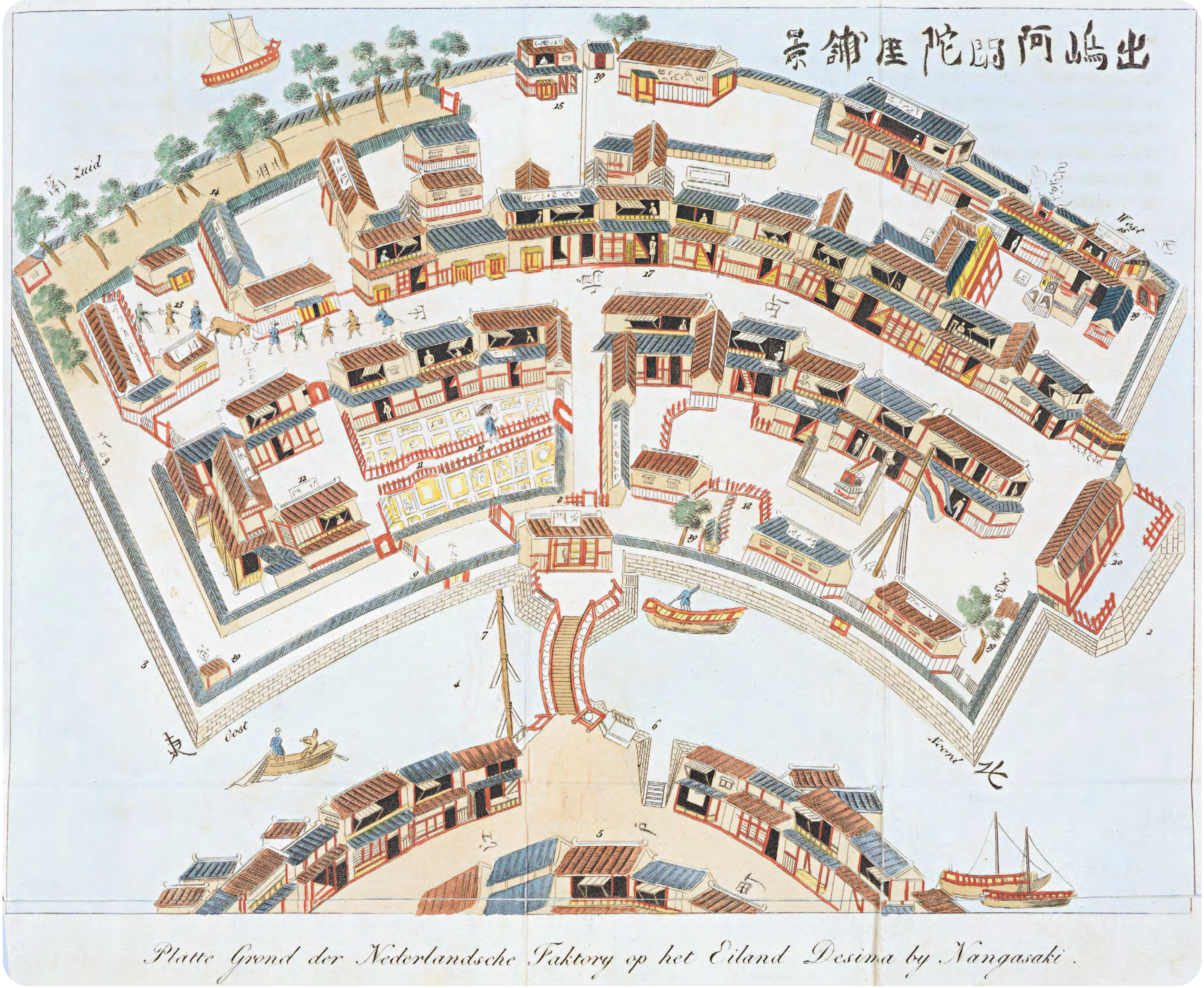


# The Netherlands and Japan as Partners in Science, Technology and Innovation

## Exploring the common ground

COMMON GROUND NL コモングラウンド オランダ

ELSEVIER
NON SOLUS

This report was produced by Elsevier's Dr. Michiel Kolman, SVP Research Networks; Dr. Anders Karlsson, VP Global Strategic Networks Asia Pacific; Paola Barr, Research Networks Analyst; Mia Yamakawa Lewis, Global Strategic Networks Associate Asia Pacific; and Steve Watson, VP Thought Leadership Programs; during March and April 2025.

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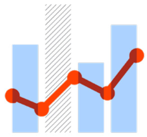
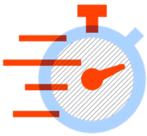
# Key Takeaways

Research collaboration between Japan and the Netherlands demonstrates remarkable scientific impact, five times the global average and growing rapidly, with particular strengths in the Physical Sciences and Clinical & Health research.

This success is significantly driven by robust corporate-academic collaborations, and also yields substantial translational impact in policy and innovation, especially within the key technology areas of quantum and photonics.



**High scientific impact**
From a Dutch standpoint, research collaboration with Japan is exceptionally impactful, exceeding the impact of its partnerships with its other top 20 collaborators. In fact, its field-weighted citation impact is a remarkable five times the world average.



**Fast growth**
While the size of the Dutch-Japanese collaboration is modest (Japan ranks as the 16th country the Netherlands is collaborating with in terms of output), it is growing fast: the long-term annual growth rate (as measured by the CAGR) is 8.5%, well above the Netherlands (4.9%), the World (5.4%) or Japan (1.2%).

**Key areas and players**
The majority of Japanese-Dutch collaborative research falls within the Physical Sciences and Clinical & Health. In terms of volume, the University of Tokyo and the University of Amsterdam are the leading academic contributors, and among the most prolific universities in these partnerships. The University of Groningen and the University of Osaka show the highest impact. A substantial amount of Japanese-Dutch collaboration includes institutions from other countries with significant contributions from prominent institutions in France, the US and UK in particular. These multinational collaborations often achieve a remarkable citation impact, frequently reaching levels ten times the world average, further highlighting the high quality of the partnership between Japan and the Netherlands.

**Impactful corporate contribution**
Worldwide, corporate-academic collaboration accounts for about 3% of published research. This figure is higher in both Japan and the Netherlands, at approximately 7% for each. However, the prevalence of academic-corporate partnerships in joint Japanese-Dutch research is strikingly high, reaching a staggering 23%. Furthermore, the research resulting from these collaborations is incredibly impactful, registering a scientific impact 9.5 times the world average. Top contributors from Japan include Astellas Pharma, NTT and Toshiba, while on the Dutch side Philips, Cardialysis, and ASML.

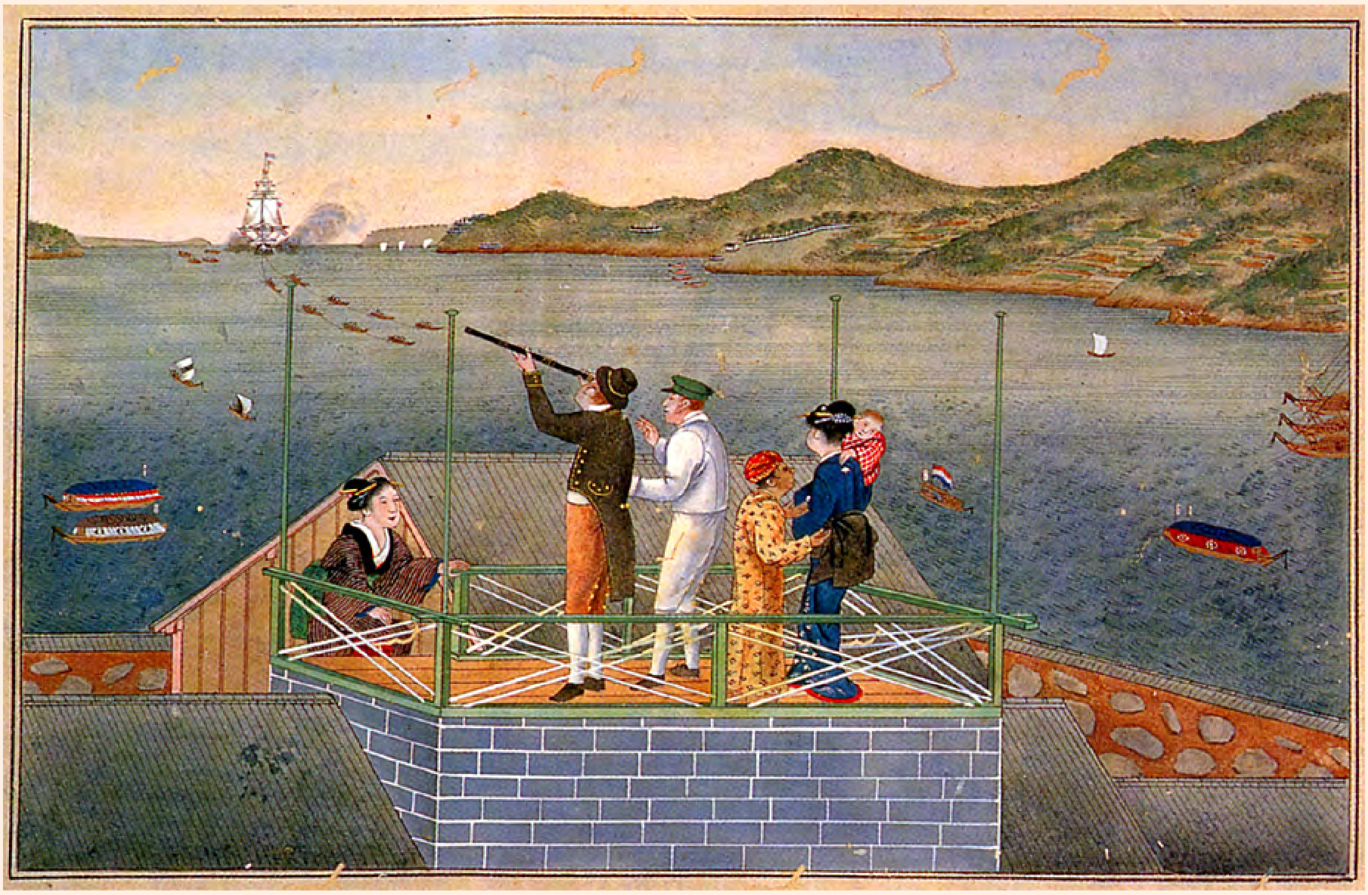
**Impact on innovation**
Patent citations offer one measure of research's influence on innovation. In this regard, both Japan and the Netherlands score well above average. Notably, their joint research demonstrates a particularly strong innovation impact, with a significantly higher share of their publications cited in patents – almost twice the worldwide average. When looking at active patents, Japan and the Netherlands exhibit distinct innovation profiles. Japan excels in patent volume, producing roughly 30 times more patents than the Netherlands. In contrast, Dutch patents tend to have a greater competitive impact, scoring approximately three times higher than those from Japan.

**Impact on policy**
When considering research cited in policy documents, Japan's overall output receives slightly less attention than the global average. In contrast, research from the Netherlands is highly influential in policy, garnering citations approximately 2.5 times the global average – a notably high figure even when compared to the EU average and many other nations. Interestingly, the collaborative research between Japan and the Netherlands demonstrates exceptional policy relevance, receiving citations in policy documents at a rate 3.5 times the global average, with a majority of the impact on intergovernmental and international policy organizations.

**Complementary strength**
Japan and the Netherlands show complementary strengths - Japan has a higher focus on the Physical Sciences (+9.1%) and Engineering & Technology (+13%) than the Netherlands, while the Dutch are more prolific in Clinical & Health (+5.4%) and Social Sciences (+7.9%).

**Key technologies**
Quantum technologies and photonics are the two key technologies where Japan and the Netherlands together have a high level of activity, showing more than twice the world average for quantum and almost 4 times for photonics. The University of Tokyo and NTT are the key Japanese players, while in the Netherlands, Delft University, the University of Amsterdam as well as LioniX and NXP are in the lead.

# Introduction



Celebrating 425 years of collaboration, beginning with the stranding of the Dutch ship de Liefde in what is now Usuki City of Oita prefecture, the relations between Japan and the Netherlands are longstanding.

**Image above:** Philipp Franz von Siebold (with Taki and his child Ine) watching an incoming Dutch ship at Dejima. Painting by Kawahara Keiga, between 1823 and 1829.

# 22

individuals from the Netherlands have been awarded a Nobel Prize, with honours spanning physics, chemistry, physiology or medicine, economics, and peace.

# 31

individuals from Japan have been awarded a Nobel Prize, with honours spanning physics, chemistry, physiology or medicine, literature, and peace.

During Japan's period of self-imposed isolation (sakoku), the small artificial island of Dejima (Exit Island) in Nagasaki Bay served as the exclusive trading post for Dutch merchants. Beyond commerce, Dejima became an unparalleled gateway for the transmission of scientific, medical, and technological advancements. Through Rangaku, directly translated as Dutch learning, Japan gained access to critical developments in Western medicine, physics, chemistry, and engineering – fields that shaped the trajectory of its modernization. This unique channel of intellectual exchange laid the foundation for a deeply ingrained tradition of bilateral cooperation in science and innovation.

The Netherlands, with 22 Nobel prizes, and Japan with 31, are both strong investors in science, technology and innovation, with robust common grounds for collaboration. Key areas of partnership today include sustainable urban development, agriculture, water management, and renewable energy technologies. The Netherlands is known for its expertise in water management and agriculture, while Japan leads in robotics and advanced manufacturing, allowing for complementary projects that address global challenges such as climate change and food security.

Both nations also engage in international research initiatives and exchange programs, promoting innovation through shared knowledge. As they commemorate their long-standing relationship, the Netherlands and Japan continue to build on their historical ties, driving advancements in science and technology for mutual growth and global sustainability.

