MAPPING OF TECHNOLOGY SPECIALISATION, COMPLEXITY AND RELATEDNESS OF THE EU AND SELECTED GLOBAL PARTNERS

Pierre-Alexandre Balland and Andrea Renda

CEPS IN-DEPTH ANALYSIS

June, 2026-06

Summary

This report analyses 15 Key Strategic Technologies (KSTs) to inform European policy on competitiveness, technological sovereignty, and international partnerships. It combines large datasets on patents, scientific publications, and venture capital investment (2010–2025) to map technological specialisation, research capacity, and entrepreneurial activity across the EU and selected global partners. Using indicators of technological complexity, relatedness, and revealed comparative advantage, it identifies Europe's strengths, gaps, and opportunities for strategic collaborations.

Results show a highly concentrated global innovation landscape in digital and emerging technologies, with the United States and China dominating patenting and venture capital investment. In contrast, the European Union is a global leader in scientific output, highlighting a persistent gap between strong research capacity and weaker performance in commercialisation and scale-up.

Across the 15 KSTs, including artificial intelligence, quantum technologies, semiconductors, robotics, cybersecurity, cloud computing, IoT, and 5G/6G networks, the analysis finds strong interconnections, with AI acting as a central hub across domains.

Europe is strong in robotics, drones, satellite systems, and telecommunications, but lags in AI, cloud computing, and venture capital-driven innovation. Promising investment areas include IoT, quantum technologies, and satellite connectivity, alongside catch-up priorities such as AI and cloud technologies.

The report concludes that strengthening investments in foundational technologies, combined with targeted partnerships with complementary innovation systems, will be essential to ensure Europe's long-term competitiveness and technological sovereignty in the rapidly evolving global digital economy.

Funded by the European Union

Pierre-Alexandre Balland is CEPS' Chief Data Scientist. Andrea Renda is CEPS' Director of Research and Head of the Global Governance, Regulation, Innovation and the Digital Economy (GRID) unit.

The EU-US Trade and Technology Dialogue (TTD) was an EU-funded initiative (2022–2026) supporting the EU-U.S. Trade and Technology Council (TTC) by fostering transatlantic cooperation on trade, technology, and economic issues. Through expert engagement, research, and stakeholder events, the project contributed analysis and policy dialogue to support the TTC and its working groups between 2022 and 2024. In 2025-2026 the project also supported research and analysis on pressing digital and trade issues, responding to growing demand for analytical work that can support future-oriented transatlantic and international policy cooperation in a rapidly evolving geopolitical and technological environment. This publication was funded by the European Union. Its contents are the sole responsibility of the authors and do not necessarily reflect the views of the European Union.

CEPS • Place du Congrès 1 • B-1000 Brussels • Tel: (32.2) 229.39.11

Executive Summary

This report analyses the global technological landscape in 15 Key Strategic Technologies (KSTs) with the aim of informing European policy on competitiveness technological sovereignty, and international partnerships. Drawing on large-scale datasets covering patents, scientific publications, and venture capital investment between 2010 and 2025, the study provides a comprehensive mapping of technological specialisation, research capacity, and entrepreneurial activity across the European Union (EU) and selected global partners. The analysis relies on approximately 7 million patents from the OECD RegPat database, 250 million scientific publications indexed in OpenAlex, and venture capital investment data from Crunchbase Pro. By combining these datasets with indicators of technological complexity, relatedness and revealed comparative advantage, the report identifies areas where Europe demonstrates strong capabilities, where gaps remain, and where international collaboration may offer strategic opportunities.

The results confirm that the global innovation landscape in digital and emerging technologies is increasingly concentrated among a small group of technologically advanced economies. Across many of the technologies examined, the United States and China emerge as the dominant actors in terms of patent activity and venture capital investment. At the same time, the European Union remains a major contributor to global scientific research, often outperforming other regions in the production of academic publications. This divergence between scientific excellence and technological or entrepreneurial performance represents one of the central structural features of the European innovation system.

The analysis covers 15 KSTs: AI, generative AI, blockchain technologies, cloud and edge computing, computer vision and natural language processing, cybersecurity technologies, drones, high-performance computing, the Internet of Things, mobile networks including 5G and emerging 6G technologies, quantum technologies, robotics, satellite connectivity, semiconductors and chips, and software engineering and system development. The study first analyses the technological relatedness between these domains. Using co-occurrence patterns in patents, publications and venture capital investments, it demonstrates that certain technologies occupy central positions within the broader technological ecosystem. Artificial intelligence emerges as the most pervasive technology, displaying strong links with many other domains including robotics, cloud computing, cybersecurity and computer vision. Mobile networks, the Internet of Things, and software engineering also appear as highly interconnected technologies, suggesting that advances in these fields can have cascading effects across multiple technological sectors. By contrast, some domains such as quantum technologies appear

more specialised and closely linked to a smaller number of complementary technologies, notably semiconductors and advanced computing architectures.

The report then examines the relative competitiveness of the European Union in each of the 15 technological domains. In AI, patent data show that the United States and China together account for more than half of global patenting activity, reflecting their powerful ecosystems of technology firms and research institutions. Europe maintains a significant presence but remains somewhat behind these global leaders in technological patenting. However, the situation changes when analysing scientific publications, where the European Union ranks among the leading global contributors and significantly outperforms the United States in publication volume. This pattern is observed in several technological domains and illustrates the strong research capacity of European universities and public research institutions.

A similar dynamic emerges in other KSTs. In cloud and edge computing, China holds the largest share of patents, followed by the United States, while the European Union ranks third but ahead of several other major economies. In the field of computer vision and natural language processing, China and the United States again dominate patent activity, while Europe retains a significant presence supported by strong research institutions and industrial actors. In cybersecurity technologies, China and the United States are also closely matched in patent counts, with Europe and Japan forming a second tier of technological innovators.

The report also highlights some domains where Europe demonstrates particular strengths. In robotics and drones, the European Union shows a comparatively strong patent position due to the presence of major aerospace and engineering companies. European firms such as Airbus, Thales, and Leonardo have built extensive patent portfolios in autonomous systems and unmanned aerial technologies. Likewise, Europe maintains strong capabilities in satellite connectivity and telecommunications infrastructure, reflecting its long-standing leadership in space technologies and telecommunications equipment.

Scientific research performance presents a somewhat different picture. In many domains, including high-performance computing, robotics, and quantum technologies, Europe emerges as one of the leading producers of academic research. In high-performance computing, for example, the European Union accounts for a larger share of scientific publications than either China or the United States. Similarly, in quantum technologies Europe demonstrates a particularly strong scientific position, reflecting decades of investment in fundamental physics and advanced research infrastructures.

However, the analysis also reveals that strong scientific capabilities do not always translate into technological patents or commercial innovation. In several sectors Europe displays a form of 'innovation gap' whereby high levels of academic research coexist with comparatively lower levels of patenting activity or venture capital investment. This gap highlights structural challenges in the European innovation ecosystem, particularly in the translation of research results into industrial applications and scalable start-up ventures.

Venture capital investment patterns further illustrate these structural differences. Across most of the technological sectors analysed, the United States dominates global venture capital investment by a wide margin. In artificial intelligence and high-performance computing, American start-ups attract the overwhelming majority of global venture funding. This reflects the scale and maturity of the American venture capital ecosystem as well as the presence of major technology hubs such as Silicon Valley, Boston and New York. Europe and China maintain smaller but still significant shares of VC investment, while countries such as Israel, Singapore and the United Kingdom have developed specialised innovation hubs in specific technological domains.

The report also analyses investment opportunities by combining indicators of technological complexity and relatedness. This approach allows the identification of technologies where investment is likely to yield the greatest strategic benefits. Technologies located in the 'optimal investment' quadrant combine high complexity with strong relatedness to existing capabilities, meaning that they are both strategically important and relatively feasible for countries to develop further. For the European Union, promising areas include the Internet of Things, computer vision and natural language processing, quantum technologies, and satellite connectivity. These technologies are strongly connected to Europe's existing industrial and research capabilities and therefore represent potential areas of strategic investment. Other technologies appear in the 'moonshot' quadrant, characterised by high complexity but weaker existing capabilities. These include artificial intelligence, generative AI, cloud and edge computing, cybersecurity, and mobile network technologies. Although Europe currently shows lower technological specialisation in these domains, they are strategically important and may require targeted investments to strengthen Europe's position in the global technological landscape.

The study further explores international collaboration networks in both technological development and scientific research. Patent co-inventorship data show that the United States is the most important technological partner for the European Union across nearly all 15 technological domains. In areas such as semiconductors, high-performance computing, robotics, and software engineering, a large share of European patents involves American co-inventors. Other important technological partners include the United Kingdom, Switzerland, Canada, India and Japan.

Scientific collaboration networks appear even more geographically diverse. While the United States remains a major partner in co-authored publications, countries such as China, the United Kingdom, Canada, India and Switzerland also feature prominently. In some domains, including drone technologies and mobile networks, China emerges as one of the leading scientific collaborators with European researchers. The global nature of academic research networks also becomes visible through collaborations with a wide range of countries including Australia, Brazil, Saudi Arabia, Norway, Pakistan and the United Arab Emirates.

Finally, the report examines technological complementarities between countries. This analysis identifies countries whose technological portfolios contain capabilities that are related to, but distinct from, those of the European Union. Such complementarities can create opportunities for mutually beneficial cooperation in emerging technologies. The results show strong complementarities between the European Union and the United States across several technological domains, particularly artificial intelligence and advanced computing. Canada, India, Japan and South Korea also display significant complementarities with Europe in specific technological sectors. In the field of semiconductors, Japan appears as a particularly important complementary partner, while India and South Korea demonstrate strong complementarities in scientific research capabilities. For European policymakers, these findings underscore the importance of strengthening the link between research excellence and industrial innovation while maintaining open international collaboration networks. Strategic investments in foundational technologies, combined with targeted partnerships with complementary innovation systems, will be essential to ensure Europe’s long-term competitiveness and technological sovereignty in the rapidly evolving global digital economy.

