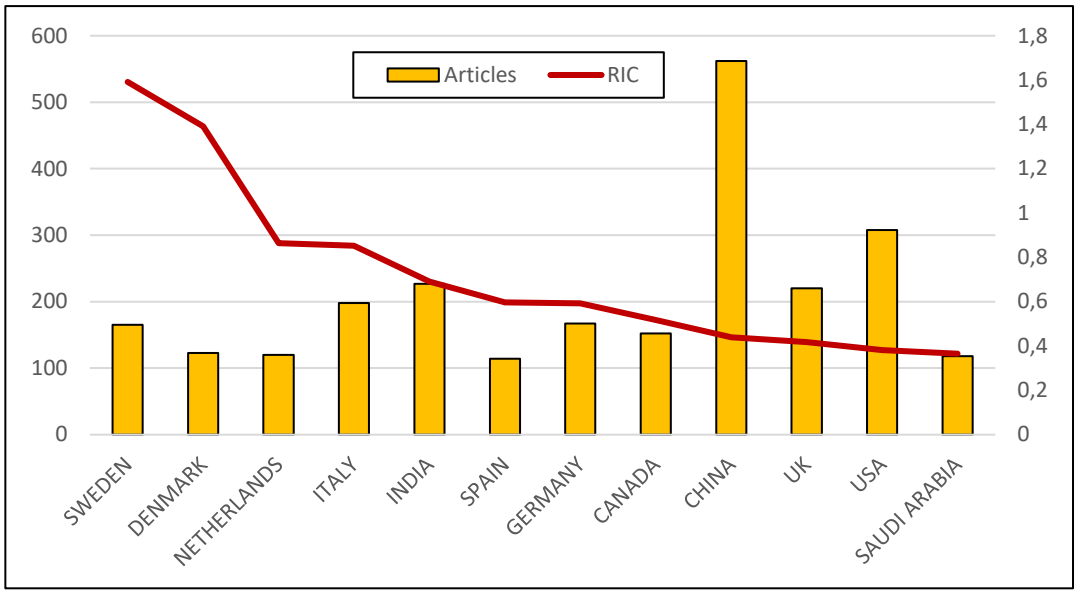

Figure 6.6. The 12 countries with the largest number of collaboration articles in technology with Norway in 2022, ranked by the relative intensity of collaboration (RIC) in each relation.

China only recently, in 2019, became Norway's largest collaboration partner in the technological sciences. *Figure 6.7* shows the development since 2001. The USA and the Nordic countries taken together were more important until ten years ago. The explanation for the temporary decrease in China's share until 2017 was given in section 3.3.1 above, China's unilateral decision to close official relations and collaboration with Norway after the Nobel Peace Prize was awarded to Liu Xiaobo in 2010 (Sverdrup-Thygeson, 2017). There is a delay in the effect because of the time it takes to publish research.

The same temporary decrease is visible in *Figure 6.8* from the perspective of China. Until then, compared to its size, Norway was on its way to become China's preferred Nordic partner in technological research. After the period of closing down, the importance of Norway has risen again, but Denmark is now the preferred partner compared to its size. The shares for all four Nordic countries are increasing.