This year, Elsevier is a proud sponsor of the Dutch pavilion at the World Expo in Osaka and we will be supporting through a series of reports – this report is the first and most in-depth.  Building on earlier work by Elsevier for the Dutch Ministry of Economic Affairs and reports for the Japanese Cabinet Office, this report explores the collaboration between Japan and the Netherlands, supported by custom analytics. We provide insights into their respective positions, joint research efforts, and key contributions, both from the academic and corporate sectors. Previous studies have included the Netherlands-Taiwan partnership in semiconductors, as well as global surveys on Artificial Intelligence and the impact of clean-energy research towards Net Zero.

For this analysis, we will also focus on key technology domains: Artificial Intelligence – AI, Semiconductors, Cybersecurity, Quantum Technologies, Biotechnology, Photonics, Rare Earths and Critical Materials, Robotics, and Battery Technologies. These sectors represent the forefront of technological innovation and hold significant potential for deepened collaboration between Japan and the Netherlands.

The report is based on data and analytics from Elsevier's comprehensive tools Scopus and SciVal. Typically we are looking at the most recent 6-year period in Scopus and Scival (2019-2024) in this report (unless a different time period is indicated).

# A Global Overview

## The global research landscape has been steadily growing and continues to be accelerated through the integration of technologies such as Artificial Intelligence.

In the year 2025, the world of research faces novel challenges, with societal changes in the perceptions of science, research integrity and higher education, shifting the dynamics of global collaboration. However, this instability merely increases the importance of focusing on the global impact internationally collaborative research can have for the greater good.

Whilst previously western-centric, global scholarly output has been shifting centrality to Asia, China, followed by India and the Middle East have been rapidly engaging and increasing their scholarly output.

In the report we measure the scientific impact through citation impact, building upon the assumption that impactful articles are cited more. As citation patterns are different in each scientific field, we normalize the citation impact compared to the world average, which is set at 1.0, thus calculating the Field Weighted Citation Impact or FWCI. A FWCI of e.g. 1.3 means an impact 30% above the world average, and a high FWCI is a good proxy for scientific impact (more information on the FWCI in the appendix).

Fig. 1 below shows the global article share, as well as the Field Weighted Impact (FWCI) of each nation, visualizing the volume and impact of output contributed by each nation. We can see the three largest regions are China, now slightly bigger than the EU, and then the US (which output is now ¾ the size of China). The Middle East and India have continued to grow at a fast rate and their output is in the region of 1.6 million research articles in the 6 years 2019-2024 period.

On a global scale, the Netherlands see high impact, but a slightly lower total output than Japan. Japan has a lower FWCI than the Netherlands but continues to contribute through scholarly output. Within the context of this global landscape, this report will initially analyse the current scholarly landscape seen in Japan and the Netherlands respectively, followed by the common ground seen in collaborative research between Japan and the Netherlands and finally discussing the contribution seen by the two nations in Key Technologies.

**World Article Share and Field Weighted Citation Impact (FWCI) for Selected Nations and Groups**

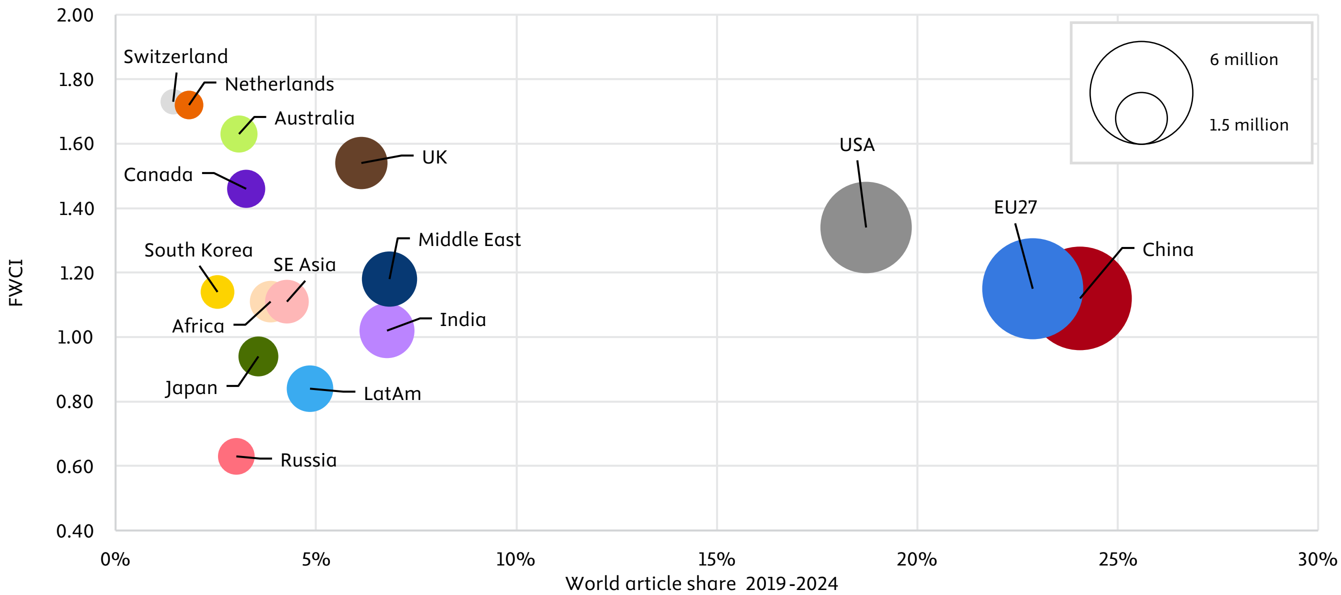



**Figure 1:** World article share (x-axis) and Field Weighted Citation Impact (y-axis) for selected nations and groups, while the bubble size indicates the volume of articles.

**3.6%**

Japan's share of the world's published articles

**1.8%**

The Netherlands' share of the world's published articles

# Japan and the Netherlands:

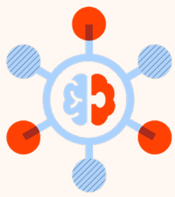
## A Comparative View

Looking at Japan and the Netherlands respectively allows us to understand the current scholarly impact of the two nations within context.

## Japan Overview

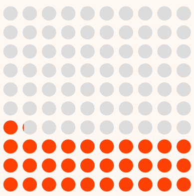
**861,777 publications**

(51.0% Open Access), over the 2019-2024 period



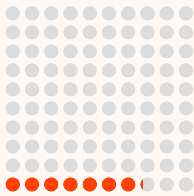
**FWCI of 0.94**

**6% below** the world average.



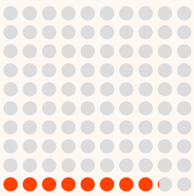
**31.1%**

of publications are co-authored with institutions in other countries or regions.



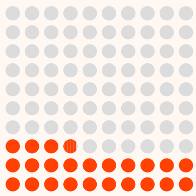
**7.2%**

of publications have both academic and corporate affiliations.



**8.1%**

of publications are in the top 10% most cited publications.



**23.9%**

of publications are in the top 10% most cited journals.

**Figure 2:** An overview of the current amount and impact of scholarly output in Japan.

On a global scale, Japan ranks 7th in terms of total scholarly output and 6th in the number of authors, with significant contribution across multiple topics with the top three subject areas being Medicine, Engineering, Physics and Astronomy. As summarised in Fig. 2, Japan sees higher than world average (21%, for reference) in international collaboration, but the other metrics of outputs in top citation percentiles and top journal percentiles fall shortly behind. Being home to over 800 universities, Japan sees a large amount of scholarly output with varying levels of impact. Further, whilst the Academic-Corporate collaboration statistic gives us greater insight into industry impact in research, it should be noted that statistics are often lower than reality, as many corporate research outcomes are not published and therefore not publicly accessible.

Japan has strong output in STEM subjects, with the Physical Sciences (36.4%) and Clinical and Health (34.9%) being the top categories, as seen in Fig. 3. Within Physical Sciences, the top institutions involved include the University of Tokyo, Kyoto University and Tohoku University. The largest collaboration partners are China, the United States, Germany and the United Kingdom. Many leading articles within the Physical Sciences involve high rates of international collaboration with multiple authors, noting Japan's involvement in global science. The subject with the highest FWCI is Law – which makes up less than 1% of total output, but this can be accounted to the fact that the leading documents involve global issues such as how to manage COVID-19 or the rise of AI.

Japan has been seeing a slow but steady increase in international collaboration overall and is seeing steady recovery in collaboration post-covid, as illustrated in Fig. 4. Over the 1996-2024 time frame, the international collaboration rate has doubled. Overall, the rate of international collaboration is still low in comparison to, for example, G7 nations, but Japan has been steadily increasing collaboration.

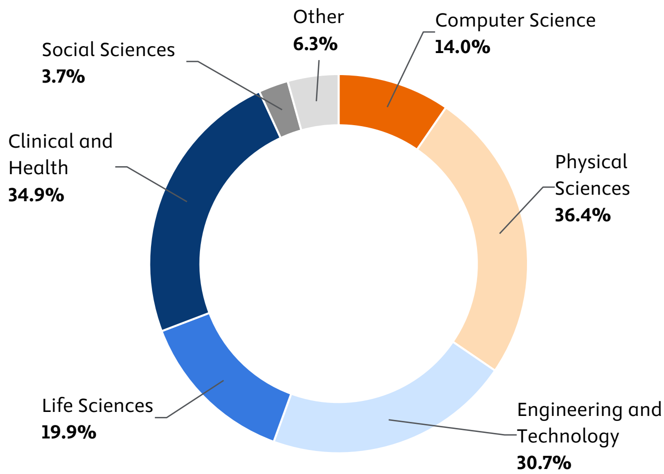



**Figure 3:** Japan's scholarly output by subject area based on the Times Higher Education classification.

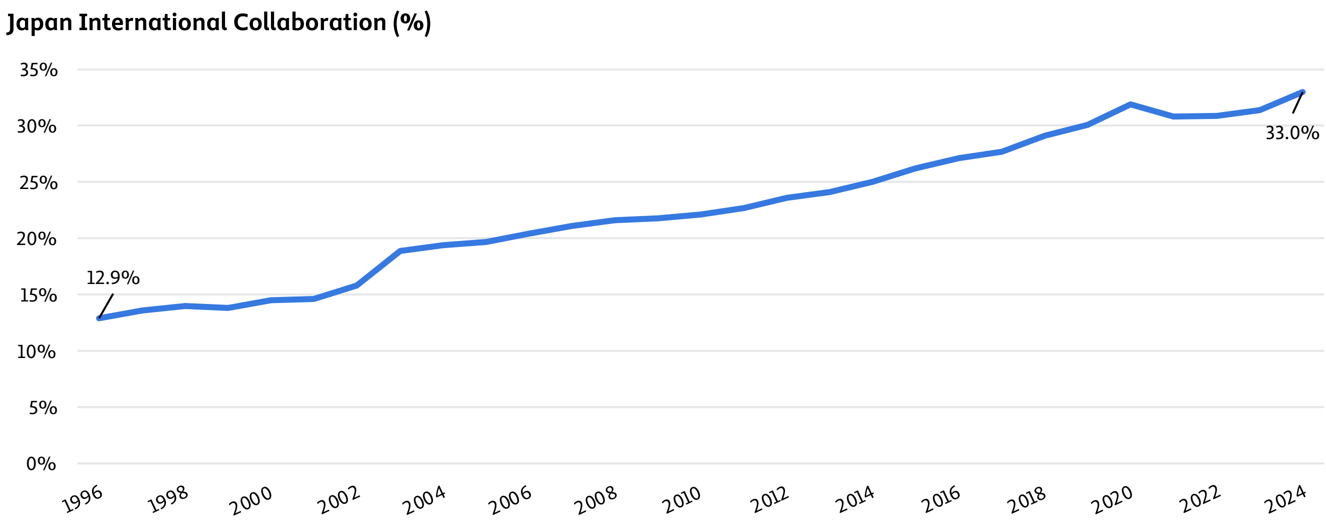



**Figure 4:** Japan's scholarly output with international collaboration from 1996-2024.

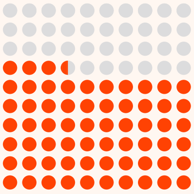
# The Netherlands Overview

**443,557 publications**

(72.5% Open Access) over the 2019-2024 period.

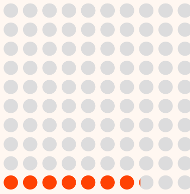
**FWCI of 1.72**

**72% above** the world average.



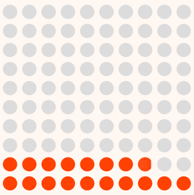
**63.5%**

of publications are co-authored with institutions in other countries or regions.



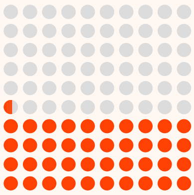
**7.1%**

of publications have both academic and corporate affiliations.



**17.9%**

of publications are in the top 10% most cited publications.



**40.6%**

of publications are in the top 10% most cited journals.

**Figure 5:** Overview of Scholarly Output and selected metrics for the Netherlands.

On a global scale, the Netherlands ranks 16th in terms of total scholarly output and 18th in terms of the number of authors (Fig. 5). A trend seen across many European nations, the Netherlands sees an extremely high rate of International Collaboration at 63.5% with Open Access articles making up 72.5% of output. This highlights how nations such as the Netherlands with slightly smaller output than its comparators show strong international impact by leveraging international collaboration.

The Netherlands sees over 40% of total output in Clinical and Health as seen in Fig. 6, with leading articles highly cited due to the prevalence of globally collaborative clinical studies, including the PRISMA 2020 statement, an in-depth study into 369 global diseases and a European Consensus on Sarcopenia. This leading category is followed by the Physical Sciences (27.3%) and Life Sciences (18.8%). The top institutions involved are the University of Amsterdam, Amsterdam UMC and Utrecht University. The Netherlands also has a higher rate of non-STEM, social science subjects with strong engagement across multidisciplinary perspectives on the challenges and implications of AI in research and policy.