Key highlights

- The global technological landscape is increasingly multipolar. The United States and China dominate many technology domains in terms of patents and venture capital investment, while the European Union remains one of the world's largest contributors to scientific research.
- Europe shows strong scientific excellence but weaker technological and entrepreneurial translation. In several domains, the EU produces a large share of global scientific publications but a comparatively smaller share of patents and venture capital investment. This suggests a persistent gap between Europe's research capacity and its ability to convert scientific knowledge into commercial innovation.
- Artificial intelligence is the most central and foundational technology in the global digital ecosystem. AI is strongly interconnected with most other key strategic technologies, including robotics, cybersecurity, cloud computing and the Internet of Things. Weaknesses in AI capabilities therefore risk affecting competitiveness in a wide range of downstream technologies.
- The United States dominates venture capital investment across almost all strategic technology sectors. The American venture capital ecosystem accounts for most of the global investment in start-ups in areas such as artificial intelligence, computer vision, cybersecurity and high-performance computing. This concentration reflects the scale of US financial markets and the strength of its entrepreneurial ecosystem.
- China has emerged as a major technological power in patents across several digital infrastructures. China holds leading or near-leading positions in patents related to mobile networks, cloud computing, the Internet of Things, cybersecurity and high-performance computing.
- Europe maintains strong industrial capabilities in several engineering-intensive technologies. The EU performs particularly well in domains such as robotics, drones, satellite connectivity and certain telecommunications technologies.
- Scientific research networks are highly globalised and more geographically distributed than technological innovation. While patent collaborations are often concentrated among a smaller group of advanced economies, scientific collaboration networks involve a much broader set of countries. European researchers collaborate extensively with partners in the United States, China, the United Kingdom, Canada, India and many emerging research systems.
- Strategic investment opportunities for Europe are concentrated in several high-complexity technologies. The analysis of technological complexity and relatedness identifies promising areas for European investment, including the Internet of Things, computer vision and language technologies, quantum technologies and satellite connectivity. These technologies combine high strategic value with relatively strong links to Europe's existing capabilities.
- Several foundational technologies remain 'moonshot' domains for Europe. Technologies such as artificial intelligence, generative AI, cloud and edge computing, cybersecurity and next-generation mobile networks are characterised by high complexity and lower current technological specialisation in Europe. Strengthening Europe's position in these areas will require sustained investment and targeted innovation policies.
- International technological complementarities create opportunities for strategic partnerships. The analysis of technological complementarities highlights strong potential collaboration between the European Union and partners such as the United States, Canada, India, Japan and South Korea. These countries possess capabilities that complement Europe's technological portfolio and could support diversification into emerging technologies.

Content

Executive Summary i
Content vi
Figures vii
Tables xi
Introduction and methodology 1
1. The 15 KSTs and their interrelations 4
2. Analysing Europe's competitiveness in 15 key strategic technologies 8
2.1. Artificial Intelligence 8
2.2. Generative AI 13
2.3. Blockchain technologies 15
2.4. Cloud computing and edge computing 18
2.5. Computer vision, natural language processing and object recognition 21
2.6. Cybersecurity technologies 26
2.7. Drones 30
2.8. High-Performance Computing 35
2.9. Internet of Things 40
2.10. Mobile networks (5G and 6G) 45
2.11. Quantum technologies 50
2.12. Robotics 55
2.13. Satellite Connectivity 59
2.14. Semiconductors and Chips 64
2.15. Software engineering and system development 69
2.16. Summary of main findings 75
3. Investment opportunities in the selected 15 KSTs 79
3.1. Canada 80
3.2. European Union 82
3.3. India 87
3.4. Japan 92
3.5. South Korea 98
3.6. The United Kingdom 103

3.7. THE UNITED STATES 107

4. NETWORKS OF COLLABORATIONS IN THE 15 KSTS: THE CASE OF THE EUROPEAN UNION 111

4.1. ARTIFICIAL INTELLIGENCE 111

4.2. GENERATIVE AI 114

4.3. BLOCKCHAIN TECHNOLOGIES 117

4.4. CLOUD COMPUTING AND EDGE COMPUTING 120

4.5. COMPUTER VISION, NATURAL LANGUAGE PROCESSING AND OBJECT RECOGNITION 123

4.6. CYBERSECURITY TECHNOLOGIES 126

4.7. DRONES 129

4.8. HIGH-PERFORMANCE COMPUTING 132

4.9. INTERNET OF THINGS 135

4.10. MOBILE NETWORKS (5G AND 6G) 138

4.11. QUANTUM TECHNOLOGIES 141

4.12. ROBOTICS 143

4.13. SATELLITE CONNECTIVITY 146

4.14. SEMICONDUCTORS AND CHIPS 148

4.15. SOFTWARE ENGINEERING AND SYSTEM DEVELOPMENT 151

4.16. SYNOPSIS 154

5. COMPLEMENTARITIES BETWEEN SELECTED COUNTRIES 158

6. KEY HIGHLIGHTS AND FUTURE RESEARCH 163

REFERENCES 167

FIGURES

FIGURE 1 – SELECTED KEY STRATEGIC TECHNOLOGIES AND THEIR INTERRELATIONS – PATENTS 5

FIGURE 2 – SELECTED KEY STRATEGIC TECHNOLOGIES AND THEIR INTERRELATIONS – SCIENTIFIC PUBLICATIONS 6

FIGURE 3 – SELECTED KEY STRATEGIC TECHNOLOGIES AND THEIR INTERRELATIONS – VC INVESTMENT 7

FIGURE 4 – PERCENTAGE OF GLOBAL PATENTS IN ARTIFICIAL INTELLIGENCE, 2010-2024 9

FIGURE 5 – PERCENTAGE OF SCIENTIFIC PUBLICATIONS IN ARTIFICIAL INTELLIGENCE, 2010-2025 11

FIGURE 6 – PERCENTAGE OF VC INVESTMENT IN START-UPS IN ARTIFICIAL INTELLIGENCE, 2010-2025 12

FIGURE 7 – PERCENTAGE OF GLOBAL PATENTS IN GENERATIVE AI, 2010-2024 13

FIGURE 8 – PERCENTAGE OF SCIENTIFIC PUBLICATIONS IN GENERATIVE AI, 2010-2025 14

Figure 9 – Percentage of VC investment in start-ups in generative AI, 2010-2025 15

Figure 10 – Percentage of global patents in blockchain technologies, 2010-2024 15

Figure 11 – Percentage of scientific publications in blockchain technologies, 2010-2025 17

Figure 12 – Percentage of VC investment in start-ups in blockchain technologies, 2010-2025.......................17

Figure 13 – Percentage of global patents in cloud and edge computing, 2010-2024 19

Figure 14 – Percentage of scientific publications in cloud and edge computing, 2010-2025 20

Figure 15 – Percentage of VC investment in start-ups in cloud and edge computing, 2010-2025 21

Figure 16 – Percentage of global patents in computer vision, natural language processing and object recognition, 2010-2024 23

Figure 17 – Percentage of scientific publications in computer vision, NLP and object recognition, 2010-2025 24

Figure 18 – Percentage of VC investment in start-ups in computer vision, NLP and object recognition, 2010-2025..25

Figure 19 – Percentage of global patents in cybersecurity technologies, 2010-2024......................................27

Figure 20 – Percentage of scientific publications in cybersecurity technologies, 2010-2025 28

Figure 21 – Percentage of VC investment in start-ups in cybersecurity technologies, 2010-2025...................30

Figure 22 – Percentage of global patents in drones, 2010-2024...32

Figure 23 – Percentage of scientific publications in drones, 2010-2025 33

Figure 24 – Percentage of VC investment in start-ups in drones, 2010-2025..35

Figure 25 – Percentage of global patents in HPC, 2010-2024...36

Figure 26 – Percentage of scientific publications in HPC, 2010-2025 38

Figure 27 – Percentage of VC investment in start-ups in HPC, 2010-2025..39

Figure 28 – Percentage of global patents in IoT, 2010-2024...41

Figure 29 – Percentage of scientific publications in IoT, 2010-2025 43

Figure 30 – Percentage of VC investment in start-ups in IoT, 2010-2025..44

Figure 31 – Percentage of global patents in mobile networks (5G/6G), 2010-2024.......................................46

Figure 32 – Percentage of scientific publications in mobile networks (5G/6G), 2010-2025 48

Figure 33 – Percentage of VC investment in start-ups in mobile networks (5G/6G), 2010-2025.....................49

Figure 34 – Percentage of global patents in quantum technologies, 2010-2024 51

Figure 35 – Percentage of scientific publications in quantum technologies, 2010-2025.................................53

Figure 36 – Percentage of VC investment in start-ups in quantum technologies, 2010-2025 54

Figure 37 – Percentage of global patents in robotics, 2010-2024 56

Figure 38 – Percentage of scientific publications in robotics, 2010-2025 58

Figure 39 – Percentage of VC investment in start-ups in robotics, 2010-2025 59

Figure 40 – Percentage of global patents in satellite connectivity, 2010-2024 61

Figure 41 – Percentage of scientific publications in satellite connectivity, 2010-2025 62

Figure 42 – Percentage of VC investment in start-ups in satellite connectivity, 2010-2025 64

Figure 43 – Percentage of global patents in semiconductors and chips, 2010-2024 66

Figure 44 – Percentage of scientific publications in semiconductors and chips, 2010-2025 67

Figure 45 – Percentage of VC investment in start-ups in semiconductors and chips, 2010-2025 69

Figure 46 – Percentage of global patents in software engineering and systems development, 2010-2024 71

Figure 47 – Percentage of scientific publications in software engineering and systems development, 2010-2025 73

Figure 48 – Percentage of VC investment in start-ups in software engineering and systems development, 2010-2025 74