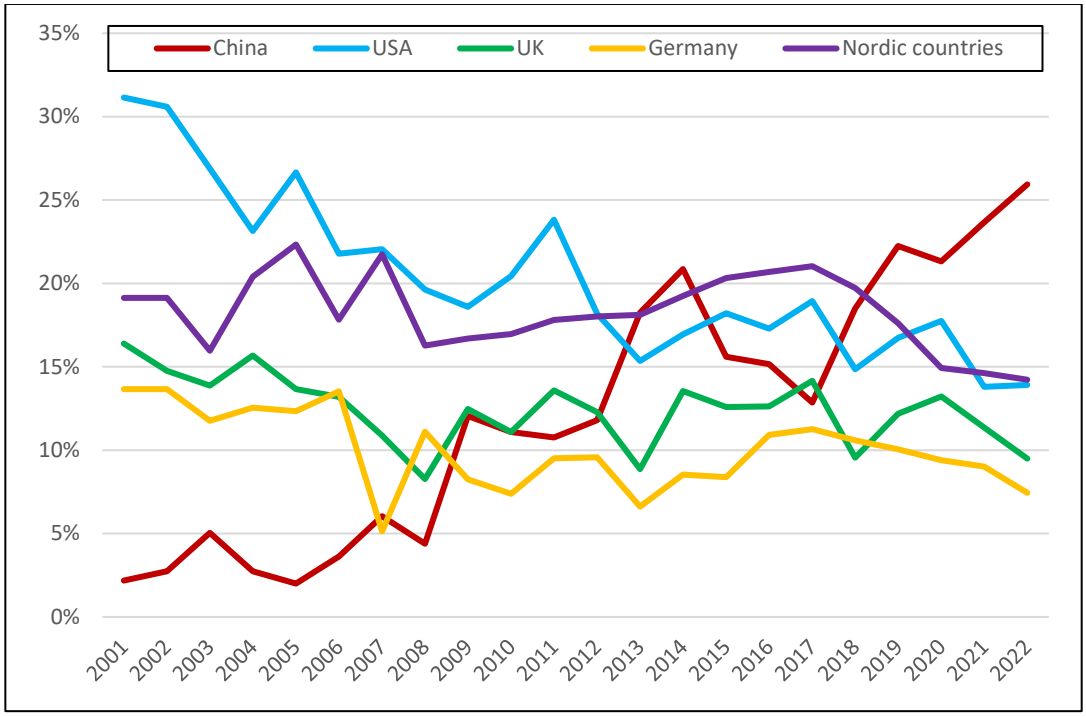

Figure 6.7. The five largest collaboration partners (with the Nordic countries grouped as one) in technology for Norway in 2022, and their relative shares in Norway's articles with international collaboration since 2001.

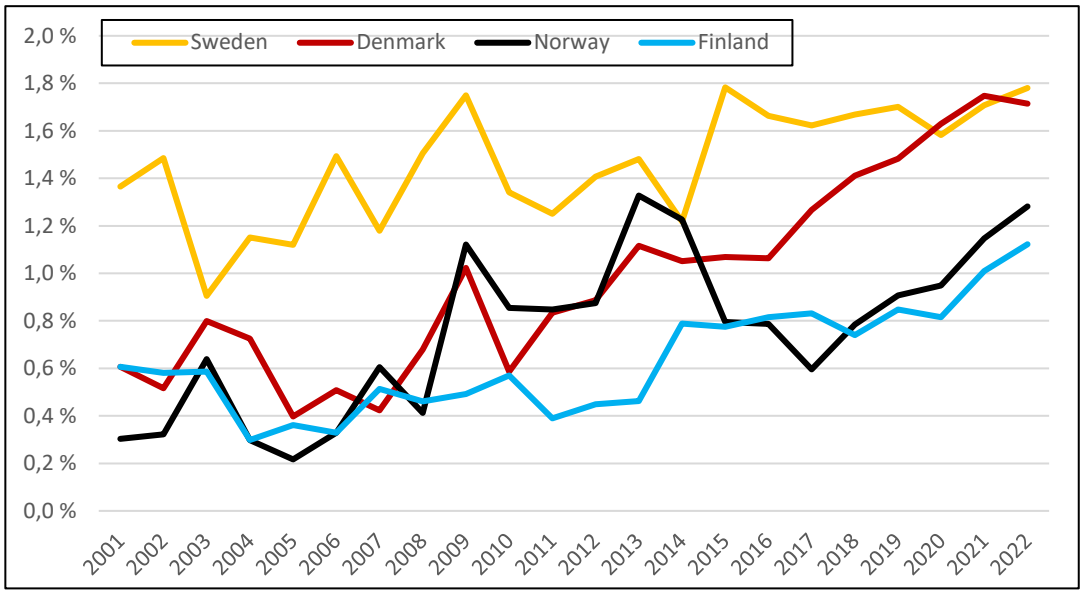

Figure 6.8. Four Nordic countries' shares in Chinese articles in technology with international collaboration since 2001.

6.5 The most active Norwegian institutions

The Norwegian higher education sector contributed with 20 different organizations to 79 percent of the articles with Sino-Norwegian collaboration in 2001-2022. The institute sector contributed with 22 different organizations to 15.5 percent of the articles, and the corporate sector with 55 different organizations to 4.2 percent of the articles. A few authorities and hospitals contributed to 1.4 percent.