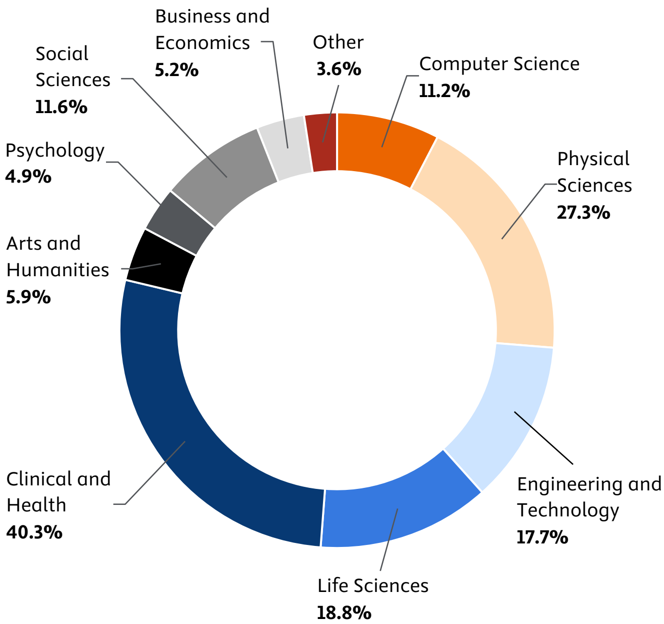



**Figure 6:** The Netherland's scholarly output by subject area based on the Times Higher Education classification.

The Netherlands has seen high rates of international collaboration, even back in 1996, and like Japan, the overall collaboration rate has doubled from 1996 to 2024, as demonstrated in Fig. 7. The growth rate has been relatively steady and not as heavily impacted by COVID-19 compared to Japan, with the slowdown in growth seen in Fig.7 extremely minimal. This could be a result of the Netherlands being on the European mainland, with international collaboration more easily accessible in comparison to an island nation. With the global average rate of international collaboration at 21%, the Netherlands is an exemplary leader in global research.

**Netherlands International Collaboration (%)**

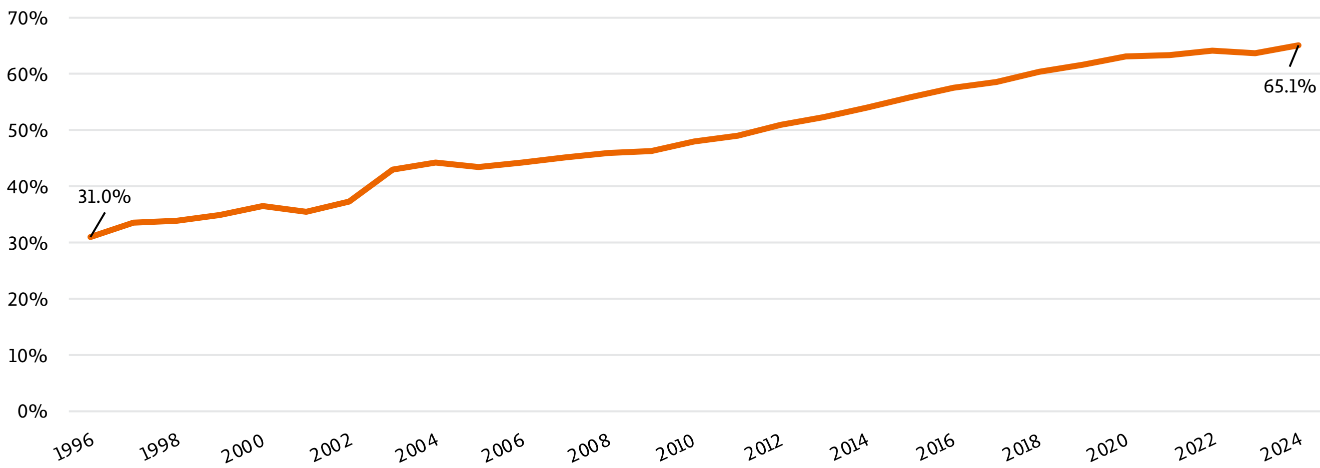



**Figure 7:** The Netherland's scholarly output with international collaboration from 1996-2024.

# 31.1%

of Japan's research involves international collaboration

# 63.5%

of The Netherlands' research involves international collaboration

# Japanese-Dutch Collaboration:

## Exploring Common Ground

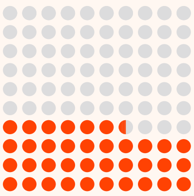
Based on the research performance of Japan and the Netherlands as individual countries established in Chapter 2, it is time to explore common ground, and study the research performed by Japan and the Netherlands collaboratively.

**12,708 publications**

(80.0% Open Access) over the 2019-2024 period.

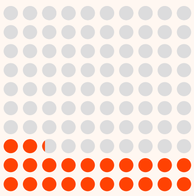
**FWCI of 4.97**

**about five times** the world average



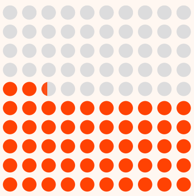
**36.5%**

of publications are in the top 10% most cited journals.



**22.2%**

of publications have both academic and corporate affiliations.



**52.4%**

of publications are in the top 10% most cited publications.

**Figure 8:** An overview of key aspects of Japanese-Dutch collaboration as reflected in co-authored articles in the period 2019-2024.

The period 2019-2024, as shown in Fig. 8, covers almost 13 thousand co-publications, with a strong growth rate of 31%. The remarkably high impact on science as measured by the field-weighted citation impact (FWCI) of 4.97 is immediately noticeable here, almost five times the world average and significantly higher than the FWCI of the individual countries (0.94 for Japan and 1.72 for the Netherlands). The shares in the 10% most cited articles and 10% most cited journals respectively, both reliable proxies for scientific impact, are also impressive at 36.5% (compared to 8% for Japan and 18% for the Netherlands) and 52.4% (compared to 24% for Japan and 41% for the Netherlands). In short, by any metric, the collaborative research between these two nations can be described as of outstanding impact on science worldwide.

Japan and the Netherlands individually have about 7% of their research in academic-corporate partnerships. However, research performed by the two nations together has a surprisingly high contribution from industry-academia collaboration: 23%. These partnerships will be explored in more detail later in this chapter.

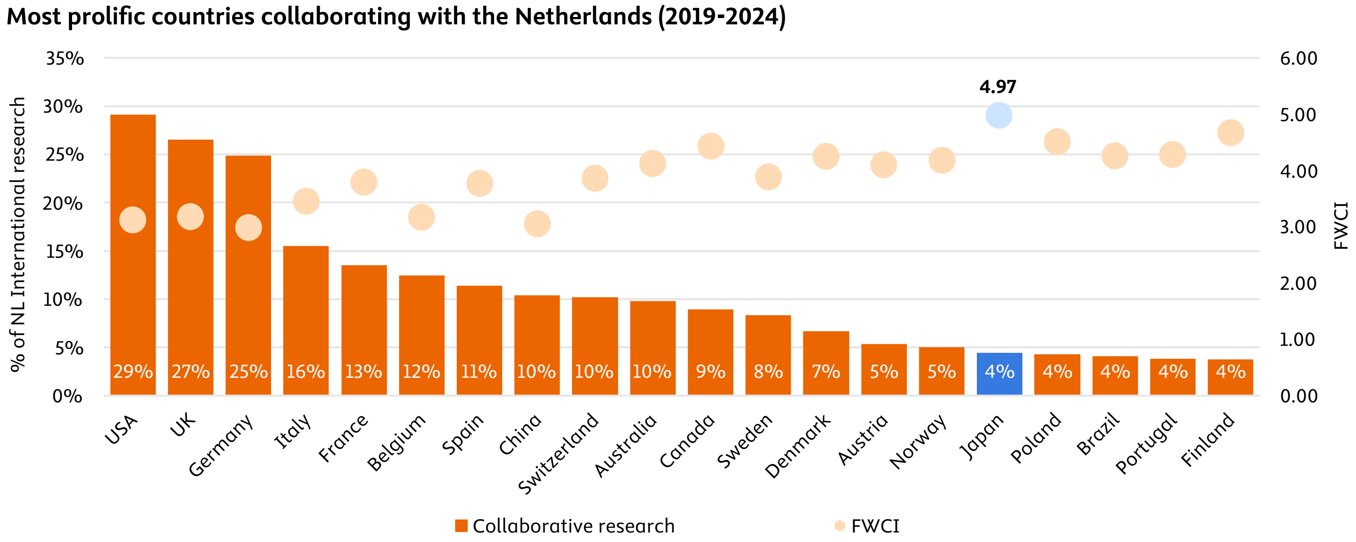



**Figure 9:** The Top 20 most prolific nations collaborating with the Netherlands ranked by the percentage of the total Dutch international partnerships (on the left y-axis), as well as the impact on science worldwide as measured by the FCWI (on the right y-axis).

When looking at international collaboration from a Dutch perspective, it is insightful to ask: which countries are in the Top 20 as measured by scientific output and what can we say about the impact on research? Fig. 9 shows the USA, UK and Germany as the countries the Netherlands collaborates with most and Japan comes in at 16th place. However, when looking into relative impact on science globally, a different picture emerges – collaborations with Japan and the Netherlands has the highest FWCI of 4.97, while the Top 3 countries by volume (US, UK and Germany) come in at a much lower FWCI of around 3.5. In conclusion, the high FWCI of 4.97 for the Japan-Netherlands collaboration is unparalleled by any nation in the Top 20 of countries partnering with the Netherlands.

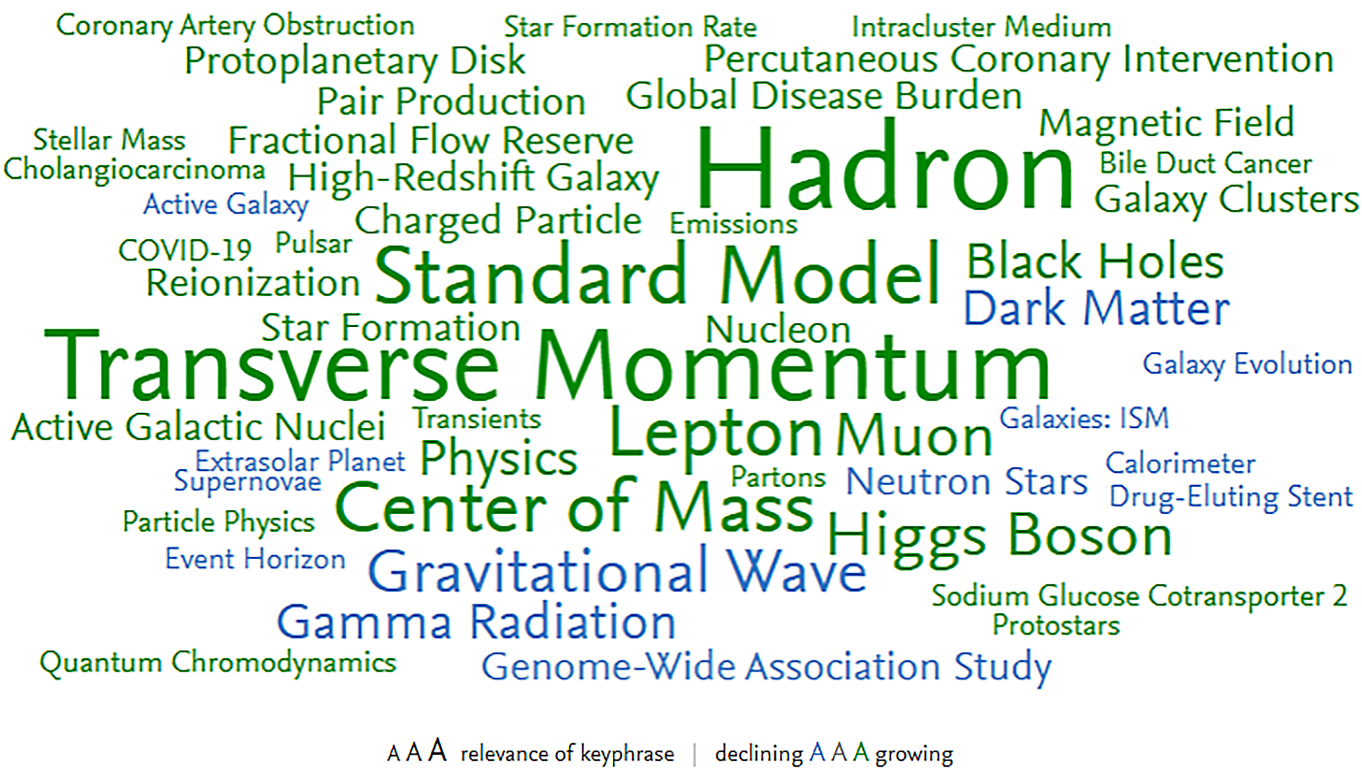



**Figure 10:** Top 50 most used key phrases in joint Japan-Dutch research. The larger the letters the more relevant the key phrase. The colour denotes the growth (in green) and decline (in blue) over time.

To understand the partnership in more detail, it is insightful to understand exactly what kind of research is performed as part of Japanese-Dutch collaboration. 42% of the output is in the physical sciences and 39% in clinical and health, the two dominant disciplines. This is also reflected in Fig. 10, a word cloud which identifies the most used phrases amongst collaborative research. High energy physics jumps out (e.g., Standard Model, Transverse Momentum, Hadron, Lepton, Higgs Boson), as well as astrophysics (e.g., Black Holes, Dark Matter, Gravitational Waves). Additionally, clinical and medical terms are also apparent, including coronary intervention and obstruction, drug-eluding stent and global disease burden.