Figure 49 – How to read our four-quadrant investment opportunity graph 80

Figure 50 – Technological opportunities in Canada 81

Figure 51 – Scientific opportunities in Canada 81

Figure 52 – Funding opportunities in Canada 82

Figure 53 – Technological opportunities for the European Union 83

Figure 54 – Scientific opportunities in the EU 85

Figure 55 – Funding opportunities in the European Union 86

Figure 56 – Technological opportunities for India 88

Figure 57 – Scientific opportunities in India 90

Figure 58 – Funding opportunities in India 92

Figure 59 – Technological opportunities for Japan 94

Figure 60 – Scientific opportunities in Japan 96

Figure 61 – Funding opportunities in Japan 97

Figure 62 – Technological opportunities for South Korea 99

Figure 63 – Scientific opportunities in South Korea 101

Figure 64 – Funding opportunities in South Korea 102

Figure 65 – Technological opportunities for the United Kingdom 104

FIGURE 66 – SCIENTIFIC OPPORTUNITIES IN THE UNITED KINGDOM....105
FIGURE 67 – FUNDING OPPORTUNITIES IN THE UNITED KINGDOM....106
FIGURE 68 – TECHNOLOGICAL OPPORTUNITIES FOR THE UNITED STATES....108
FIGURE 69 – SCIENTIFIC OPPORTUNITIES IN THE UNITED STATES....110
FIGURE 70 – FUNDING OPPORTUNITIES IN THE UNITED STATES....110
FIGURE 71 – EU NETWORK OF TECH COLLABORATIONS IN ARTIFICIAL INTELLIGENCE, 2010-2024....112
FIGURE 72 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN ARTIFICIAL INTELLIGENCE, 2010-2025....114
FIGURE 73 – EU NETWORK OF TECH COLLABORATIONS IN GENERATIVE AI, 2010-2024....116
FIGURE 74 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN GENERATIVE AI, 2010-2025....117
FIGURE 75 – EU NETWORK OF TECH COLLABORATIONS IN BLOCKCHAIN, 2010-2024....119
FIGURE 76 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN BLOCKCHAIN TECHNOLOGIES, 2010-2025....120
FIGURE 77 – EU NETWORK OF TECH COLLABORATIONS IN CLOUD AND EDGE COMPUTING, 2010-2024....122
FIGURE 78 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN CLOUD AND EDGE COMPUTING, 2010-2025....123
FIGURE 79 – EU NETWORK OF TECH COLLABORATIONS IN COMPUTER VISION, NLP AND OBJECT RECOGNITION, 2010-2024....125
FIGURE 80 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN COMPUTER VISION, NLP AND OBJECT RECOGNITION, 2010-2025....126
FIGURE 81 – EU NETWORK OF TECH COLLABORATIONS IN CYBERSECURITY TECHNOLOGIES, 2010-2024....127
FIGURE 82 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN CYBERSECURITY TECHNOLOGIES, 2010-2025....129
FIGURE 83 – EU NETWORK OF TECH COLLABORATIONS IN DRONE TECHNOLOGIES, 2010-2024....130
FIGURE 84 – EU NETWORK OF SCIENTIFIC COLLABORATIONS DRONE TECHNOLOGIES, 2010-2025....132
FIGURE 85 – EU NETWORK TECH COLLABORATIONS IN HPC, 2010-2024....133
FIGURE 86 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN HPC, 2010-2025....135
FIGURE 87 – EU NETWORK OF TECH COLLABORATIONS IN IOT, 2010-2024....136
FIGURE 88 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN IOT, 2010-2025....138
FIGURE 89 – EU NETWORK OF TECH COLLABORATIONS IN MOBILE NETWORKS (5G/6G), 2010-2024....139
FIGURE 90 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN MOBILE NETWORKS (5G/6G), 2010-2025....140
FIGURE 91 – EU NETWORK OF TECHNOLOGY COLLABORATIONS IN QUANTUM TECHNOLOGIES, 2010-2024....142
FIGURE 92 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN QUANTUM TECHNOLOGIES, 2010-2025....143
FIGURE 93 – EU NETWORK OF TECHNOLOGY COLLABORATIONS IN ROBOTICS, 2010-2024....144
FIGURE 94 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN ROBOTICS, 2010-2025....145

FIGURE 95 – EU NETWORK OF TECHNOLOGY COLLABORATIONS IN SATELLITE CONNECTIVITY, 2010-2024 147

FIGURE 96 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN SATELLITE CONNECTIVITY, 2010-2025 148

FIGURE 97 – EU NETWORK OF TECHNOLOGY COLLABORATIONS IN SEMICONDUCTORS AND CHIPS, 2010-2024 149

FIGURE 98 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN SEMICONDUCTORS AND CHIPS, 2010-2025 151

FIGURE 99 – EU NETWORK OF TECHNOLOGY COLLABORATIONS IN SOFTWARE ENGINEERING AND SYSTEMS DEVELOPMENT, 2010-2024..152

FIGURE 100 – EU NETWORK OF SCIENTIFIC COLLABORATIONS IN SOFTWARE ENGINEERING AND SYSTEMS DEVELOPMENT, 2010-2024..154

FIGURE 101 – COMPLEMENTARITIES BETWEEN SELECT COUNTRIES IN AI – BASED ON PATENT AND PUBLICATIONS DATA 160

FIGURE 102 – COMPLEMENTARITIES BETWEEN SELECT COUNTRIES IN QUANTUM TECHNOLOGIES – BASED ON PATENT AND PUBLICATIONS DATA 161

FIGURE 103 – COMPLEMENTARITIES BETWEEN COUNTRIES IN SEMICONDUCTORS & CHIPS – BASED ON PATENT AND PUBLICATIONS DATA 162

TABLES

TABLE 1 – SUMMARY OF COMPETITIVENESS RESULTS FOR 15 KEY STRATEGIC TECHNOLOGIES IN SELECT COUNTRIES.............77

TABLE 2 – SUMMARY OF FINDINGS – EU TECHNOLOGY AND SCIENTIFIC NETWORKS OF COLLABORATION...........................156

TABLE 3 – SUMMARY OF FINDINGS PER SELECTED COUNTRY AND SPECIALISATION..165

INTRODUCTION AND METHODOLOGY

Over the past years, Europe has increasingly realised the need to take action to boost its sovereignty and competitiveness in digital technologies, and particularly foundations technologies that support industrial transformation, boosting productivity and triggering growth. At the same time, the technology stack underpinning key general-purpose-technologies such as Artificial intelligence (AI) or the Internet of Things (IoT) is increasingly complex, and dominated by-products and solutions that are seldom produced in Europe. This in turn has led to an emerging debate on the prospects for reconciling Europe's competitiveness and technological sovereignty. On the one hand, European companies would need to rely on the best available solutions to ensure its competitiveness in global markets, regardless of where such solutions come from. On the other hand, excessive reliance on specific countries, or specific companies, can lead Europe to significant exposure and vulnerability, especially as the evolving geopolitical landscape makes the 'weaponisation' of vulnerabilities particularly likely.

The quest for competitiveness and technological sovereignty has already triggered various initiatives at the EU level. They often lead to attempts to boost internal production, as in the CHIPS Act or in the recent Industrial Accelerator Act proposal; yet they also take the form of revamped international partnerships with players that can offer alternative sources of supply. The EU International Digital Strategy adopted in June 2025 envisages the possibility to engage with selected partners, focusing on key areas such as secure and trusted digital infrastructure, cybersecurity, the Digital Public Infrastructure, online platforms and foreign information manipulation and interference (FIMI).

This report contains an analysis of three large-scale datasets on scientific publications (250 million records from OpenAlex, covering 2010–May 2025); patents (7 million documents from the OECD RegPat database, 2010–2024) and investment in start-ups (Crunchbase Pro data, 2010–May 2025).[1] The aim is to provide enhance situational awareness to EU policymakers on the relative competitive advantage of the EU vis-à-vis its partners, as well as areas of complementarity, possibly triggering future collaborations. The focus of the report is on 15 Key Strategic Technologies in the technology space:

1. Artificial Intelligence (AI)
2. Generative AI

[1] It is important to note that the report therefore does not include private R&D investments in large companies.

3. Blockchain technologies
4. Cloud and Edge computing
5. Computer vision, natural language processing and object recognition
6. Cybersecurity
7. Drones
8. High-Performance computing
9. Internet of Things
10. Mobile networks (5G and 6G)
11. Quantum Technologies
12. Robotics
13. Satellite Connectivity
14. Semiconductors and Chips
15. Software engineering and system development

For each technology, the report provides several insights and significant new data. More specifically:

- The analysis of patents reveals the technological relatedness between key strategic domains, and is carried out based on normalised co-occurrences on the same patent documents, which is then used to build a recommender system and evaluate untapped technological potential.
- The analysis of publications unveils the scientific relatedness between key strategic domains, and is based on normalised co-occurrences on the same scientific publication. The results are used to feed the recommender system and evaluate untapped scientific potential.
- Investment analysis measures investment relatedness between key strategic domains. Here too, we rely on normalised co-occurrences on the same funded start-up. The results are used to validate our classifications.

Key indicators derived from these data include absolute and per capita counts, Revealed Comparative Advantage (RCA), and relatedness density. Composite indices are calculated by averaging and scaling patent, publication, and investment scores, balancing both absolute and relative strengths. This analysis allows us to identify which technologies require the largest investments to close gaps with other countries, but also to identify innovation opportunities to be leveraged by the European Union in the coming years. We also provide an assessment of the complementarity between Europe and select partners, which could feed priority-setting in bilateral relations.

The remainder of this report is structured as follows. Section 1 below shows the relatedness of the 15 KSTs in terms of co-occurrences in publications, patents and venture capital investment, shedding lights on the interrelation between their development. Section 2 contains an analysis of Europe's scientific and technological competitiveness in the selected 15 KSTs. Section 3 maps investment opportunities in the 15 KSTs using relatedness and complexity indices. Section 4 maps collaborations and dependencies in the 15 KSTs. Section 4 contains a summary analysis of the complementarities between selected countries. Section 5 concludes with key highlights and possible future research areas. Given the amount of data generated by our research, where needed the report shows results for a subset of the 15 KSTs, inviting the reader to consult the interactive dashboard for access to the complete data (see box below).

How to read this report: a guide to consulting the data

Many of the figures and graphs included in this document are static representations of richer interactive tools. To gain the full benefit of this analysis, readers are strongly encouraged to explore the hyperlinks provided in the text and figure captions. These links lead to interactive visualisations that contain a wealth of additional data. For instance, while the main report offers deep dives into selected Key Strategic Technologies (KSTs), the complete analyses for all 15 KSTs are available online in interactive format.

You will be able to consult:

- 3 domain space graphs
- 45 position bar charts.
- 21 smart investment graphs
- 210 Network graphs
- 32 Complementarity graphs
- 630 Organisational ecosystems graphs

For a total of 941 interactive graphical visualisations.