The Norwegian University of Science and Technology (NTNU) dominates among the universities by contributing to almost half of all the articles affiliated with the higher education sector, as seen in *Figure 6.9*. University of Oslo, University of Agder and University of Stavanger are also important participants in Sino-Norwegian collaboration in technology.

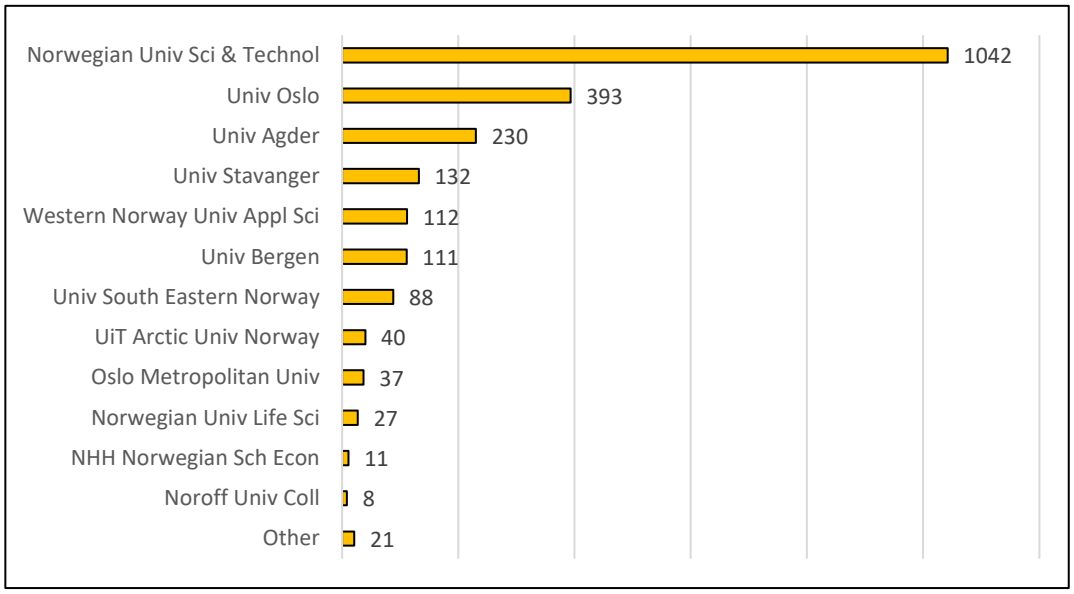

Figure 6.9. The number of articles in technology with Sino-Norwegian collaboration that Norwegian higher education institutions contributed to in 2001-2022.

In the institute sector, Simula Research Laboratory, SINTEF, and the Norwegian Geotechnical Institute are the most important contributors, as seen in *Figure 6.10*. Although not active in technological research, NIFU is listed with eight articles. The reason is that journals covering bibliometric research are classified as information science or computer science in Web of Science. One of the eight articles from NIFU occurs in the reference list of this report.

The most active organizations in the Norwegian corporate sector are the DNV Group (22 articles), Super Radio AS (13), Statoil (12), Schlumberger (5), and Aker Solutions (5).