**4.97**

FWCI of the JP-NL collaboration

**23%**

of all JP-NL collaborations are academic-corporate partnerships

# How has collaboration between Japan and the Netherlands changed over time?

Figure 11 below demonstrates how Japanese-Dutch collaboration has changed over the long-term, studying the 2000-2024 period. Below, the compound annual growth rate (CAGR) is visualised, showing the Netherlands with a similar growth rate to the world average, but less so for Japan. In that 25 year period the Dutch output grew from 25,637 to 76,513 research articles, and Japan from 106,004 to 140,372 research articles. The collaboration between Japan and the Netherlands has grown with an impressive CAGR of 8.5%, well above the world or Dutch rate – it grew from 352 to 2,294 research articles in 25 years.

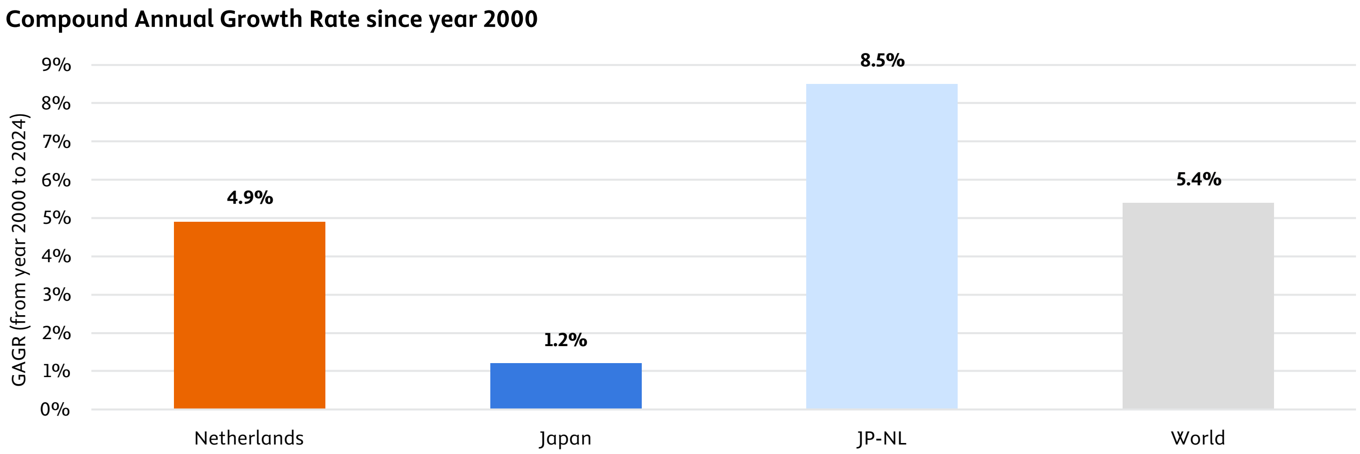



**Figure 11:** The compound annual growth rate (CAGR) since 2000 for the Netherlands, Japan, the collaboration between Japan and the Netherlands and the World.

Even within the short-term, a similar pattern can be seen. Fig. 12 shows international collaboration growth over the past six years (2019-2024), showing that for international research with Japan the growth rate is 10% and for the Netherlands this is 19%. Importantly, for the Japanese-Dutch collaborations this is 32%, illustrating a robust increase over time. The consistent growth in both the long and short terms illustrates the strength of the Japanese-Dutch relationship in research, with further growth in collaborative research to be expected – based on past trends.

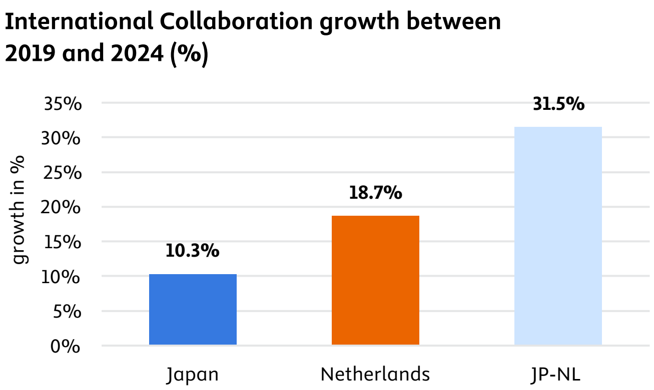



**Figure 12:** The growth rate of international collaboration for Japan, the Netherlands, and the research between Japan and the Netherlands for the 2019-2024 period.

# Which universities are most active in collaborative Japanese-Dutch research?

**Most prolific academic institutions in Japan and in The Netherlands in JP-NL co-authorship**

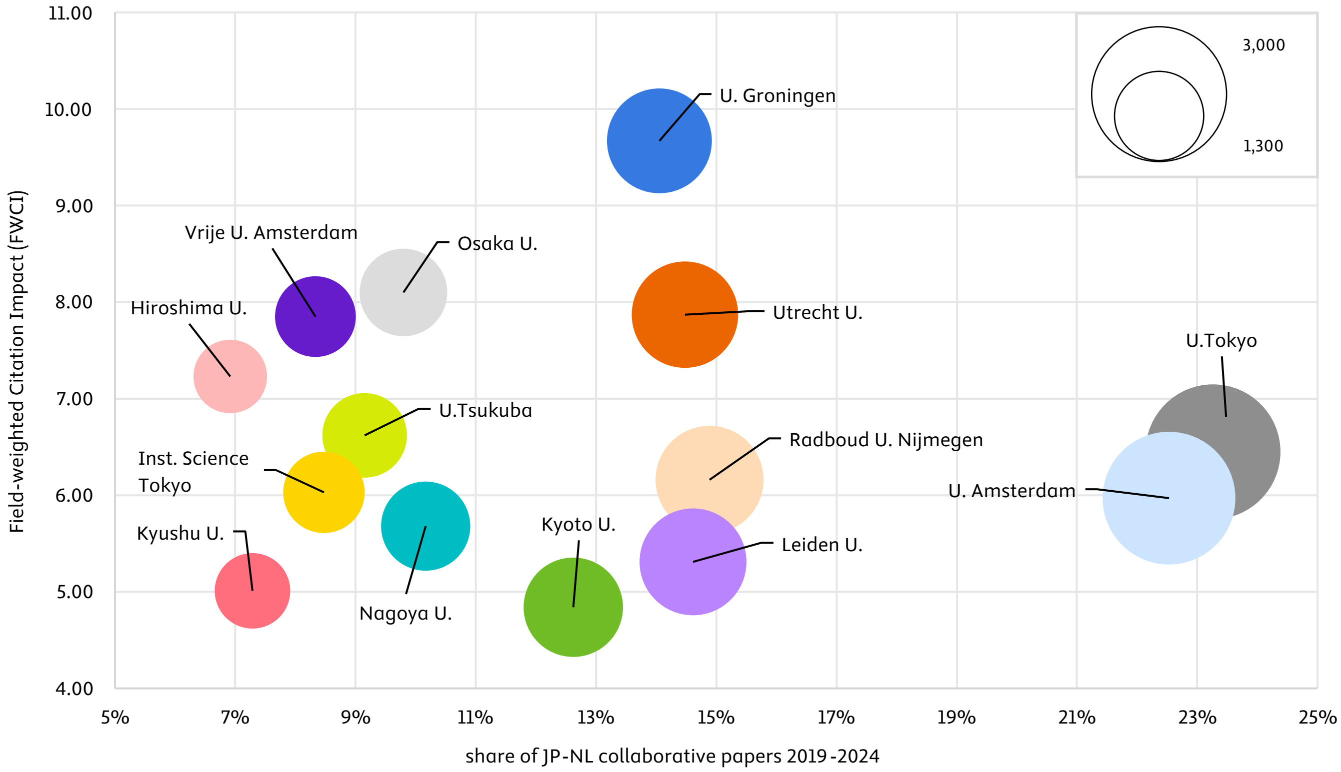



**Figure 13:** Most prolific academic institutions in Japan and in The Netherlands involved in collaborations, 2019-2024. The x-axis shows the relative share, the y-axis the relative scientific impact and the bubble size indicates the volume of publications.

When looking into the institutions in Japan and the Netherlands that contribute most to collaborations, Fig. 13 visualises the University of Tokyo and University of Amsterdam as biggest contributors (both representing almost a quarter of all output). All these prolific institutes have an exceptional impact on research globally as reflected by their high FWCI ranging between 5 and 10 (while the world average is 1.0), with the University of Groningen coming out on top with an FWCI of 9.7 for the Netherlands and Osaka University in the lead on the Japanese side with an FWCI of 8.1.  The distribution of universities from both nations highlights balanced collaboration, taking advantage of each institution and nation's particular strengths to broaden research impact.

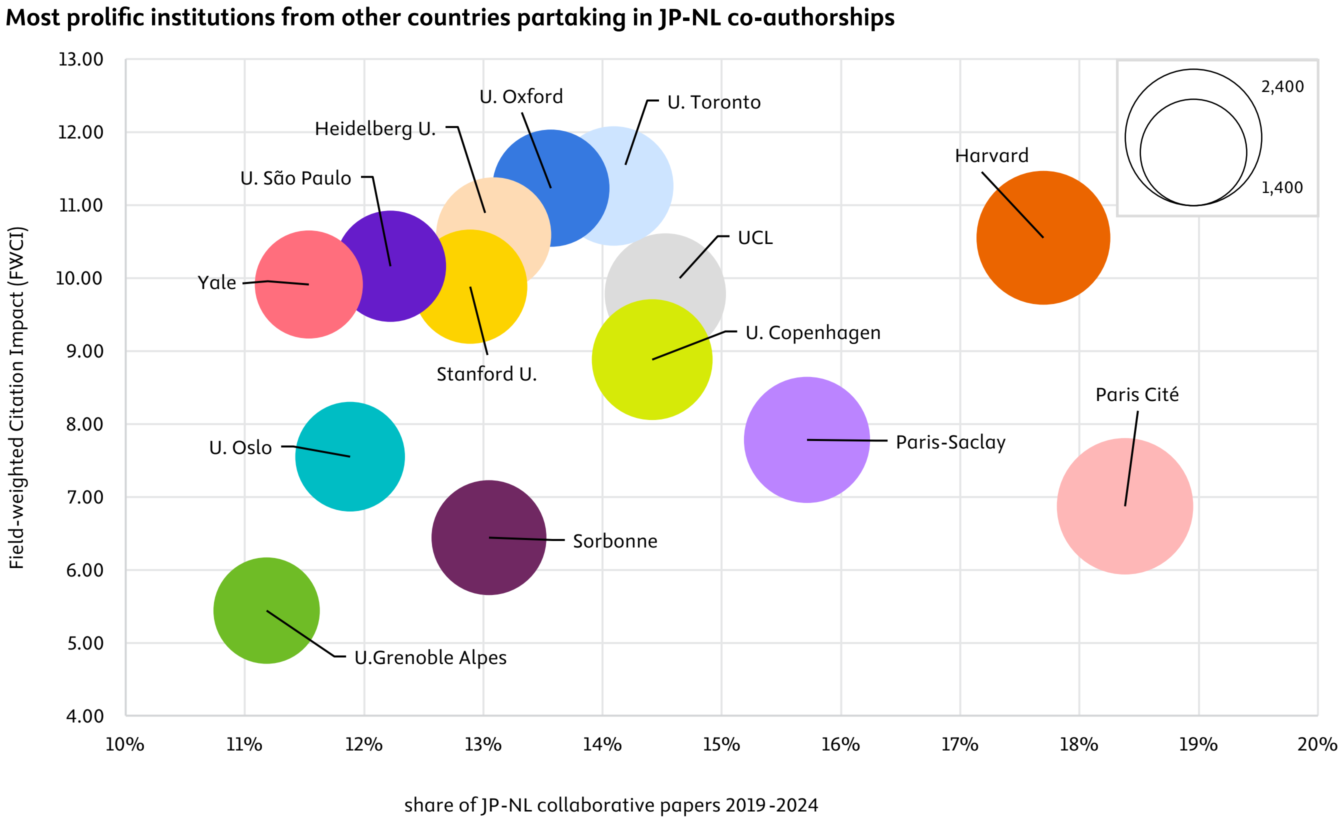
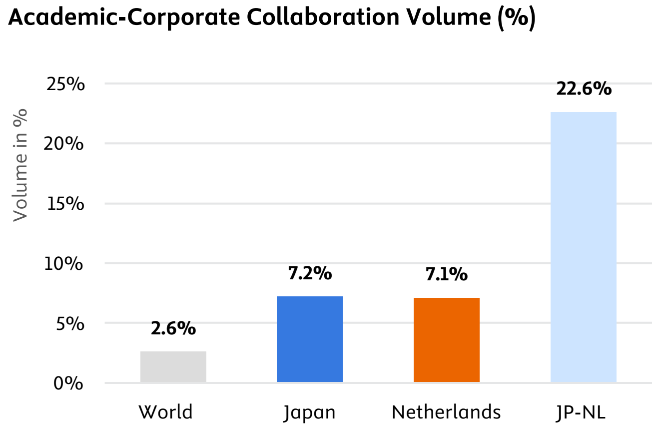



**Figure 14:** Third nation institutions with the highest contributions to Japanese-Dutch collaborations in volume (relative contribution on the x-axis, relative citation impact on the y-axis, while the bubble size indicates the volume of publications).

As international collaboration is typically conducted by multiple nations, such as research for the detection of the Higgs boson in high energy physics and the observations of black holes in astronomy, this pattern is reflected within Japanese-Dutch collaboration. In most of the collaborative research, scientists from multiple nations are involved. The US is part of 64%, UK 52% and Germany 51% of all Japan-Netherlands collaborations, respectively. Only 11% of the Japanese-Dutch partnerships are exclusive between these two nations. If we look at the third nation institutes that are most often involved in the Japan – Netherlands collaborations seen in Fig. 14, it is interesting to identify all partner institutions are globally leading universities with high scientific impact (FWCI between 5 and 11). This is again a testament to the high scientific impact of the Japanese – Dutch partnerships: they are connected to the academic powerhouses around the globe.