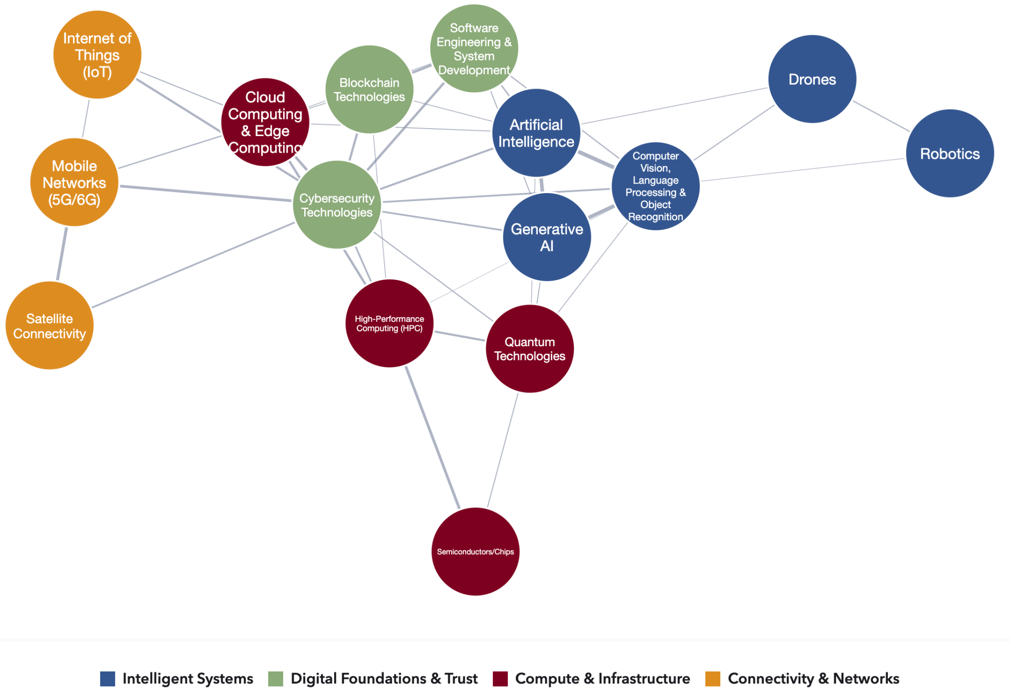
1. THE 15 KSTS AND THEIR INTERRELATIONS

Being competitive in KSTs is particularly important in the context of a changing geopolitical landscape, increased technology insecurity, as well as rising importance of general-purpose technologies such as AI, which is expected to underpin the transformation of leading economies in the years to come. Even within the selected domains, not all KSTs are equally foundational; moreover, given public finance constraints and current re-prioritisation of investment at the national and EU level towards defence, it is important to note that not all KSTs are dual use technologies, and as such likely to cater to the region's geo-economic needs; this is also relevant, as in the future EU research and innovation funding will focus particularly on technologies with both military and civilian uses (ESIR 2025).

One feature that is distinctive of each KST is its links and hierarchical relations with other technologies. Below, we present three graphs that show (statically) the interrelations between KSTs when measured in terms of co-occurrences in patent claims, scientific publications and investment.

Figure 1 shows the inter-linkages in terms of patents: the interactive version shows how foundational technologies such as i.a. 'Artificial Intelligence' and 'Cybersecurity technologies' are comparatively more linked to other, downstream technological domains such as IoT or robotics. This, in turn, means that even if Europe holds a leading position in IoT or robotics, lagging behind on transformational technologies such as AI may weaken its position and exacerbate its dependency on foreign technologies in the future. This, in turn, may alert policymakers and businesses that something has to be done to strengthen Europe's competitive position in foundational domains. This is also in line with the findings of the Draghi Report, which relies on a similar methodology in terms economic complexity

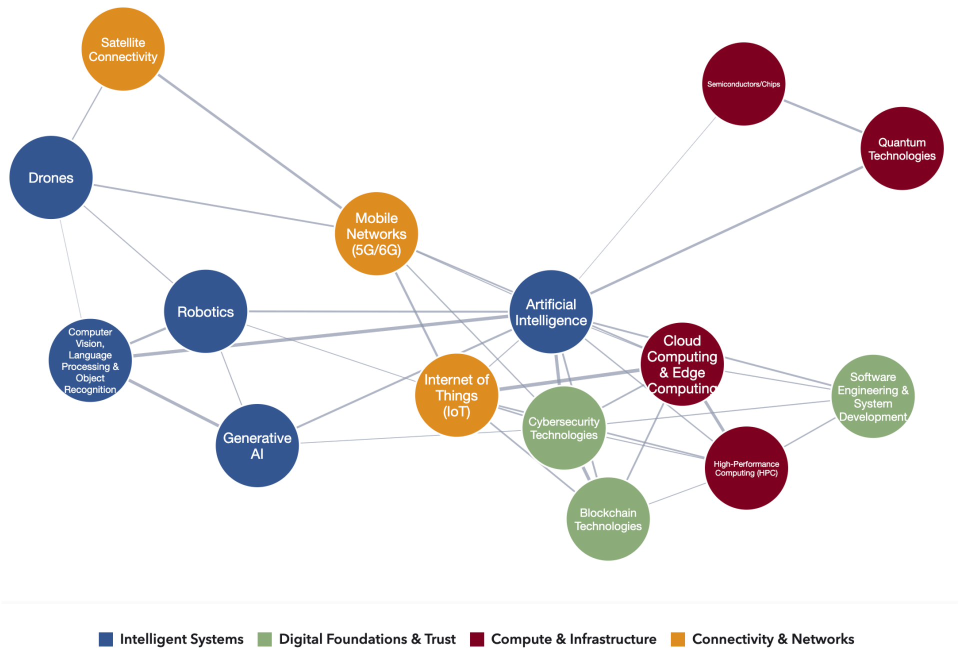
Figure 1 – Selected Key Strategic technologies and their interrelations – Patents



Source: https://www.paballand.com/ceps/ttd/domain-space/regpat.html

Likewise, Figure 2 shows the links between KSTs in scientific publications, revealing (in the interactive graph) a similar degree of centrality and 'betweenness' of 'Artificial Intelligence', but also the Internet of Things, Mobile Networks and Cloud and Edge Computing, as well as software engineering and systems development. This compared to other fields, like Quantum technologies, that appear particularly related to AI and Semiconductors/Chips, but less with other KSTs.

Figure 2 – Selected Key Strategic Technologies and their interrelations – Scientific Publications



Source: https://www.paballand.com/ceps/ttd/domain-space/openalex.html

Finally, Figure 3 shows the relatedness analysis for venture capital investments. This analysis shows a high degree of centrality of AI as a pervasive technology, particularly interrelated with almost all other KSTs (with the partial exception of mobile networks and satellite connectivity).

Figure 3 – Selected Key Strategic Technologies and their interrelations – VC investment

Source: https://www.paballand.com/ceps/ttd/domain-space/crunchbase.html

2. ANALYSING EUROPE'S COMPETITIVENESS IN 15 KEY STRATEGIC TECHNOLOGIES

Below, we analyse the current scientific, technological and investment competitiveness of the European Union and select partners in the selected KSTs.

2.1. ARTIFICIAL INTELLIGENCE

In the domain of artificial intelligence technologies, the patent landscape is dominated by the United States and China, which together account for more than half of all patents in this field. The United States holds the leading position with approximately 29.3 % of global AI-related patents. This strong position reflects the country's powerful ecosystem of technology companies, research universities, and venture-backed start-ups that actively develop AI applications across multiple sectors, including cloud computing, autonomous systems, and data analytics. Major technology companies such as Google, Microsoft, and IBM have accumulated extensive patent portfolios related to machine learning algorithms, natural language processing, computer vision, and large-scale data processing systems.

China follows closely with about 27.5 % of global patents in artificial intelligence technologies. China's strong presence reflects the rapid expansion of its digital economy and the strategic priority assigned to AI development in national industrial policies. Chinese technology companies have actively filed patents covering applications such as intelligent recommendation systems, automated decision-making systems, and AI-enabled digital platforms. Firms such as Baidu, Alibaba, and Tencent play a central role in advancing AI technologies and building large intellectual property portfolios in this domain.

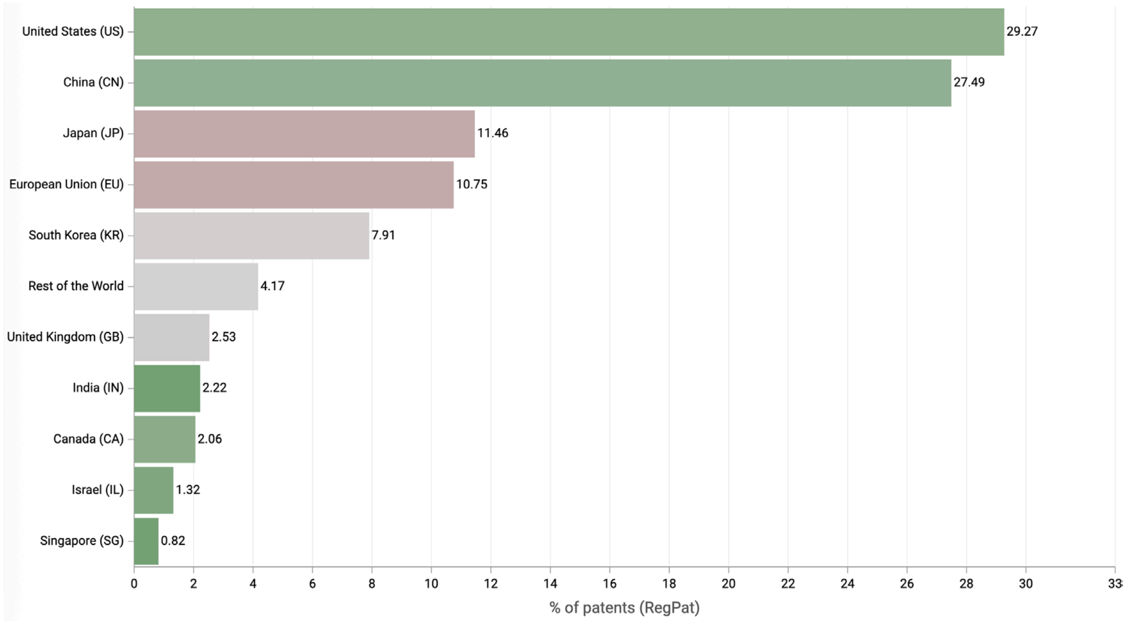
Japan ranks third with approximately 11.5 % of global AI patents, outperforming the European Union, which accounts for around 10.75 %. Japan's strong performance reflects its expertise in robotics, industrial automation, and intelligent manufacturing systems, where AI technologies are increasingly integrated into advanced production processes and electronic devices. Companies such as Sony and Fujitsu contribute significantly to innovations in AI-enabled systems and data-driven technologies.

The European Union, while slightly behind Japan in patent counts, remains an important contributor to the global AI innovation landscape. European companies and research institutions have developed important technologies related to machine learning, industrial automation, and AI-driven software systems. Firms such as SAP and Siemens have invested heavily in AI-enabled enterprise software and industrial digitalisation platforms.

Finally, South Korea accounts for approximately 7.9 % of global patents in artificial intelligence technologies. South Korea's strong electronics and semiconductor industries support significant innovation in AI applications integrated into consumer electronics, mobile devices, and digital services. Companies such as Samsung Electronics are actively developing AI-enabled hardware and software systems across a wide range of digital technologies.