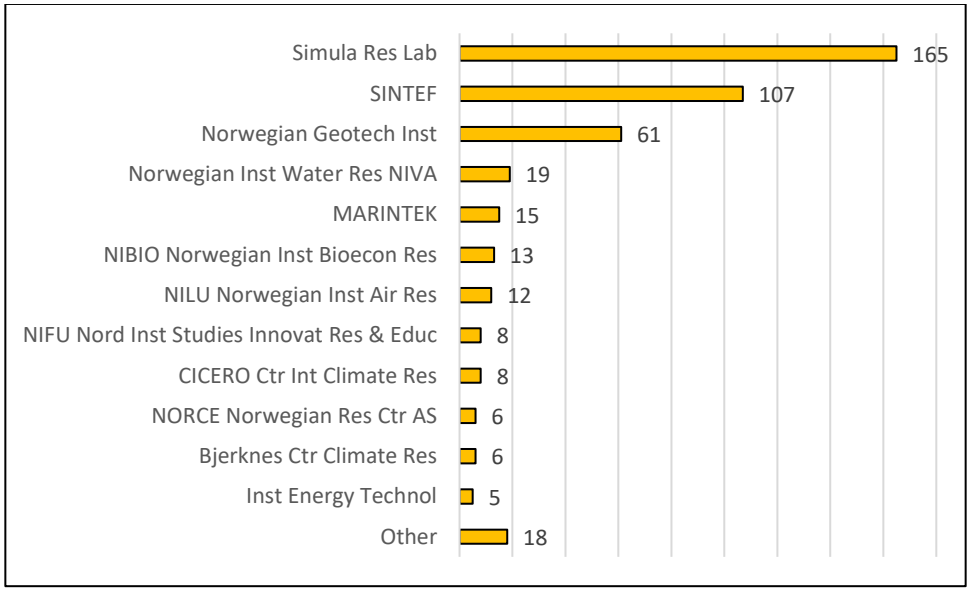

Figure 6.10. Number of articles in technology with Sino-Norwegian collaboration that organizations in the Norwegian institute sector contributed to in 2001-2022.

6.6 The most active Chinese institutions

The Chinese higher education sector contributed with 316 different organizations to 81.6 percent of the articles with Sino-Norwegian collaboration in 2001-2022. The Chinese institute sector contributed with 167 different organizations to 11.4 percent of the articles, and the corporate sector with 136 different organizations to 5.5 percent of the articles. 30 different national and regional authorities contributed to 1.6 percent.

Collaboration with Norway in technology is distributed among a very large number of Chinese higher education institutions. *Figure 6.11* lists the 34 universities contributing to 30 or more of the articles. The remaining 282 universities not listed contribute to 1,359 articles (41 percent). Harbin Institute of Technology, China's leading university in this area, is the most active. Most of the other active institutions are specialized in technological research or even in particular technologies. Four of the so-called "Seven Sons", the Chinese universities that the US government banned from sending students to the USA in 2022, are present in *Figure 6.11*: Harbin Institute of Technology (173), Harbin Engineering University (43), Nanjing University of Science and Technology (41), and Beihang University (41).