# What is the role of corporate-academic partnerships in the Japanese-Dutch collaborations?



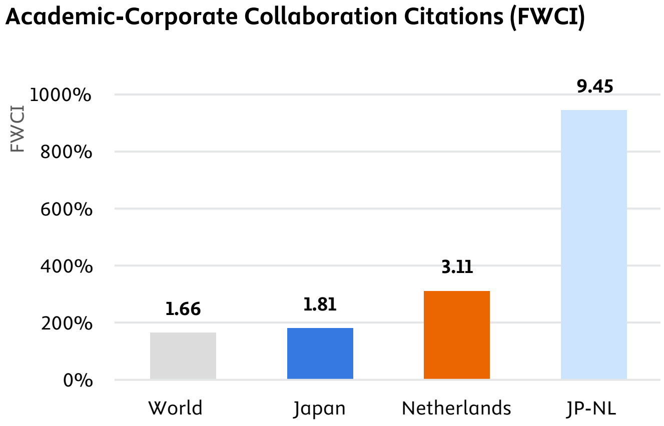




**Figure 15:** The share of academic-corporate partnerships from the World, Japan, the Netherlands and in the Japanese-Dutch collaboration (left) and the relative scientific impact as measured by the FWCI (right).

A large part of investments in research and developments are done by the corporate sector. Collaborations between academia and industry allow each party to leverage on complementary strengths, often collaborations could be between entities in different countries. In this section we explore further the role of academia-corporate collaborations between Japan and the Netherlands. The role of research conducted in the corporate world is significant, with the global average 2.6% of all research originating from industry – academic partnerships, but for Japan and the Netherlands (see Fig. 15) we see almost three times higher levels for both countries. The corporate-academic contribution to Japanese-Dutch collaborations is even much higher at 23%. Looking at the relative citation impact (Fig. 15), we see that the industry-academic partnerships as part of the Japan-Netherlands collaboration have an incredibly high FWCI of 9.45, thus with extraordinary impact on global science. In summary the corporate-academic contribution to the Japanese-Dutch collaboration is stellar, being extremely high in scientific impact at 9.5 times the world average.

Fig. 16, as shown on the next page, highlights the key players in these influential corporate-academic partnerships. In Japan there is a mix of pharmaceutical and engineering companies, with Astellas Pharma, NTT and Toshiba in the Top 3. In the Netherlands, Philips, Cardialysis and ASML take up the top 3 spots. Contributors from outside Japan and the Netherlands are mainly pharmaceuticals, with very high FWCI values. It should be noted that Japanese-Dutch collaboration looks at a subset of a subset, resulting in a low number of articles, making statistical conclusions less reliable than in the case of large datasets.

| In Japan | | Scholarly Output | FWCI |
|---|---|---|---|
| Astellas Pharma Inc. | | 61 | 8.19 |
| Nippon Telegraph & Telephone | | 39 | 3.48 |
| Toshiba Corporation | | 31 | 2.16 |
| Takeda Pharmaceutical Company Limited | | 27 | 4.51 |
| Advanced Telecommunications Research Institute International | | 23 | 2.75 |
| Daiichi Sankyo Company, Limited | | 23 | 11.16 |
| Fujitsu | | 16 | 1.32 |
| Sony Group Corporation | | 14 | 7.29 |
| CYBERDYNE Inc. | | 13 | 2.97 |
| INPEX Corporation | | 13 | 0.77 |
| Mitsubishi Chemical Holdings Corporation | | 12 | 1.8 |
| Otsuka Pharmaceutical Co Ltd. | | 11 | 6.16 |
| OYO Corporation | | 11 | 0.12 |
| Tokyo Electron Limited | | 11 | 3.24 |
| Toyota Motor | | 10 | 2.39 |
| **In the Netherlands** | | | |
| Koninklijke Philips N.V. | | 44 | 2.56 |
| Cardialysis B.V. | | 19 | 6.94 |
| ASML Netherlands BV | | 18 | 2.2 |
| Dutch Polymer Institute | | 13 | 1.11 |
| Elsevier | | 12 | 1.81 |
| FrieslandCampina | | 11 | 5.9 |
| Royal Dutch Shell PLC | | 11 | 1.25 |
| **Elsewhere** | **Country** | | |
| China Nuclear Corporation | China | 279 | 2.05 |
| Samsung | South Korea | 184 | 13.61 |
| AstraZeneca | UK | 131 | 17.27 |
| MOH Holdings Pte Ltd. | Singapore | 113 | 8.78 |
| F. Hoffmann-La Roche AG | Switzerland | 96 | 15.71 |
| Novartis | Switzerland | 96 | 9.83 |
| Johnson & Johnson | USA | 94 | 7.11 |
| AbbVie | USA | 92 | 8.9 |
| Pfizer | USA | 88 | 23.93 |
| Amgen Incorporated | USA | 80 | 12.55 |
| Merck | USA | 77 | 14.13 |
| Eli Lilly | USA | 70 | 15.12 |
| Leidos | USA | 69 | 6.21 |
| Genentech Incorporated | USA | 66 | 19.99 |
| Alphabet Inc. | USA | 63 | 28.33 |
| Novo Nordisk Foundation | Denmark | 60 | 31.84 |

**Figure 16:** The most prolific corporate contributors to the Japanese-Dutch collaborations from Japan, the Netherlands and third countries contributing to Japan – Netherlands partnerships.

# What is the impact of Japanese-Dutch research on innovation and what do the respective innovation landscapes look like?

In this section we discuss the impact of the joint Japanese-Dutch research on innovation and we will also look into more detail what the patent landscape looks like in Japan and in the Netherlands. One way to measure the impact research has on innovation is through the connection between scientific articles and patents (here we study the time frame 2014-2024 and data collected in May 2025). For Japan and the Netherlands individually, as shown in Fig. 17, the relative share of research articles cited in patents is very similar, between 4% and 5%, still above the world average of 3.6%. However, for the collaborative research between Japan and the Netherlands it is higher at 6.3%. Taking a closer look at articles cited in patents, the data reveals that many of the articles predominantly come from medicine (53%) and life sciences (33%), with such articles having a high scientific impact.

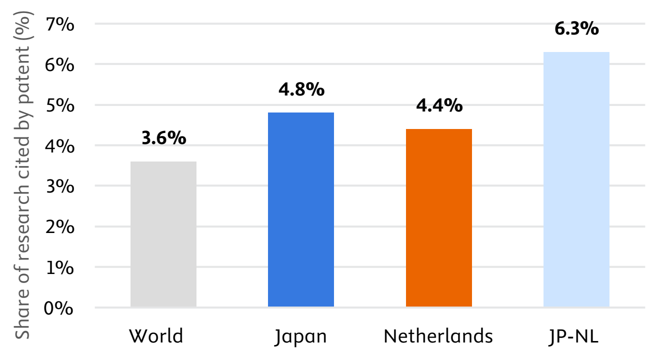
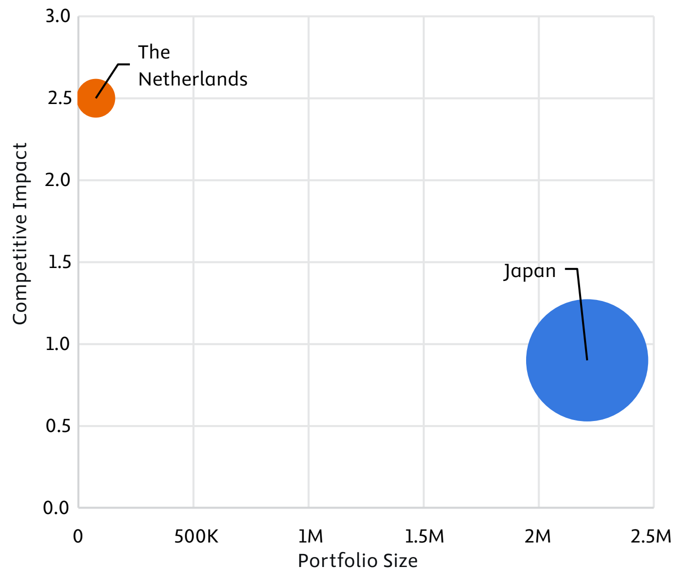



**Figure 17:** Share of research published between 2014 and 2024 with at least one citation by a patent.

Next we explore the patent landscape in the individual countries Japan and the Netherlands (we are not focusing here on the joint collaboration aspect between these two countries). Fig. 18 shows an overall visualisation of the patent landscape, with the x-axis showing competitive impact, y-axis the total portfolio size and the size of the bubbles representing the patent asset index. The competitive impact estimates the business value of a patent (a relative metric: a competitive impact of 2 means the patent's impact is twice as strong as that of an average patent from the field), while the patent asset index is a measure of global tech strength and innovation (see Appendix 1 for definitions). We see that Japan is almost 30 times larger than the Netherlands in terms of portfolio size, while the patent competitive impact shows another picture: the Netherlands is almost 3 times larger than Japan.




**Invented in:**

| **The Netherlands** | | **Japan** | |
|---|---|---|---|
| Portfolio size: | 75,744 | Portfolio size: | 2,210,582 |
| Competitive Impact: | 2,5 | Competitive Impact: | 0.9 |
| Patent Asset index: | 191,100 | Patent Asset index: | 1,895,799 |