Overall, the patent landscape in artificial intelligence reflects intense technological competition among major global innovation systems. While the United States and China clearly dominate in terms of patent volume, Japan, the European Union, and South Korea also play significant roles in advancing AI technologies through strong industrial capabilities and sustained investments in digital innovation.

Figure 4 – Percentage of global patents in Artificial Intelligence, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/artificial-intelligence.html

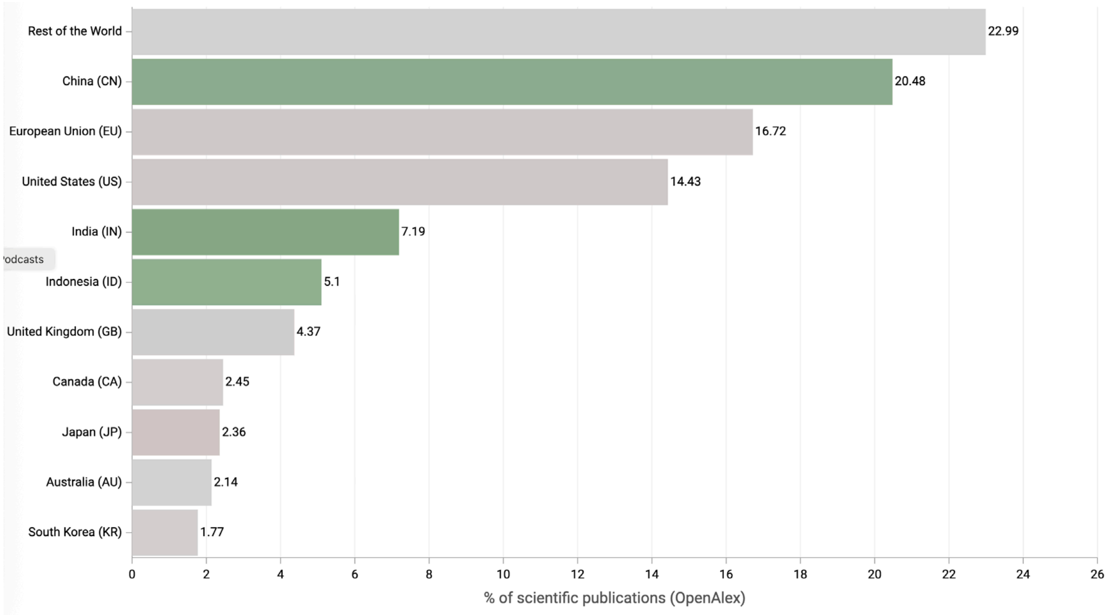
The situation is markedly different when looking at scientific publications in artificial intelligence. Data reported by OpenAlex show a research landscape that is less concentrated than the patent landscape. In this case, China leads with approximately 20.4 % of global publications, followed by the European Union, which accounts for about 16.7 % of total research output. The United States ranks third with around 14.4 % of the publications. While the United States remains a central actor in artificial intelligence research, its share of publications is significantly lower than its share of patents or venture capital investment in the field.

Another notable feature of the scientific publication landscape is the emergence of India as a major contributor to global AI research, with around 7 % of total publications. India's strong presence reflects the rapid expansion of its higher education system and the large number of researchers working in computer science, data science, and machine learning. More generally, the global distribution of AI scientific publications appears less concentrated than that observed in patents – or, as will be discussed later, venture capital investment. Indeed, the rest of the world collectively accounts for roughly 23 % of all AI-related publications indexed in OpenAlex for the period 2010–2025, highlighting the increasingly global nature of research activity in this field.

Interestingly, Japan holds only about 2.4 % of the total publications in artificial intelligence. This relatively small share contrasts with Japan's stronger position in the patent landscape and reflects a lower propensity to publish peer-reviewed scientific articles as part of industrial research processes that ultimately lead to patented innovations. In many cases, Japanese firms and research laboratories prioritise applied development and proprietary research rather than academic publication.

This situation stands in contrast with that of the European Union, where strong scientific performance in artificial intelligence is not always matched by an equivalent level of patenting activity. Europe's universities and public research institutions produce a large volume of high-quality scientific research, yet this knowledge does not always translate into technological patents or commercial innovations to the same extent observed in other major innovation systems. This divergence highlights structural differences in the organisation of research and innovation across regions, particularly in the relationship between academic research, industrial development, and intellectual property generation.

Figure 5 – Percentage of scientific publications in Artificial Intelligence, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/artificial-intelligence.html

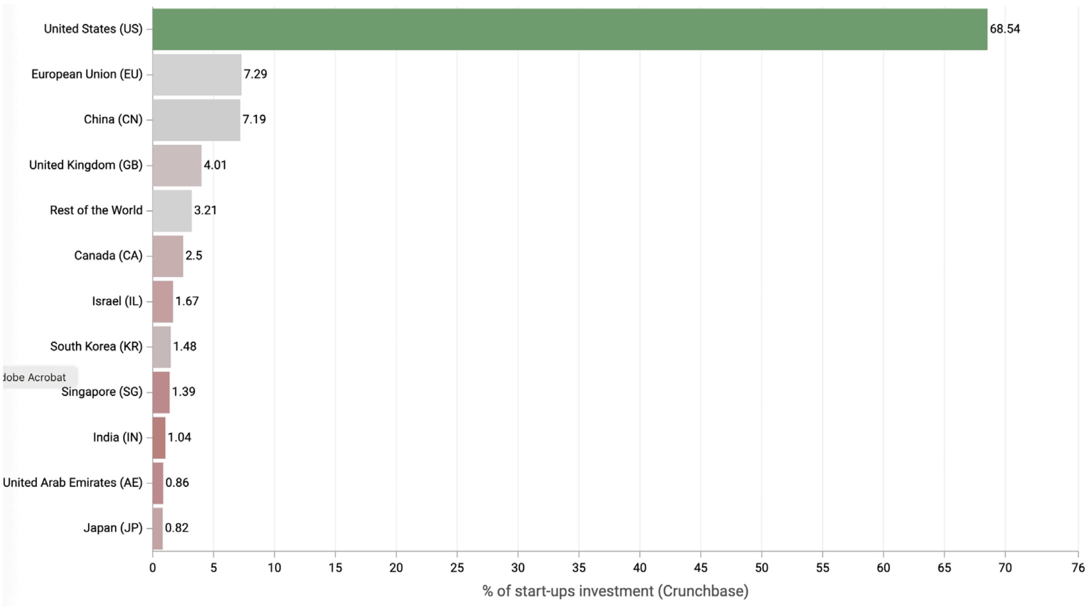
Finally, when examining venture capital investment in artificial intelligence start-ups, the United States clearly dominates the global landscape. According to data reported by Crunchbase, the United States accounts for approximately 68.5 % of the total value of venture-backed deals in AI start-ups over the period 2010–May 2025. This overwhelming share reflects the extraordinary strength of the American venture capital ecosystem and the central role of US technology hubs – particularly Silicon Valley – in financing the commercialisation of AI technologies. Numerous start-ups developing machine learning platforms, Generative AI models, and AI-enabled software systems have attracted large investment rounds from venture capital funds and technology companies.

The European Union and China follow at a considerable distance, each accounting for roughly 7 % of the total value of venture capital investment in AI start-ups over the same period. In Europe, the AI start-up ecosystem has been expanding steadily, supported by strong research institutions and an increasing number of venture funds specialising in deep-tech investments. China also hosts a large and rapidly evolving AI industry, although venture capital investment in start-ups is often complemented by the role of large technology firms and state-backed investment programmes.

Interestingly, countries that appear as strong innovators in the patent landscape play a much more limited role in venture capital investment. Japan, for example, holds a substantial share of patents in artificial intelligence technologies but accounts for less than 1 % of venture capital investment in AI start-ups. This reflects structural differences in innovation systems: in Japan, technological development is often driven by large established corporations with significant internal research and development capabilities rather than by venture-backed start-ups.

Overall, the venture capital landscape in artificial intelligence highlights the strong concentration of entrepreneurial financing in the United States. While Europe and China maintain active start-up ecosystems, their shares remain significantly smaller, illustrating the continuing dominance of the US venture capital market in supporting the commercialisation and rapid scaling of AI technologies.

Figure 6 – Percentage of VC investment in start-ups in Artificial Intelligence, 2010-2025

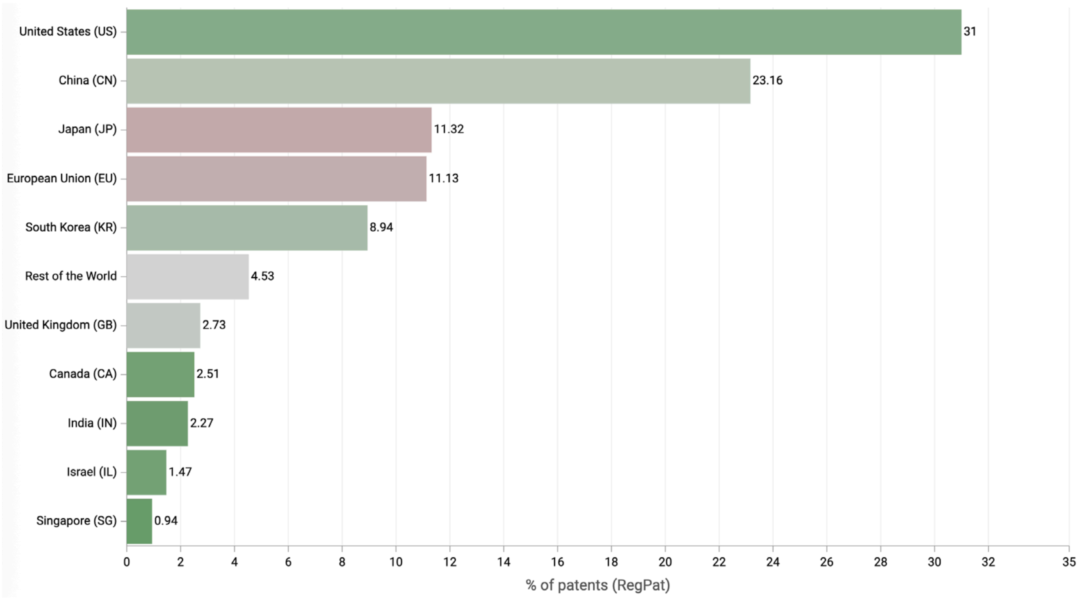


Source: https://www.paballand.com/ceps/ttd/position/crunchbase/artificial-intelligence.html

2.2. GENERATIVE AI

In the domain of Generative AI, the situation is slightly different compared to the broader AI area. Here the United States clearly leads with 31 % of all patents, followed by China with 23.2 %. The EU accounts for approximately 11 % of patents, a share similar to that of Japan. Among select partners, South Korea holds a significant share, close to 9 % of all patents.