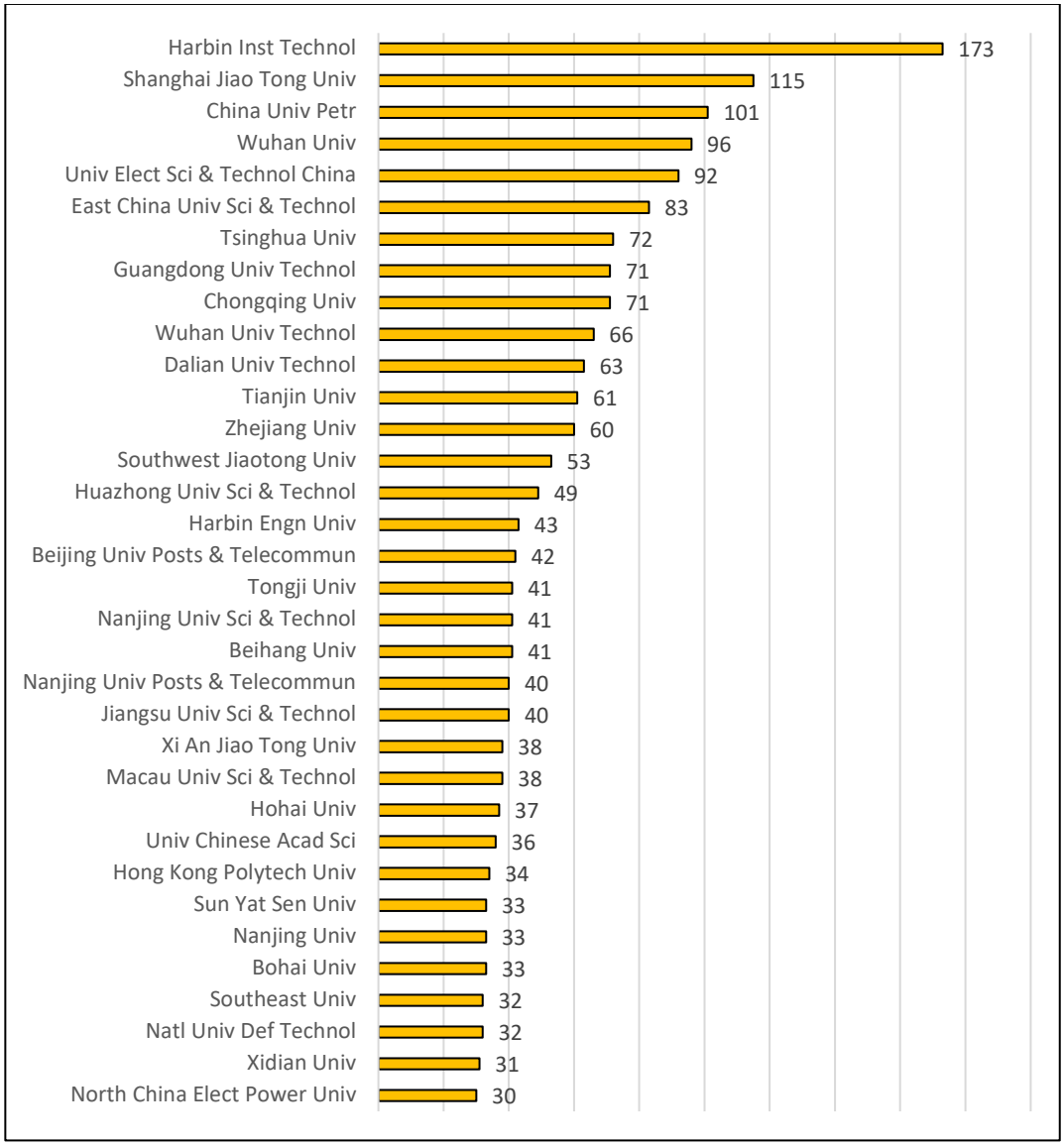

Figure 6.11. The number of articles in technology with Sino-Norwegian collaboration that the 34 most active Chinese higher education institutions contributed to in 2001-2022.

The research institutes of the Chinese Academy of Sciences contribute to the largest number of articles from the institute sector in China. Among the remaining 166 other institutes, only sixteen contribute with four or more articles, as shown in *Figure 6.12*. They represent technological specializations to a much higher degree than the more general Norwegian research institutes. Some of them are national while others are organized jointly by the technical universities of China.

Among the 136 contributing organizations in the Chinese corporate sector only sixteen contribute to three or more articles. They are listed in *Figure 6.13*. As with the Chinese research institutes, most of them represent technologies that are

typical strengths in Norway's research profile, e.g., marine technology, hydrology, petrology, and scientific computing.