**Figure 18:** Patents invented in the Netherlands and in Japan. (Source: PatentSight)

**Patents invented in the Netherlands (75,805 patent families)**

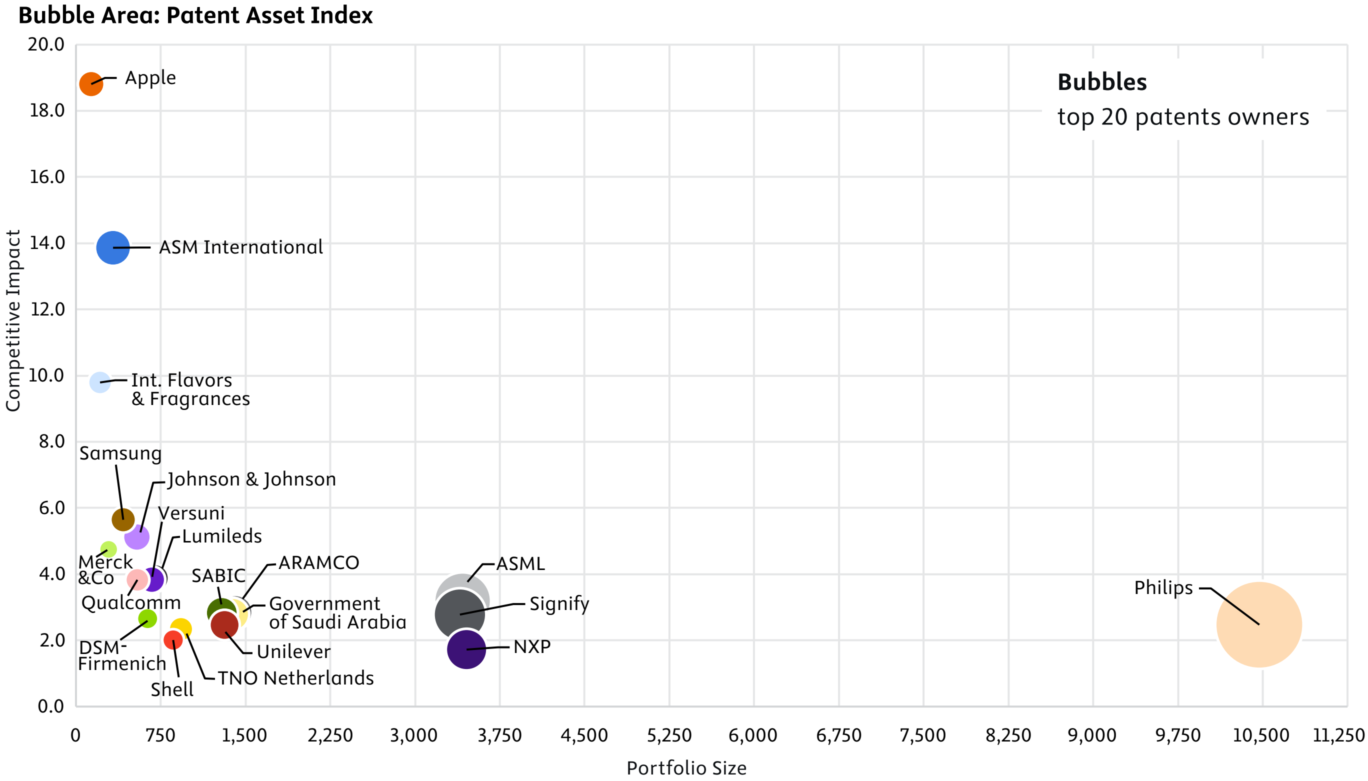



**Figure 19:** Patents invented in The Netherlands, top 20 patents owners. (Source: PatentSight)

**Patents invented in Japan (2,218,154 patent families)**

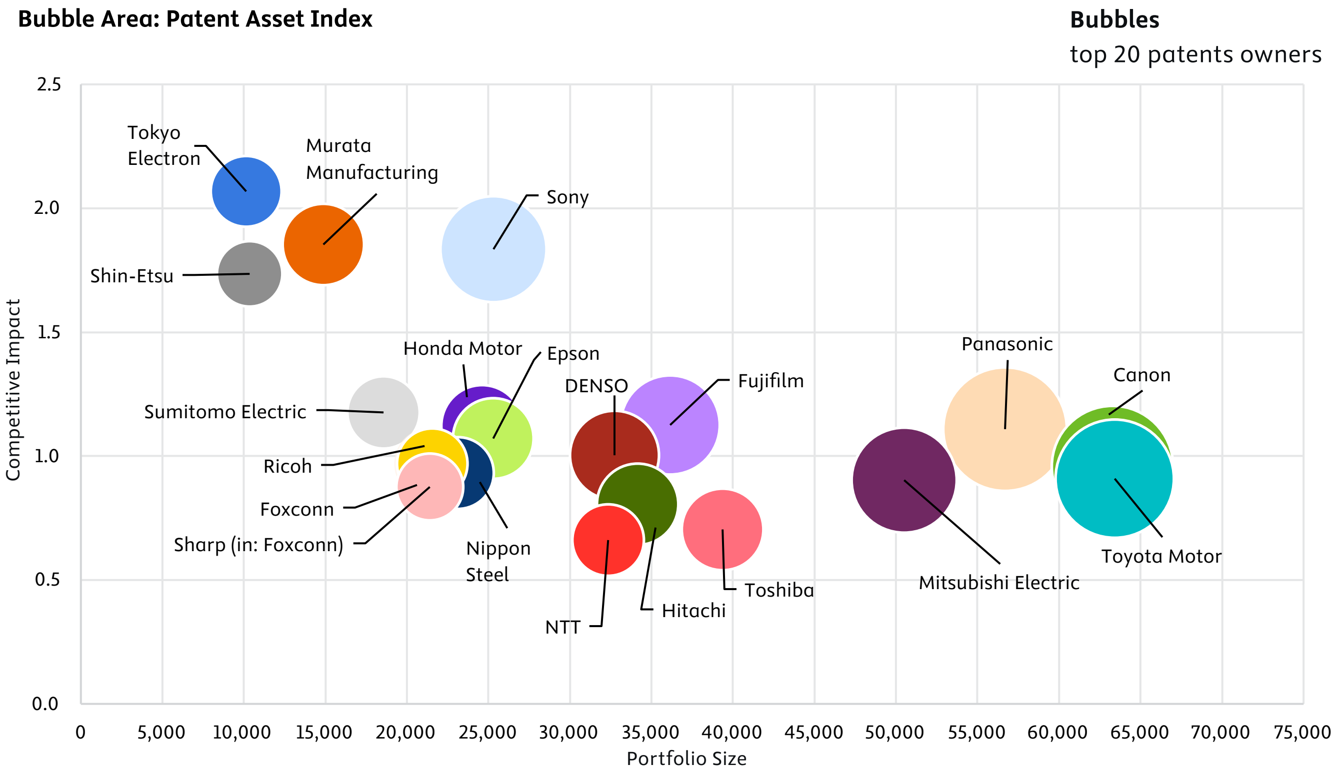



**Figure 20:** Patents invented in Japan, top 20 patents owners. (Source: PatentSight)

Further, Fig. 19 and 20 demonstrate how patent strategies and companies present in each nation impact the volume and competitive impact of such patents. The Dutch patent landscape is dominated by Philips, outperforming any other player in number of patents by far. Other key players are a mix of Dutch and non-Dutch companies such as NXP, ASML, Shell, Unilever, but also Apple (with a patent competitive impact of 19), International Flavors & Fragrances, and several Saudi-linked companies – some of these international companies might be legally linked to the Netherlands (or even traded at the Amsterdam stock exchange) but might not be really part of the Dutch innovation ecosystem. By contrast in Japan the patent landscape is dominated by the Japanese corporate 'household names': Canon, Toyota, Panasonic, and Mitsubishi, who all do well on patent portfolio size. Tokyo Electron and Sony perform well on patent competitive impact (both around 2, still far removed from Apple's 19).

Comparison of patent activity between countries is not straight-forward, as certain sectors in industry are very patent-rich. If such sectors are dominant, a country will be a patent leader. Japan, for example, excels in sectors like electronics, automotive, and materials science and is therefore inherently patent-rich. On the other hand, the Netherlands is stronger in agriculture, logistics, software and services which are typically less patentable. Nevertheless, it is fair to state that Japan is a powerhouse on the patent front and that Japanese and Dutch research and especially Japanese-Dutch science is well cited in patents worldwide – a strong indication of the impact of research on innovation.

# What is the impact of research on policy?

The impact of science on policy can be measured through the research articles cited in policy documents worldwide. Fig. 21 shows a large difference between Japan and the Netherlands with 4% and 13%, respectively, while the Japanese-Dutch partnerships come in at an even higher level of 17%, which is more than 3 times the world average which is 4.6%.  What kind of research articles are cited in policy documents? Most are in Clinical & Health (60%), followed by Physical Sciences (24%) and Life Sciences (22%).

It should be noted that many of the policies that cite research are from intergovernmental and international government organizations, which explains the lower percentage of citations from Japan and the Netherlands. Overall, Dutch research, but even more so Japanese-Dutch research has strong impact on global policies but perhaps not so much on their national policies.

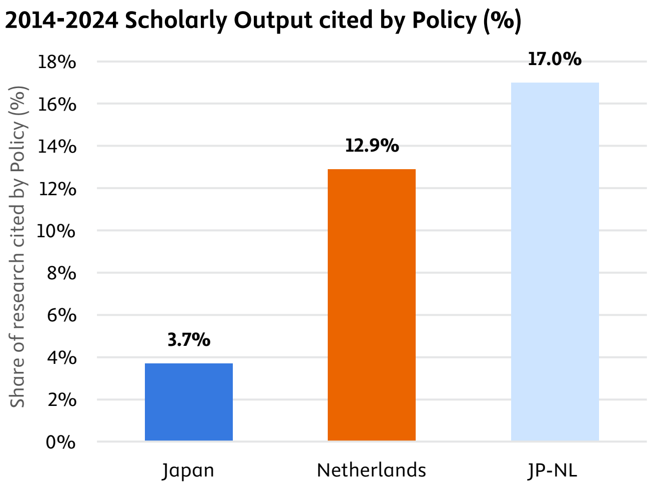



**Figure 21:** Share of scholarly output cited by policy documents (the world's average is 4.6%) as of April 2024.

# The Role of Research in Key Technologies

## Key technologies drive innovation, competitiveness, and economic growth. As a result, they are often also seen as part of national security.

Japan identified seven key strategic technologies that support its economy in the 6th Basic Science, Technology and Innovation Plan. In the Netherlands, the National Technology Strategy of 2024 identified 10 key technologies of national priority.

As like-minded nations with shared common ground, collaborations between the Netherlands and Japan in key technologies serve to strengthen both nations. This chapter explores the Netherlands and Japan's research collaboration, as well as each country's activity in the following key technologies identified by both nations as strategic: Artificial Intelligence – AI, Semiconductors, Cybersecurity, Quantum Technologies, Biotechnology, Photonics, Rare Earths and Critical Materials, Robotics, and Battery Technologies. The datasets used to map out the key technologies can be found in Appendix 3.

# Which institutions are most active in Key Technology scholarship in Japan and the Netherlands?

To give further context to the Japan and the Netherlands collaboration, in this section we investigate some detail around some of key technologies for Japan and the Netherlands. This will also help to understand where collaboration could be to be developed further around key technologies.

As already seen in the chapter dealing with academia-corporate collaboration, notably looking at patent portfolios, Japan is a technological powerhouse with some of the highest investments in research and development globally. In terms of key technologies, looking at Fig. 22, we see that Robotics, Photonics, Quantum Technologies and Semiconductors are strong areas in terms of relative activity for Japan with Quantum Technologies especially highly cited. To provide a bit further context, as seen in Fig. 23, Japan has a strong photonics tradition with e.g. Nippon Telegraph and Telecommunications – NTT, Fujitsu, and Hamamatsu Photonics, to mention only three corporates involved. Japan further has had active research in quantum technologies, both from academia and industry, and in terms of quantum computing, the so-called Moonshot R&D program is one of the national strategic projects. It is interesting to observe the high FWCI of Japanese quantum technologies (more than 40% above world average).

In robotics, historically Japan has been a leader in industrial robotics, e.g. with the “Big Four” Fanuc, Yaskawa, Kawasaki, and Daifuku; as well as in service robotics, the first full scale humanoid robot WABOT-1 demonstrated already in 1973 by Waseda University. Looking at the chart, however, in robotics Japan has less citation impact and less international collaboration. In semiconductor technology, Japan was an early leader, however, has notably fallen behind Taiwan as well as South Korea. Whilst research remains strong, the recent investments both of TSMC of Taiwan and the creation of the RAPIDUS consortia with investments into 2nm technologies, is motivating Japan to regain its former strength in semiconductor manufacturing. As already noted earlier, relative activity in AI, Cybersecurity and Rare-Earths and Critical Materials is below the world average. With investments increasing this may, however, change in the coming years.

**Key Technologies in Japan (2019-2024)**

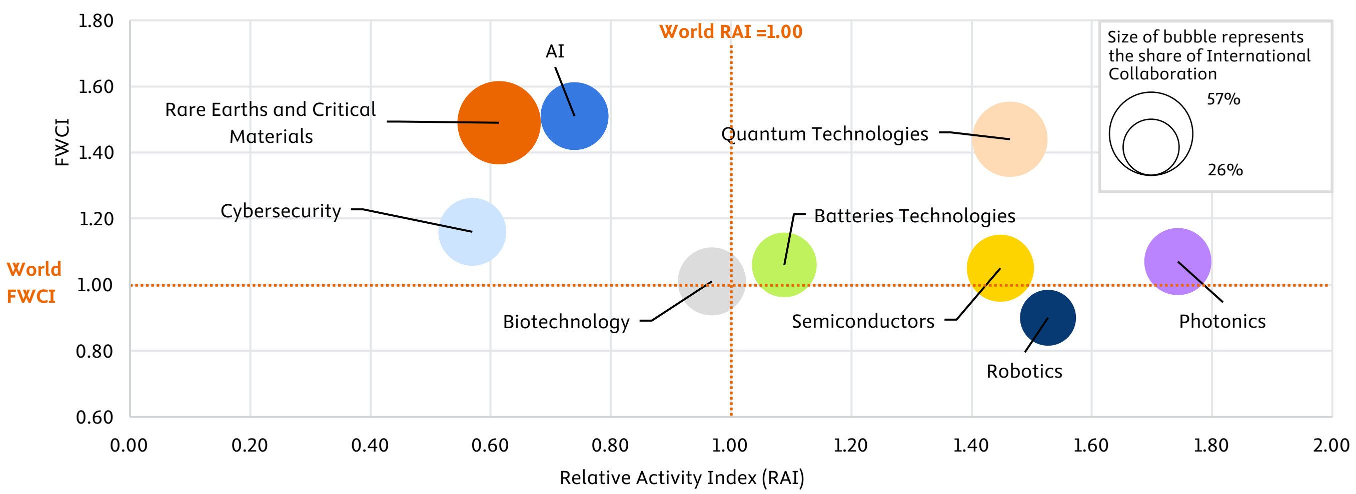



**Figure 22:** Relative Activity Index (RAI), Field-Weighted Citation Impact (FWCI) and International Collaboration levels in Japan

| Prolific institutions in Japan 2019-2024 | University 1 | University 2 | University 3 | Corporate 1 | Corporate 2 | Corporate 3 |
|---|---|---|---|---|---|---|
| **AI** | U. Tokyo | Kyoto U. | U. Osaka | Nippon Telegraph & Telephone | NEC Corp | Mitsubishi Electric Corporation |
| **Semiconductors** | U. Tokyo | Tohoku U. | U. Osaka | Nippon Telegraph & Telephone | Mitsubishi Electric Corporation | Hitachi Ltd |
| **Cybersecurity** | U. Tokyo | Waseda U. | U. of Electro-Communication | Nippon Telegraph & Telephone | KDDO Corporation | NEC Corporation |
| **Quantum Technologies** | U. Tokyo | U. Osaka | Kyoto | Nippon Telegraph & Telephone | Toshiba Corp | Hitachi Ltd |
| **Biotechnology** | U. Tokyo | Kyoto U. | U. Osaka | Takeda Pharmaceutical | Ajinomoto Co Inc | Daiichi Sankyo |
| **Photonics** | U. Tokyo | Kyoto U. | U. Osaka | Nippon Telegraph & Telephone | Hamamatsu Photonics K.K. | Mitsubishi Electric Corporation |
| **Rare Earths and Critical Materials** | U. Tokyo | Kyushu U. | Tohoku U. | Nippon Steel Corp | Toyota Central R& D | Hitachi Ltd |
| **Robotics** | U. Tokyo | U. Osaka | Institute of Science Tokyo | Honda Motor Co | Hitachi Ltd | Nippon Telegraph & Telephone |
| **Battery Technologies** | Kyoto U. | Tohoku U. | Osaka Metropolitan U. | Toyota Central R&D | Toyota Motor | Hitachi Ltd |

**Figure 23:** Top three academic and top three corporates in Key Technologies for Japan.

Figure 23 shows the top three most prolific academic institutions and corporations are shown in terms of scholarly output for the key technologies. It is striking to see the strong position of the University of Tokyo in most key technology areas, as well as Nippon Telegraph and Telephone (NTT). It is to be noted that the telecom company NTT, which was government owned until 1995 has a strong basic research and core technology research unit. To further note, not shown in the table, is that large public research organizations, such as RIKEN and National Institute of Advanced Industrial Science and Technology (AIST) also play a key role in key technology research.

Moving to the activity of the Netherlands around key technologies, looking at areas of strong relative activity, visualised in Figures 24, in the area of Photonics the Netherlands has a strong network of research institutions, including the Dutch Research Institute for Photonics (Dutch Institute for Fundamental Energy Research, DIFFER), and universities such as Delft University of Technology, and corporations such as LioniX. In Quantum Technologies, QuTech at TU Delft, and the Netherlands Organization for Applied Scientific Research (TNO) have strong contributions to quantum computing, quantum cryptography, and quantum networks.

Further, the government has initiatives such as the "National Agenda Quantum Technology" to position the Netherlands as a global leader in quantum research and applications. TNO also recently announced that it will double its quantum testing facilities with the launch of a new hub at the House of Quantum in Delft. The new TNO hub, strategically located in the heart of the Delft quantum ecosystem provides enhanced accessibility and support for startups and is partly funded by the National Growth Fund programme Quantum Delta NL.