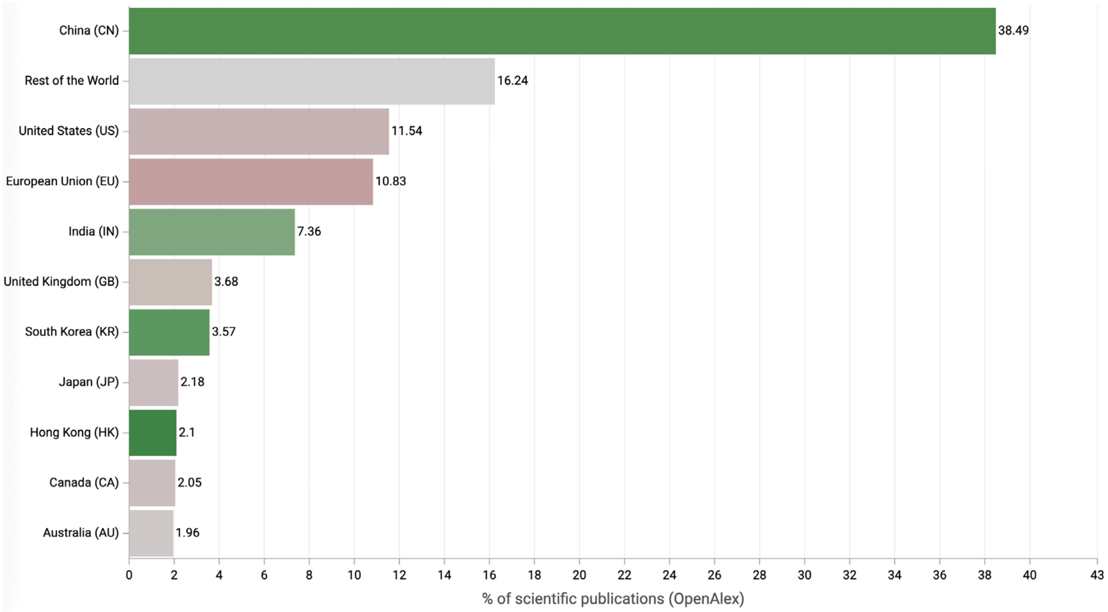
Figure 7 – Percentage of global patents in generative AI, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/generative-ai.html

Our analysis of scientific publications on generative artificial intelligence indicates a clear leadership of China in terms of publication volume. Bibliometric data show that China accounts for the largest share of papers in this field, significantly exceeding other regions. The United States and the European Union follow with relatively similar shares, each representing roughly 11 % of global publications. India ranks next, contributing around 7 % of the total output. This distribution highlights the rapid expansion of China's research system in emerging digital technologies and its strong emphasis on publication output. At the same time, the United States and the European Union maintain important roles in the field through highly cited research, leading universities, and strong links between academic research and industry innovation. India's growing share also reflects the expansion of its information technology sector and research capacity in artificial intelligence. Overall, the global landscape of Generative AI research demonstrates increasing competition among major scientific regions, with China leading in publication quantity while other regions remain influential through research impact and technological development.

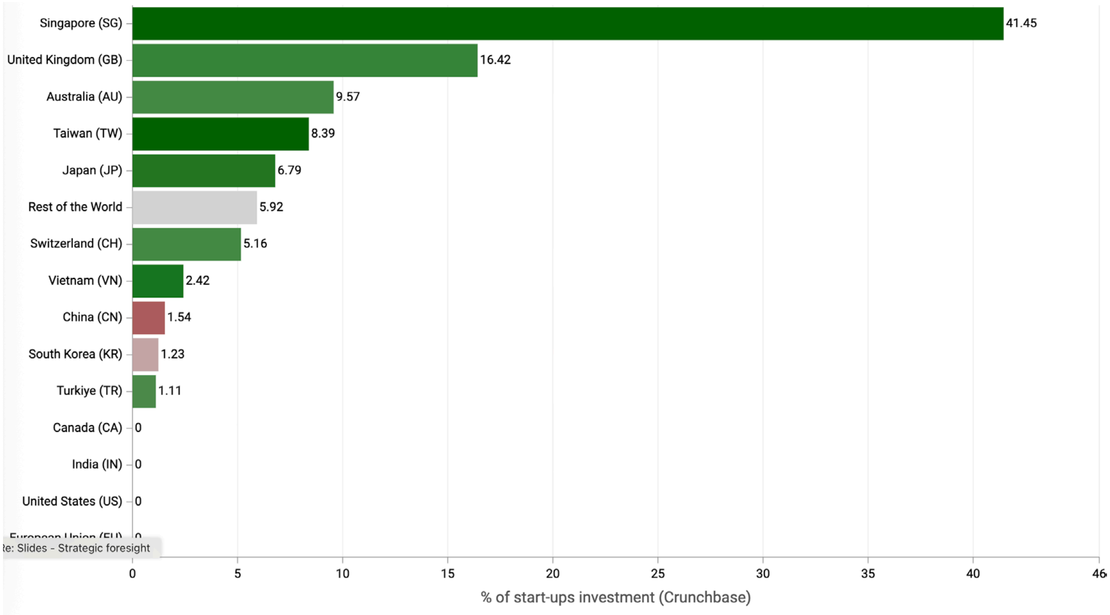
Figure 8 – Percentage of scientific publications in generative AI, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/generative-ai.html

Our data on VC investment in new start-ups show Singapore as the leading country, followed by the United Kingdom, Australia, Taiwan and Japan. Singapore appearing as the leading country in Generative AI venture investment in Crunchbase data does not necessarily mean it leads the world in Generative AI development. Rather, it reflects the role of Singapore as a regional start-up and investment hub, the influence of large funding rounds, and the way venture capital datasets assign geographic location to start-ups. Venture capital datasets typically assign investments to the location where a start-up is legally registered or headquartered, not necessarily where most research, development, or market activity takes place. Many start-ups – especially in technology sectors like Generative AI – register their headquarters in international financial hubs. Singapore has become a major hub for venture capital in Asia because of its favourable regulatory environment, strong financial sector, and tax advantages. As a result, many AI start-ups that operate across Asia choose Singapore as their official headquarters, which causes VC investment to be attributed there in Crunchbase data. Moreover, venture capital statistics can be strongly influenced by a small number of very large funding rounds. If several Generative AI companies registered in Singapore receive large investments in a short period, this can temporarily push the country to the top of rankings. Venture investment data are therefore often more volatile than scientific publication data and can change significantly from year to year.

Figure 9 – Percentage of VC investment in start-ups in generative AI, 2010-2025

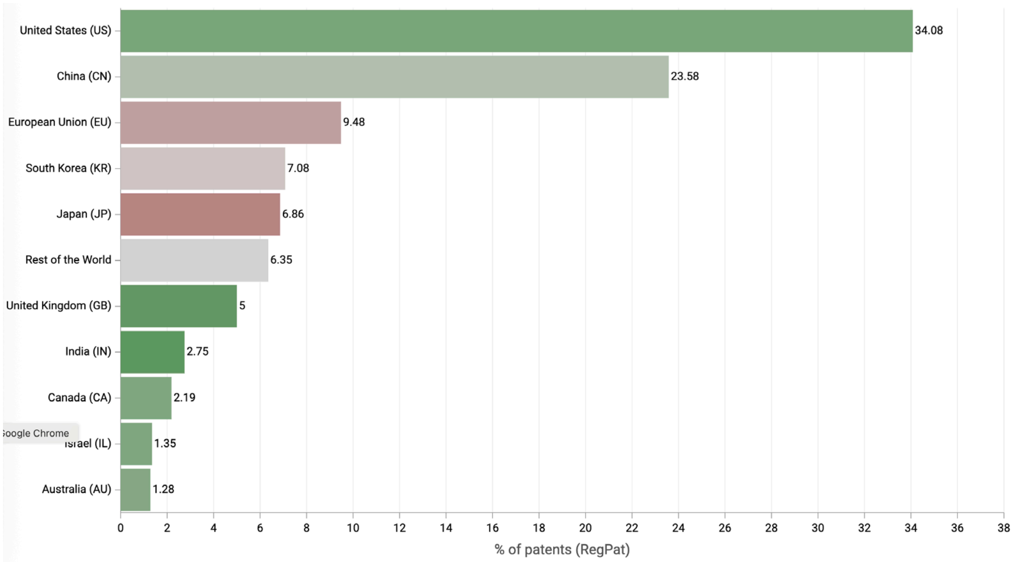


Source: https://www.paballand.com/ceps/ttd/position/crunchbase/generative-ai.html

2.3. BLOCKCHAIN TECHNOLOGIES

In the domain of blockchain technologies, the United States leads with 34 % of all patents, followed by China with 23.6 %. The EU accounts for slightly less than 10 % of patents, followed by South Korea and Japan.