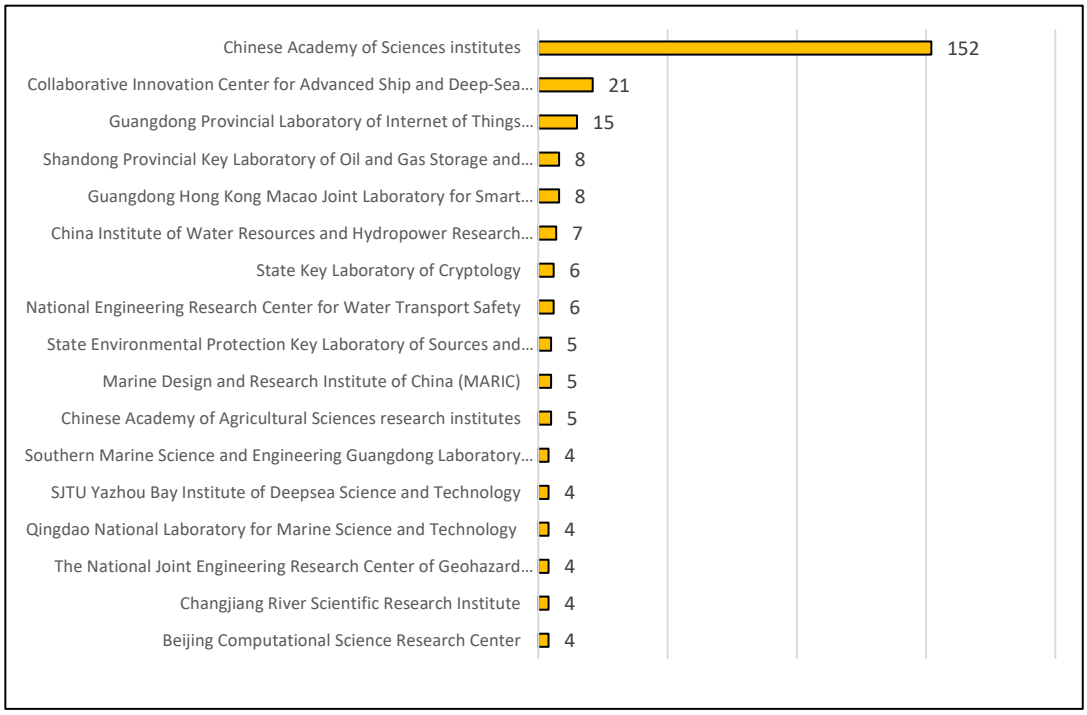

Figure 6.12. The number of articles in technology with Sino-Norwegian collaboration that the 17 most active Chinese research institutes contributed to in 2001-2022.

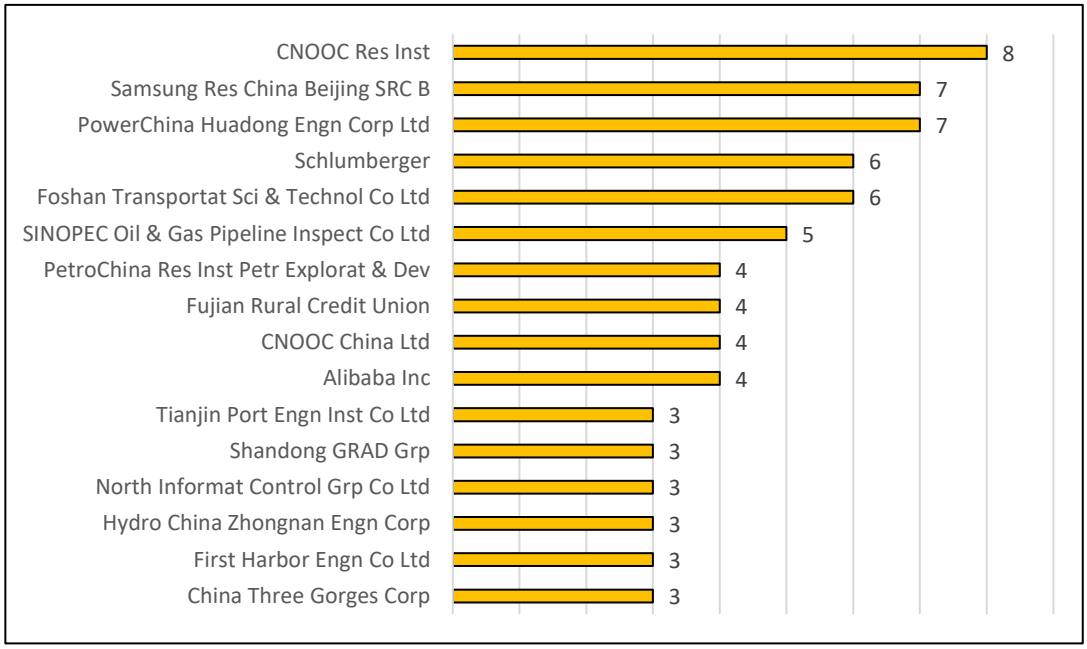

Figure 6.13. The number of articles in technology with Sino-Norwegian collaboration that the 16 most active Chinese corporate organizations contributed to in 2001-2022.

6.7 Summary

The analysis of technological collaboration with China is based on the journal categories "Engineering" and "Computer Science" in Web of Science. China now contributes to almost half of the world's articles in these categories while the share of the USA is steeply decreasing towards ten percent.

China and the USA collaborated intensely in technological research until recently. The last five years have shown a relative decrease in this bilateral relation which is not found in China's relations to other Western countries. In general, there is a lack of indications that the collaboration profiles of the two countries follow the borders of defence alliances.

From the Norwegian perspective, China recently, in 2019, became our largest collaboration partner in technological research. The relative intensity is even higher now than in the relations to the UK and the USA. The USA and the Nordic countries taken together were more important for Norway until ten years ago. At that time, Norway was on its way to become China's preferred Nordic partner in technological research. After a temporary closing down of Sino-Norwegian relations, the importance of Norway has risen again after 2017, but Denmark is now the preferred partner compared to its size. The shares of all four Nordic countries in China's collaboration profile are increasing.

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