In semiconductors, key players like ASML, ASM and NXP semiconductors have cemented the country's leadership in manufacturing and innovation. Recent efforts to concentrate the ecosystem with the ChipNL Competence Centre as part of the European Chips Act will further enhance growth prospects. As such, photonics, quantum and nanotechnologies are strong focus areas for Dutch innovation, with several technology missions from the Netherlands to Japan. Hence, it is insightful to see how this focus is reflected in terms of relative activity as well.

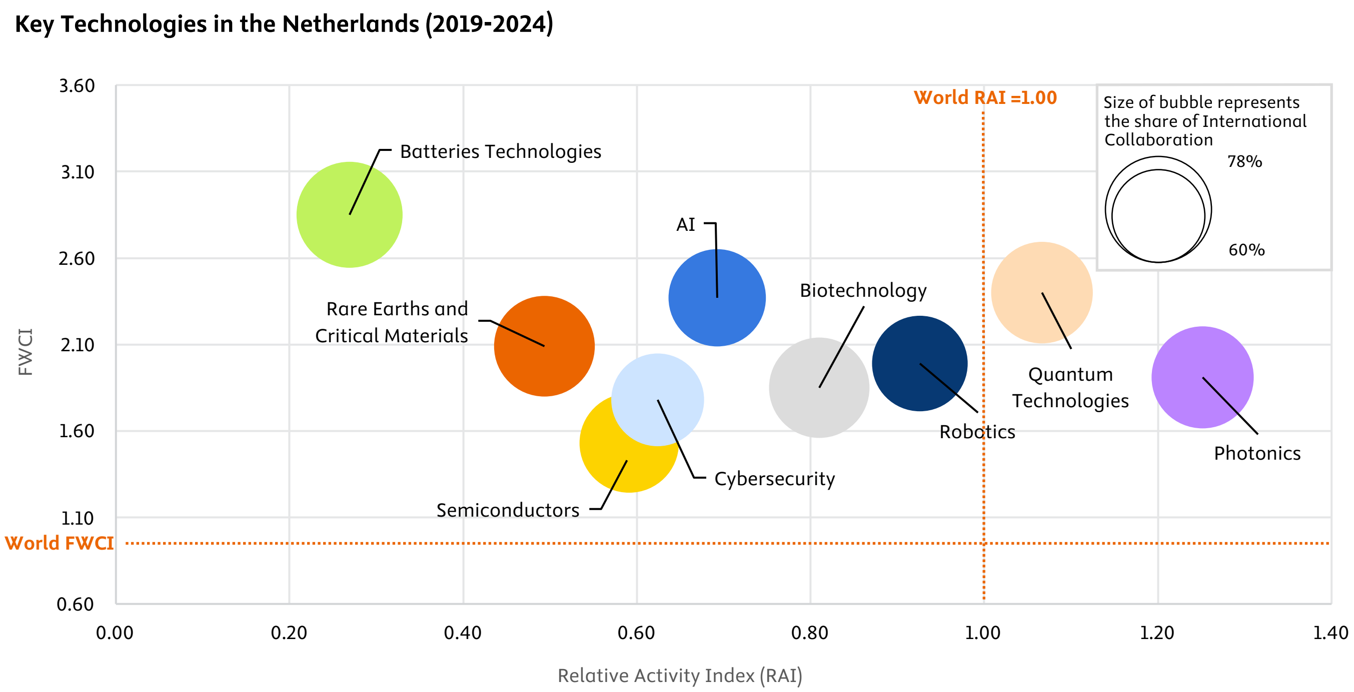



**Figure 24:** Relative Activity Index (RAI), Field-Weighted Citation Index (FWCI) and international collaboration levels of Dutch research in selected key technologies

| Prolific institutions in the Netherlands 2019-2024 | University 1 | University 2 | University 3 | Corporate 1 | Corporate 2 | Corporate 3 |
|---|---|---|---|---|---|---|
| **AI** | Delft | U. Amsterdam | Eindhoven | Koninklijke Philips | ASML Netherlands | Elsevier |
| **Semiconductors** | Delft | Eindhoven | Twente | NXP Semiconductors | ASML Netherlands | LioniX International |
| **Cybersecurity** | Delft | Twente | Leiden | NXP Semiconductors | Koninklijke Philips | Airbus |
| **Quantum Technologies** | Delft | U. Amsterdam | Eindhoven | NXP Semiconductors | Single Quantum BV | LioniX International |
| **Biotechnology** | Wageningen | Delft | Utrecht | DSM Food Specialties | Koninklijke Philips | NIZO food research |
| **Photonics** | U. Amsterdam | Eindhoven | Groningen | LioniX International | ASML Netherlands BV | Single Quantum BV |
| **Rare Earths and Critical Materials** | Delft | Eindhoven | Utrecht | Royal Dutch Shell PLC | AkzoNobel | Advanced Electromagnetics BV |
| **Robotics** | Delft | Twente | Eindhoven | Koninklijke Philips | Airbus | ASML Netherlands BV |
| **Battery Technologies** | Delft | Eindhoven | Twente | Stellantis N.V. | NXP Semiconductors | Royal Dutch Shell PLC |

**Figure 25:** Top three academic and corporates in terms of scholarly output in the Netherlands.

In Fig. 25, the top three academic institutions and corporates from the Netherlands in key technologies are presented. The strong position of Delft is particularly notable, alongside Eindhoven and Twente in many areas. Not surprisingly there is a strong position of NXP Semiconductors, Philips and ASML. Elsevier features in AI because of its publications related to AI in chemistry and drug discovery.

# What is the focus from the Netherlands, Japan and the Netherlands-Japan collaboration on Key Technologies?

Let us first examine the key technology focus areas of collaboration between Japan and the Netherlands over the past five years. We do this by looking at the relative activity (or RAI, definition in Appendix 1) of Japan, the Netherlands, and the collaborative effort around key technologies. In the paragraph to follow we will in some more detail address what is the focus of Japan and the Netherlands separately, this helps to provide further context around how Japan and the Netherlands collaborate.

Fig. 26 shows the relative activity - RAI for each relative technology in comparison to overall research output across all key technologies for Japan, the Netherlands, and Japan-Netherlands Collaboration. It is important to note that relative activity is normalized against the world, for instance in battery technologies and Artificial Intelligence, the increasingly strong activity of China and India will make other countries seem less active. This stated, Fig. 26 notably visualises the strong activity around Photonics and Quantum Technologies, but less collaboration in other areas, such as battery technologies, semiconductors, and AI. Joint research on key technologies also has a strong academic impact, five times the world average, again illustrating the power of collaboration between these two nations.

**Volume of research in relative activity | Selected key technologies**

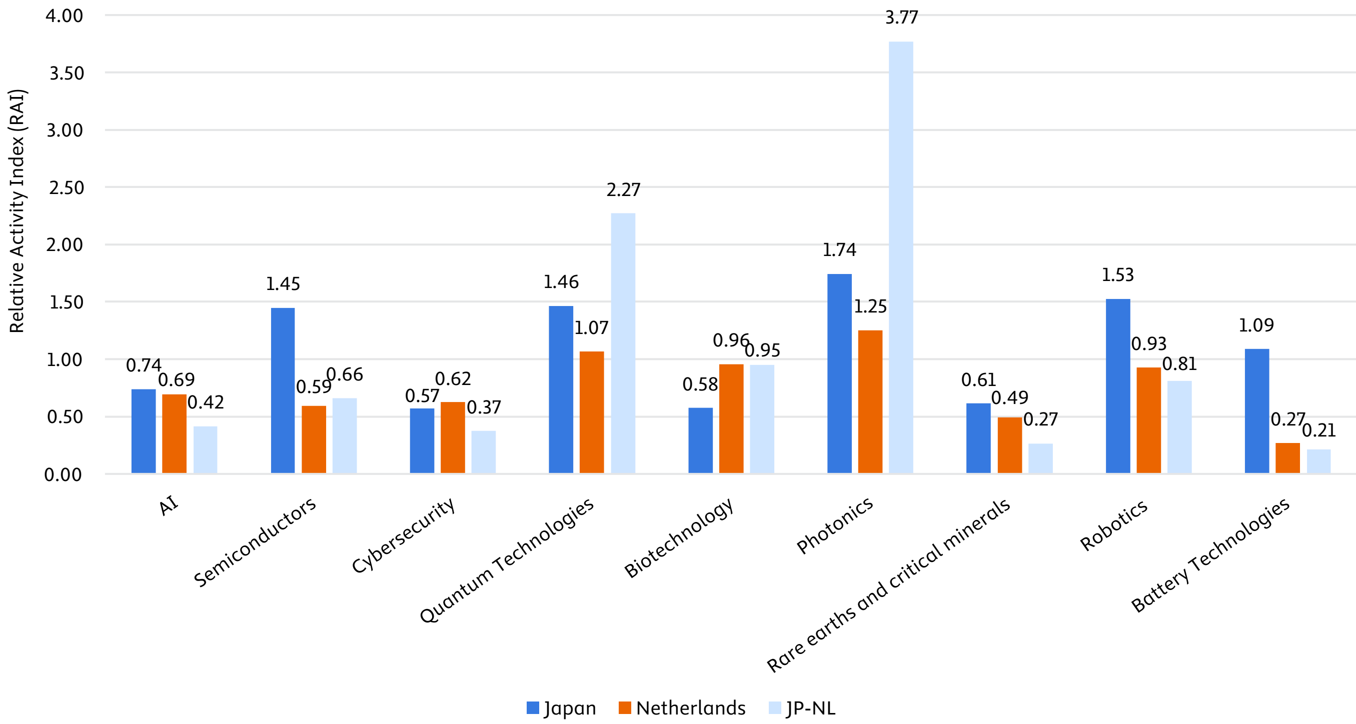



**Figure 26:** Volume of research expressed in relative activity in selected key technologies in Japan, in the Netherlands and in Japanese-Dutch collaboration.

It is interesting to note the lower relative activity in Cybersecurity and AI both for the Netherlands and Japan. While Japan had an early focus AI with the fifth-generation computer project in the 1980s, the country lost some of its competitive edge to rapid global development. At present, the national AI strategy launched in 2019 put focus on three research centres at the University of Tokyo, RIKEN and at the National Institute for Advanced Industrial Technology (AIST). There is also increasing industry investment by large corporates, as well as start-ups such as the Unicorn Preferred Networks, Abeja and Sakana.AI. Recently NVIDIA and the Japanese telecom company Softbank are collaborating to build an integrated AI ecosystem in Japan – one that spans everything from AI research and development to its commercialization in telecommunications and beyond.

With the acceleration driven by generative AI, the Dutch government has announced its ambition to establish a strong AI ecosystem in the Netherlands and the EU. This approach strives to take every opportunity for innovation based on responsible generative AI. The current focus particularly emphasises embracing opportunities and accelerating adaption of AI, in ways deemed to serve public values and contribute to well-being, prosperity, sustainability, justice, and security. Improving access to supercomputing, high-quality data and expertise for businesses, researchers, and public institutions are to be embedded in the Dutch Digitalization Strategy to be released mid-2025.

# What other countries are most active in collaborations with Japanese-Dutch co-authored research on Key Technologies?

Let us finally look at the broader international collaboration aspects of key technologies. It is worthwhile to note that despite many of these technologies being of importance for national competitiveness and security, research collaboration is highly international. For instance, for the Netherlands, 67% of the Netherlands publications in key technologies are with international partners. In Fig. 26, the left table shows the international partners for Japan and the Netherlands across all areas of research, and the right table across key technologies. From the bar charts in Fig. 27, comparing to scholarship overall, there is an interesting dynamic as the USA leads significantly in collaboration overall and in key technologies, but beyond the US, within key technologies, Germany takes over, the UK falling not too far behind the USA. Looking further to the right, China and Switzerland are more prevalent within Key Technology collaboration for Japan-Netherlands – highlighting how differing partnerships are utilized for their strengths across research areas.

To summarize this chapter, the collaboration between Japan and the Netherlands in key technologies complements and strengthens national efforts in both nations. Both countries have identified strategic areas of key technologies, including Artificial Intelligence, Semiconductors, Quantum Technologies, Photonics, and Robotics, which align with their national technology strategies. Quantum technologies and photonics are the two key technologies where Japan and the Netherlands together have a high level of activity, showing more than twice the world average for quantum and almost 4 times for photonics. The University of Tokyo and NTT are the key Japanese players, while in the Netherlands, Delft University, the University of Amsterdam as well as LioniX and NXP are in the lead.

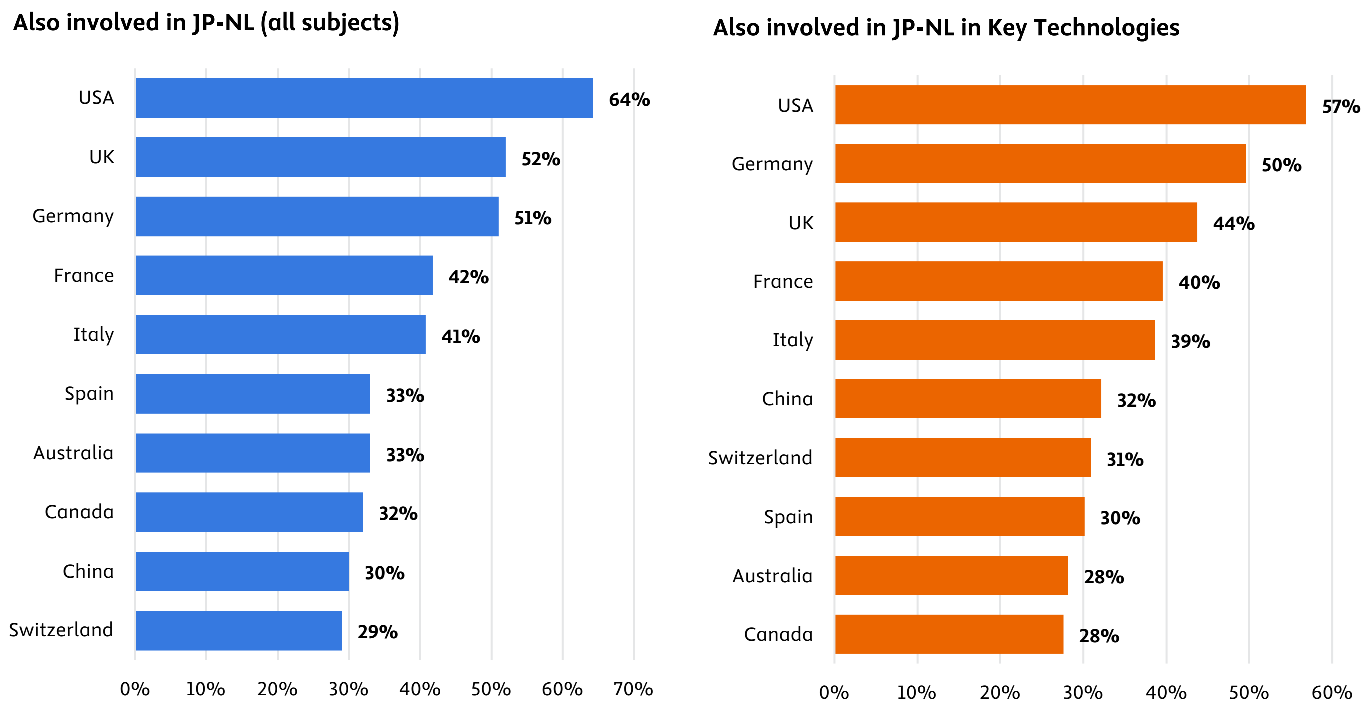



**Figure 27:** Top countries active in Japanese-Dutch collaborative research, for all research (in blue) and for research in Key Technologies (in orange).