Figure 10 – Percentage of global patents in blockchain technologies, 2010-2024

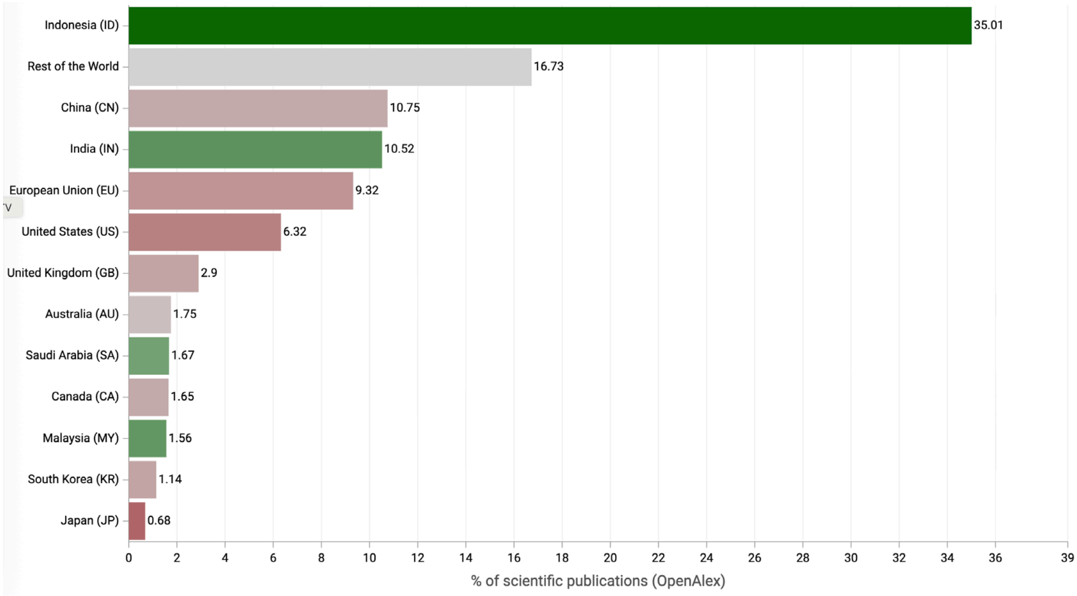


Source: https://www.paballand.com/ceps/ttd/position/regpat/blockchain-technologies.html

The situation on scientific publication is very different, and somehow surprising as Indonesia holds by far the largest share (35 %). This finding requires a deeper analysis, as it may depend on the peculiar structure of academic publishing in computer science. In fields such as blockchain, many papers are published in conference proceedings rather than traditional journals. Indonesian universities participate heavily in international conferences indexed in databases like Scopus, which increases the visible number of publications affiliated with Indonesian institutions. In addition, Indonesian higher-education policies strongly encourage academics and graduate students to publish research papers. Publications are often required for doctoral graduation, academic promotion, and institutional evaluation, which leads to a significant increase in research output in emerging technological topics. Another contributing factor is the rapid growth of interest in blockchain and cryptocurrency within Indonesia itself. The country has become one of the largest markets for crypto adoption in the world, with millions of users and a growing ecosystem of start-ups, exchanges, and research initiatives. This widespread adoption has stimulated academic interest and encouraged universities to explore blockchain applications in finance, supply chains, digital identity, and public administration. As a result, many Indonesian researchers choose blockchain as a research topic. That said, despite the relatively high number of publications in some datasets, Indonesia's influence in blockchain research is still developing. Countries that lead the field typically produce work with higher citation impact, larger research funding, and stronger collaboration networks. Indonesia's growing publication volume therefore reflects an expanding research community and strong institutional incentives rather than clear global dominance in the scientific influence of blockchain studies.

Another interesting finding here is the relative underdevelopment of the blockchain scientific research in the United States, which fares well below China, the EU and India. Compared to our findings in AI, the United Kingdom also appears to be less competitive from this specific perspective.

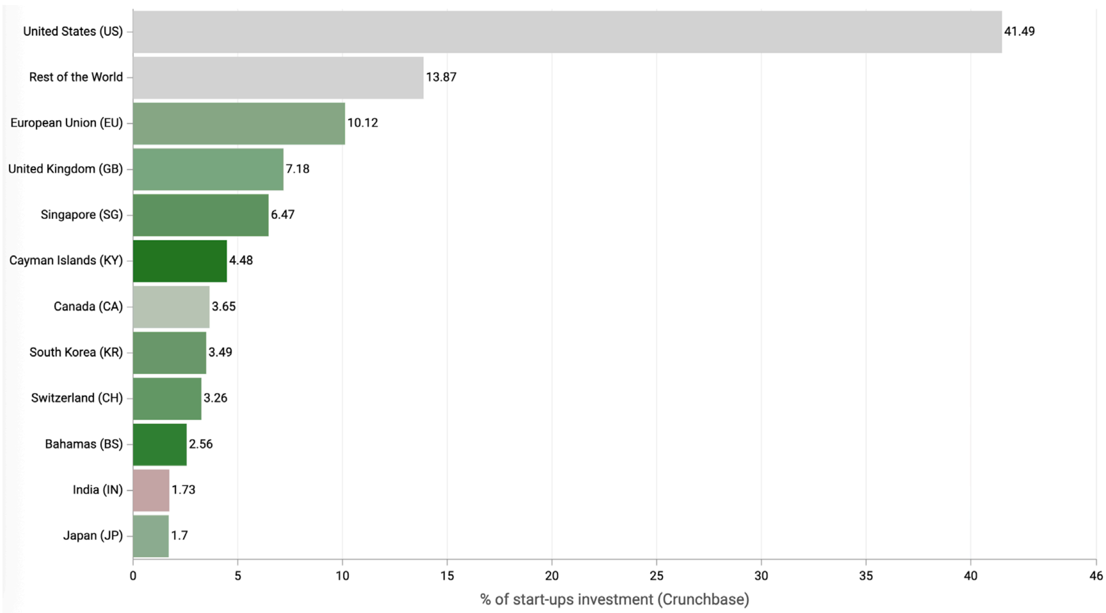
Figure 11 – Percentage of scientific publications in blockchain technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/blockchain-technologies.html

In terms of VC investment the US still shows its leadership, thanks to its deep capital markets. The EU holds a 10 % market share in this domain, which is comparatively higher than that observed in AI.

Figure 12 – Percentage of VC investment in start-ups in blockchain technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/blockchain-technologies.html

2.4. CLOUD COMPUTING AND EDGE COMPUTING

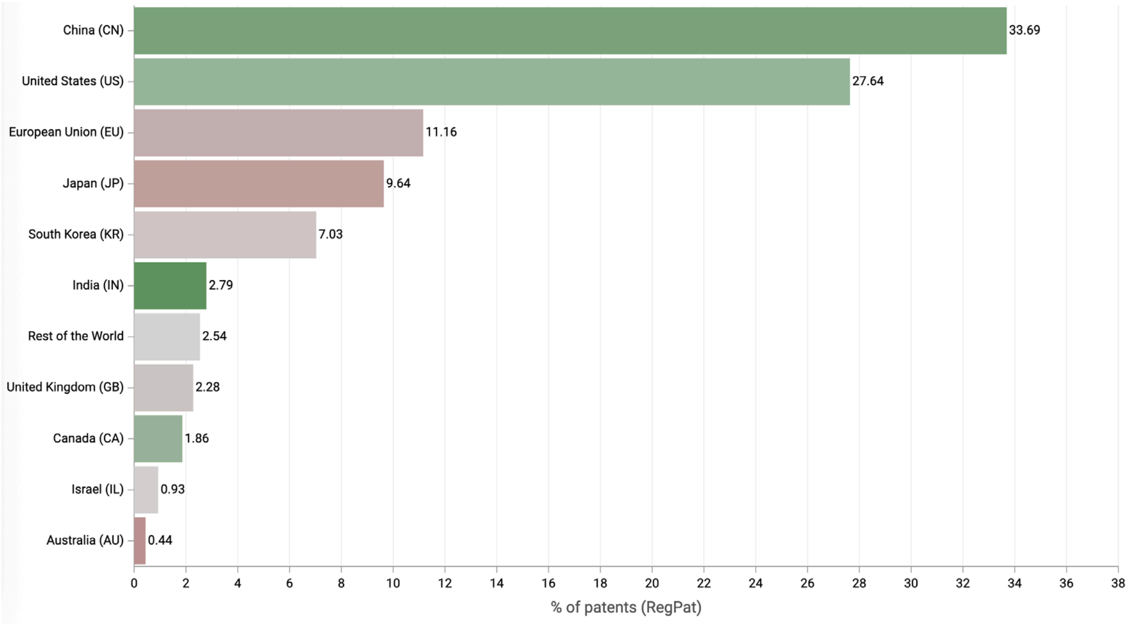
In the domain of cloud and edge computing, patent data indicate a strong concentration of technological innovation in a few major economies and large technology firms. China holds more than one third of global patents in this field, reflecting the rapid expansion of its digital infrastructure and strong government support for strategic technologies. Chinese companies are among the most active patent holders, particularly telecommunications and network-equipment manufacturers. Firms such as Huawei have built very large intellectual-property portfolios and are among the world's most prolific patent applicants, with thousands of patents related to telecommunications networks, cloud infrastructure, and distributed computing systems.

The United States follows China with about 27.6 % of global patents in cloud and edge computing. US patenting activity is largely driven by major technology companies that dominate the global cloud services market. Companies such as Amazon, Microsoft, IBM, and Google play a central role in developing cloud platforms, distributed computing architectures, and data centre technologies. These firms invest heavily in research and development and hold extensive patent portfolios covering infrastructure, virtualisation technologies, and cloud-based services.

The European Union holds around 11 % of global patents in cloud and edge computing, placing it ahead of Japan and South Korea in this specific technological domain. European patent activity is often driven by telecommunications and network technology companies. For example, Ericsson possesses tens of thousands of patents related to network technologies and plays a major role in the development of advanced digital infrastructures, including cloud-based network architectures and mobile edge computing. Other European actors, such as Nokia, also contribute significantly to patenting activity related to cloud infrastructure and data-streaming technologies.

Overall, the global patent landscape in cloud and edge computing is characterised by the dominance of large multinational technology companies and telecommunications equipment manufacturers. These firms possess extensive research capabilities and large intellectual-property portfolios, allowing them to shape the technological standards and infrastructure that underpin next-generation digital services.

Figure 13 – Percentage of global patents in cloud and edge computing, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/cloud-computing--edge-computing.html

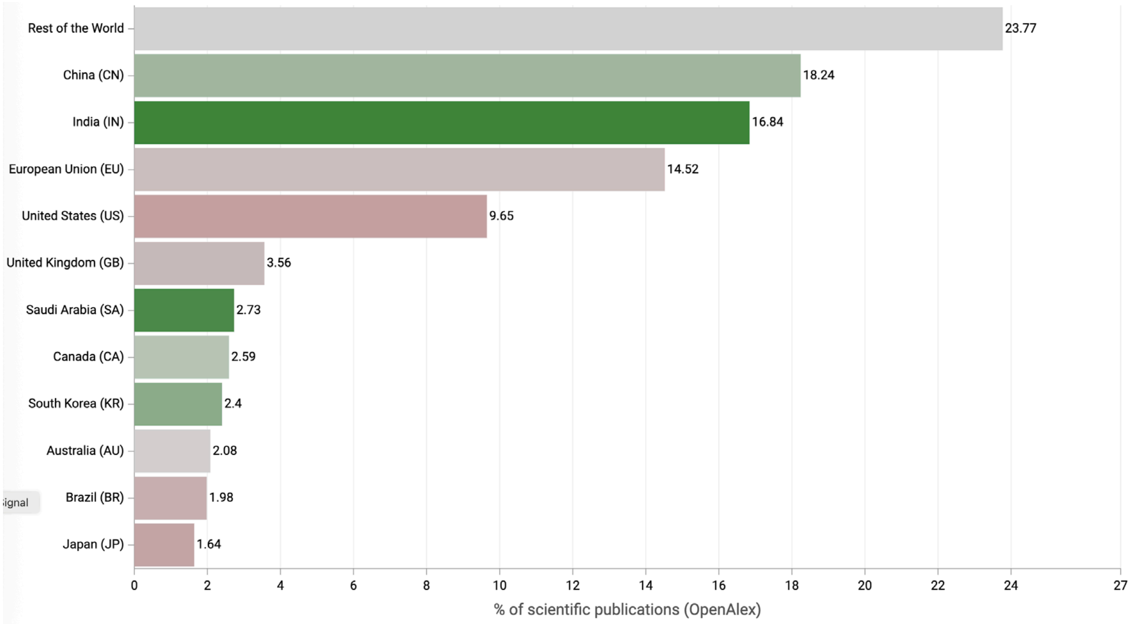
On scientific publications, China holds the leading position with a 18.2 % share of total publications. This reflects the rapid expansion of the Chinese research system over the past decade, supported by strong public investment in digital technologies and large-scale academic research programmes. China's universities and research institutes have significantly increased their scientific output in areas related to cloud infrastructure, distributed systems, and data-intensive computing.