# Conclusions

The collaboration between Japan and the Netherlands can be characterized as a story of success and opportunity and represents a significant force in the global research landscape, characterized by a shared commitment to advancing scientific inquiry and innovation.

As we have observed, both nations have adapted to the shifting dynamics of global scholarship, where the centre of gravity is increasingly moving towards Asia. Despite the challenges posed by rising competitors such as China and India, the Netherlands and Japan maintain their positions as influential contributors to international research, leveraging their unique strengths to enhance their scholarly impact.

First and foremost, individually both nations see successes across scholarly output. Japan, with its rich tradition in STEM fields, ranks prominently on the global stage, exhibiting strong outputs in medicine, engineering, and physical sciences. While Japan's international collaboration rates have historically been lower compared to its peers, recent trends indicate a steady increase in cooperative research efforts, particularly in response to societal challenges and technological advancements. Conversely, the Netherlands has consistently demonstrated high levels of international collaboration, with a remarkable 65% of its research involving international partners. This collaborative ethos is reflected in its strong contributions to clinical and health sciences, social sciences, and engineering, which are bolstered by a robust culture of Open Access publishing.

The data presented in this report underscores the exceptional impact of Japanese-Dutch research collaborations. With nearly 13,000 co-publications from 2019 to 2024, the partnership has achieved a Field Weighted Citation Impact (FWCI) of 5, an impressive five times the world average. Moreover, out of the top 20 partner nations with the Netherlands, collaborations with Japan show the highest impact – highlighting the unique character of this partnership. Amongst these collaborations, the impact seen on innovation is twice the world average, and four times the global average for policy.

A key role in this success story is played by the partnership between industry and academia which contributes almost a quarter of all Japanese-Dutch collaborations (almost eight times the world average) with a scientific impact of almost ten times the global average – a truly impressive feat.

When we look at key technologies of strategic importance then two areas jump out where Japan and the Netherlands are far more active compared to other countries: photonics and quantum technology. The focus on key technologies such as quantum technologies, photonics, and artificial intelligence exemplifies how both countries can leverage their respective strengths to foster advancements that contribute to economic growth and societal well-being.

Amongst these successes, there is still room for new opportunities. Whilst the impact of the collaboration between these two nations is high and multi-facetted, the level of collaboration is modest: Japan ranks only 16th in the Top 20 most prolific countries the Netherlands is collaborating with, contributing 4% to all international partnerships. There is room for improvement and growth here in terms of engagement and volume of collaboration.

Further, potential areas to look for growth would be the key technologies where Japan is much more active than the Netherlands: semiconductors, robotics and battery technologies.

Both nations are building on centuries of relations, supported on both sides by academia, corporates and governments, all further strengthening the common ground between Japan and the Netherlands.

# Appendix 1: Definitions

This report is primarily based on analysis made with Elsevier's tool SciVal. SciVal is based on output and usage data from Scopus, a source-neutral abstract and citation database curated by independent subject matter expert (see Appendix 2). Here the terminology used within the report is defined.

### Scholarly Output
Scholarly Output describes the products of scholarly activity, such as journal articles, books, book chapters, conference papers, and other forms of research dissemination. Throughout the report, when looking at collaborations, we use whole counting, meaning that collaborating entities on a scholarly publication all get a full count in terms of contribution.

### Authors
The number of authors is a deduplicated count of authors at the institution who have contributed to the 'Scholarly output' (i.e. the number of papers published) at that institution during the time analysed.

### Citation
A citation is a formal reference to earlier work made in document, frequently to other scholarly papers, but also to policy documents or patents. A citation is used to credit the originator of an idea or finding and is typically used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by a paper from subsequently published papers and/or policy documents as well as patents, can be used as a proxy of the quality, importance, societal impact or economic translational value of the reported research.

### FWCI (Field-Weighted Citation Impact)
Field-weighted citation impact (FWCI) is an indicator of mean citation impact and compares the actual number of citations received by a paper with the expected number of citations for papers of the same document type (article, review, or conference proceeding), publication year, and subject area. When the paper is classified in two or more subject areas, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (e.g., reviews typically attract more citations than research articles), as well as subject specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

### Subject Area Classification
The subject area classification used in this report is based on the Journal Classification (ASJC) used in Scopus database, further condensed using the classification by Times Higher Education for their subject rankings. Scopus uses a hierarchical structure with 27 main subject areas. Times Higher Education THE agglomerate these 27 areas into 11 broader subject areas which makes comparison more manageable. Each publication can be linked to multiple ASJCs and this means that when you look at the breakdown by subject area a publication will be counted twice if it appears in a Scopus Source mapped to two categories, as SciVal doesn't use fractionalization. Therefore, for most entities in SciVal, if you add up the percentage values in the pie or donut charts, they will equal more than 100%. The percentages represent the relative publication share per subject area.

### International Collaboration
International collaboration in this report is indicated by papers with at least two different countries listed in the authorship byline.

### Academic-Corporate Collaboration
Academic -Corporate collaboration in this report is indicated by papers with at least one author from an academic institution and one author from a corporate institution listed in the authorship byline.

### Patent Citations
This is the count of Scholarly Output published by an entity (e.g. a university) that have been cited by Patents. In the report we use the percentage of total output of an entity which is cited in patents. The SciVal tool used in the report collects Patent data from 107 Patent Offices worldwide.

### RAI (Relative Activity Index)
Relative Activity Index is defined as the share of an entity's publications in a subject relative to the global share of publications in the same subject. A value of 1.0 indicates that an entity's research activity in a field corresponds exactly with the global activity in that field; higher than 1.0 implies a greater emphasis while lower than 1.0 suggests a lesser focus.

### Patent Asset Index
The Patent Asset Index is an objective measure of global technological strength and innovation. It takes into account both the number of patent-protected inventions and their quality of value. Methodology have been validated in scientific research. The Patent Asset Index is defined as the aggregated Competitive Impact of all patents in a portfolio. It can be calculated for the overall portfolio of a company, or for only those patents relevant to a certain technology, or for any other group of patents.

### Competitive Impact in Patents
The Competitive Impact the key indicator used in the Patent Asset Index method, estimate how much business value a patent has. It is based on the combined effect of the Technology Relevance and the Market Coverage of a patent. It is algorithmically derived. Competitive Impact is a relative measure comparing the business value of a patent with an average patent from the same field. A competitive impact of 2 means the patent's impact is twice as strong as that of an average patent from the field.

# Appendix 2: Data sources

**Scopus**
Scopus is a comprehensive, source-neutral abstract and citation database curated by independent subject matter experts who are recognized leaders in their fields. 100.8+ million items include data from 7,000+ publishers, 94,000+ affiliation profiles and 19.5+ million authors. Scopus puts powerful discovery and analytics tools in the hands of researchers, librarians, research managers and funders to promote ideas, people and institutions Delivering a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities, our state-of-the-art search tools and filters help uncover relevant information, monitor research trends, track newly published research and identify subject experts. Worldwide, Scopus is used by more than 3,000 academic, government and corporate institutions and is the main data source that supports the Elsevier Research Intelligence portfolio.

www.scopus.com

**SciVal**
SciVal is a web-based analytics solution with unparalleled flexibility that provides access to the research performance of over 20,000 academic, industry and government research institutions and their associated researchers, output and metrics. SciVal allows users to visualize research performance, benchmark relative to peers, develop strategic partnerships, identify and analyse emerging research trends, and create uniquely tailored reports.

**www.scival.com**

**Overton**
Overton is the world's largest searchable index of policy documents, guidelines, think-tank publications and working papers. Its database consists of more than 1.65 million policy documents, with data collected from 182 countries and over a thousand sources worldwide. These policy documents include white papers from international multilateral organisations, as well as guidelines from city councils, parliamentary transcripts and other classes of the so-called "gray literature." Around half of these documents make citations to academic or scholarly publications. More than 2 million distinct journal-based publications are cited by at least one policy document in the database.

www.overton.io

**PatentSight**
PatentSight compiles bibliographic patent data from over 95 authorities worldwide and has the most comprehensive full-text patent data with patent documents, drawings and illustrations of inventions and PDFs that are searchable (OCR) and quickly downloadable. A combined process of automated checks followed by manual quality control ensures that data is highly accurate and reliable.

**www.patentsight.com**

# Appendix 3: Datasets for Key Technologies

| Key Technologies | Dataset used (2019-2024) | How dataset was obtained |
|---|---|---|
| AI | Artificial Intelligence, based on Elsevier AI Report methodology, available as Research Area to all subscribers | Artificial Intelligence, based on Elsevier AI Report methodology, available as Research Area to all SciVal subscribers |
| Semiconductors | Research Area in Scival created with an ad hoc string based on selected keyword(s) | "semiconductor*" OR "microchip*" OR "integrated circuit*" OR "CMOS" OR "VLSI" OR "nanoelectronics" OR "quantum dot*" OR "spintronics" OR "optoelectronics" OR "silicon photonics" OR microelectronics OR "bipolar transistor" OR "system on a Chip" OR "SoC" OR "multichip modules"OR "Fully-depleted-SOI" OR ("FD-SOI") |
| Cybersecurity | Research Area in Scival created with an ad hoc string based on selected keyword(s) | ((cybersecurity) OR (phishing) OR (ransomware) OR (ddos) OR ("distributed denial of service") OR (encryption) OR (firewall) OR ("intrusion detection system") OR ("antivirus software") OR ("cyber security") OR ("cyber-security") OR ("information security") OR (malware) OR ("web security") OR ("data security") OR ("data protection") OR ("web security" ) OR ("network security") OR ("cyber attacks") OR ("cyber warfare") OR ("cyber crime") OR (cybercrime OR (cyberwarfare) OR (cyberattack) OR ("cyber vulnerabilit*")) |
| Quantum Technologies | SciVal Research Area | Available as Research Area to all SciVal subscribers |
| Biotechnology | ASIC Sub-Subject Area | ASJC subject area: We used the subset "Biotechnology" part of the ASJC Subject Area: Biochemistry, Genetics and Molecular Biology |
| Photonics | Research Area in Scival created with an ad hoc string based on selected keyword(s) | "photonics" |
| Rare Earths and Critical Materials | Research Area in Scival created with an ad hoc string based on selected keyword(s) | ("sustainable" OR "sustainability" OR "environmentally friendly" OR "eco-friendly" OR "supply-chain" OR "green energy" OR "renewable energy" OR "sustainable energy" OR "clean energy" OR "low-carbon energy" OR "energy transition" OR "decarbonization" OR "fossil fuel transition" OR "digital transition") AND (("mine" OR "mining" OR "extraction") OR ("process" OR "processing" OR "treatment" OR "refining") OR ("utilize" OR "utilizing" OR "use" OR "using" OR "application" OR "applying")) AND (("rare earth" OR "rare-earth" OR "critical material" OR "critical element" OR "critical metals" OR "cobalt" OR "nickel" OR "manganese" OR "graphite" OR "vanadium" OR "zinc" OR "copper" OR "aluminium" OR "steel" OR "lithium" OR "lanthanum" OR "cerium" OR "praseodymium" OR "neodymium" OR "promethium" OR "samarium" OR "europium" OR "gadolinium" OR "terbium" OR "dysprosium" OR "holmium" OR "erbium" OR "thulium" OR "ytterbium" OR "lutetium" OR "scandium" OR "yttrium") OR ("lithium-ion batteries" OR "cobalt batteries" OR "nickel batteries" OR "manganese batteries" OR "graphite batteries" OR "vanadium batteries" OR "zinc batteries") OR ("wind turbine" OR "wind turbines" OR "wind energy")) |
| Robotics | Research Area in Scival created with an ad hoc string based on selected keyword(s) | "robotics" |
| Battery Technologies | Research Area in Scival created with an ad hoc string based on selected keyword(s) | ("lead acid batteries") OR ("Nickel-Cadmium") OR ("NiCd") OR ("Nickel-Metal Hydride") OR ("Lithium-Ion") OR ("Li-ion") OR ("Sodium-Sulfur") OR ("Vanadium-Redox Flow") OR ("Lithium-Air") OR ("Solid-State Batteries") |

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**Front cover image:** An imagined bird's-eye view of Dejima's layout and structures, copied from a woodblock print by Toshimaya Bunjiemon of 1780 and published in Isaac Titsingh's *Bijzonderheden over Japan* (1824/25).