A notable feature of the publication landscape is the strong position of India, which accounts for almost 17 % of the total publications listed in OpenAlex. India's high share is largely explained by the rapid growth of its higher education sector and the large number of researchers working in computer science and information technologies. Indian universities are particularly active in publishing conference papers and applied research related to software systems, networking, and cloud-based applications.

The European Union also performs strongly in this field, significantly outperforming the United States in terms of publication volume. The EU accounts for approximately 14.5 % of global publications, compared with 9.6 % for the United States. This difference partly reflects the large number of universities and public research institutions across EU Member States that contribute to academic output. It also illustrates the collaborative nature of European research, where multi-country academic networks and publicly funded research programmes contribute to a steady flow of scientific publications in emerging digital technologies.

Overall, these figures highlight the increasingly global distribution of research activity in cloud and edge computing. While China leads in publication share, India's rapid growth and the strong academic output of the European Union demonstrate the expanding participation of multiple research systems in the development of these technologies.

Figure 14 – Percentage of scientific publications in cloud and edge computing, 2010-2025



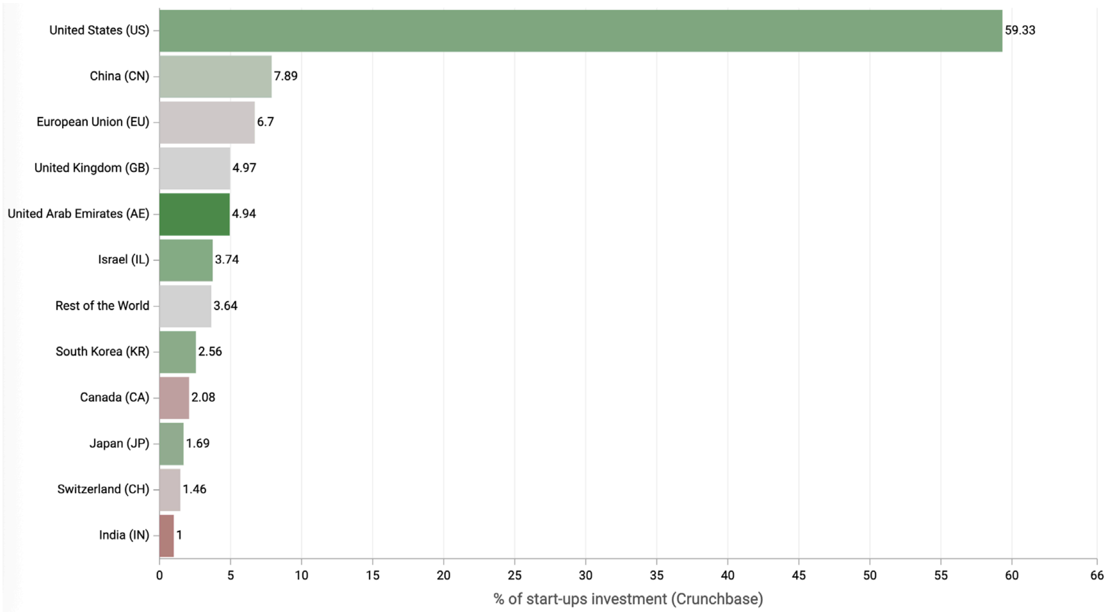
Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/cloud-computing--edge-computing.html

Finally, data on venture capital investment in start-ups confirm the United States as the leading market in this technological domain. According to information available from Crunchbase Pro, the United States accounts for close to 60 % of the total value of venture capital investment between 2010 and May 2025. This dominant position reflects the depth of the American start-up ecosystem, the presence of large venture capital funds, and the strong connections between universities, technology companies, and investors. Major innovation hubs such as Silicon Valley, New York, and Boston continue to attract a large share of global venture capital, particularly in digital infrastructure, cloud services, and emerging computing technologies.

Significantly, China holds a higher share of venture capital investment than European Union, accounting for approximately 7.9 % of total investment compared with 6.7 % in Europe. China's position reflects the rapid growth of its technology sector and the emergence of large domestic venture capital funds supporting digital innovation and platform companies. The United Kingdom follows with almost 5 % of global venture capital investment, highlighting the country's role as one of the main start-up and financial hubs in Europe, particularly in areas such as fintech, artificial intelligence, and cloud-based services.

In addition, Israel stands out with about 3.7 % of global venture capital investment despite its relatively small size. Israel has developed one of the most dynamic technology ecosystems in the world, supported by strong research universities, military-driven technological expertise, and close connections with international venture capital networks. This has enabled the country to specialise in high-technology start-ups and attract significant investment in advanced digital and computing technologies. Overall, these patterns illustrate the strong concentration of venture capital in a limited number of global innovation hubs.

Figure 15 – Percentage of VC investment in start-ups in cloud and edge computing, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/cloud-computing--edge-computing.html

2.5. COMPUTER VISION, NATURAL LANGUAGE PROCESSING AND OBJECT RECOGNITION

For patents in the domains of computer vision, natural language processing, and object recognition, the global landscape is largely dominated by China and the United States, which appear to be in close technological competition. China holds a slightly larger share of patents, accounting for about 27.7 % of the total, compared with 25.8 % for the United States. This narrow gap reflects the rapid expansion of China's artificial intelligence sector over the past decade, supported by strong public investment, large-scale data resources, and the strategic prioritisation of AI technologies in national innovation policies. Chinese technology firms and research institutes have actively expanded their patent portfolios in computer vision and language technologies, particularly in applications such as facial recognition, automated translation, and intelligent surveillance systems.

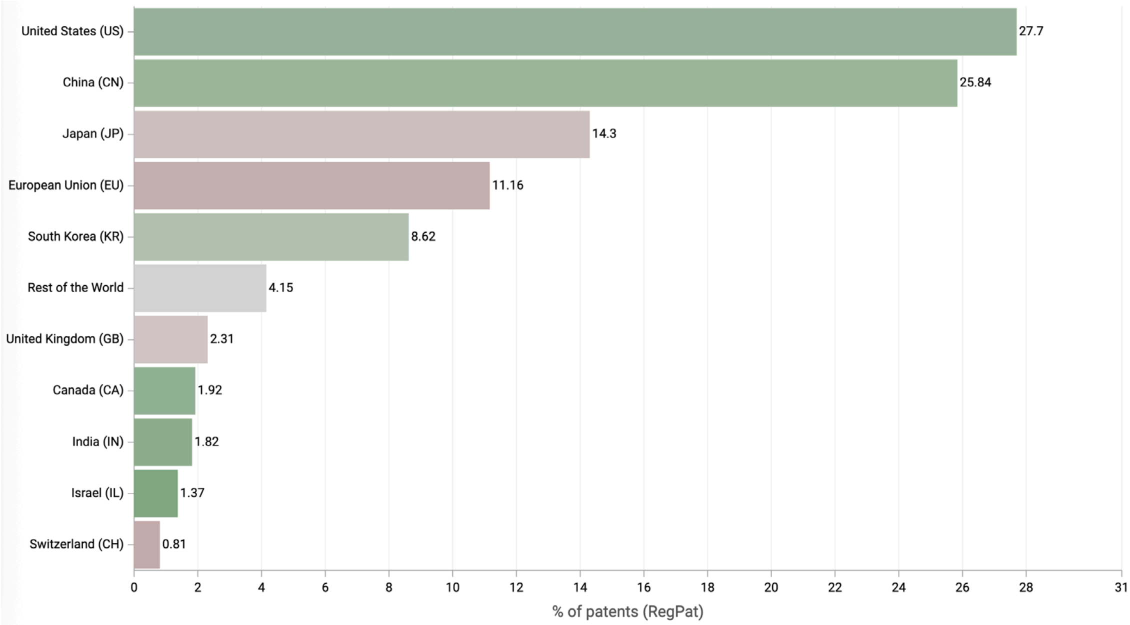
At the same time, the United States remains a major driver of innovation in these fields. American technology companies have been pioneers in the development of deep learning architectures and large-scale AI systems that underpin modern computer vision and natural language processing technologies. Large multinational firms play a key role in patenting activity. Companies such as Microsoft, Google, IBM, and Amazon hold extensive patent portfolios related to machine learning algorithms, image recognition systems, and language-processing technologies, reflecting their major investments in artificial intelligence research and development.

Japan also performs particularly well in this technological domain, accounting for about 14 % of global patents. Japan's strong position is largely driven by large electronics and technology companies with long-standing expertise in imaging systems, sensors, and robotics. Firms such as Sony and Canon have been important contributors to innovations in imaging technologies that underpin computer vision applications.

By comparison, the European Union holds around 11.16 % of patents in these areas, placing it behind Japan. European patenting activity is more fragmented across countries but still supported by strong industrial actors and research institutions. Companies such as Siemens, Nokia, and Ericsson contribute to AI-related patenting, particularly in applications linked to industrial automation, telecommunications networks, and data analytics.

Overall, the patent landscape in computer vision and natural language processing reflects intense technological competition between major innovation systems. China's slightly higher patent share demonstrates its rapid rise in AI technologies, while the United States continues to maintain a powerful innovation ecosystem driven by leading technology firms and advanced research institutions. Japan and the European Union remain important contributors, although their patent activity is more concentrated in specific industrial sectors and companies.

Figure 16 – Percentage of global patents in computer vision, natural language processing and object recognition, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/computer-vision-language-processing--object-recognition.html

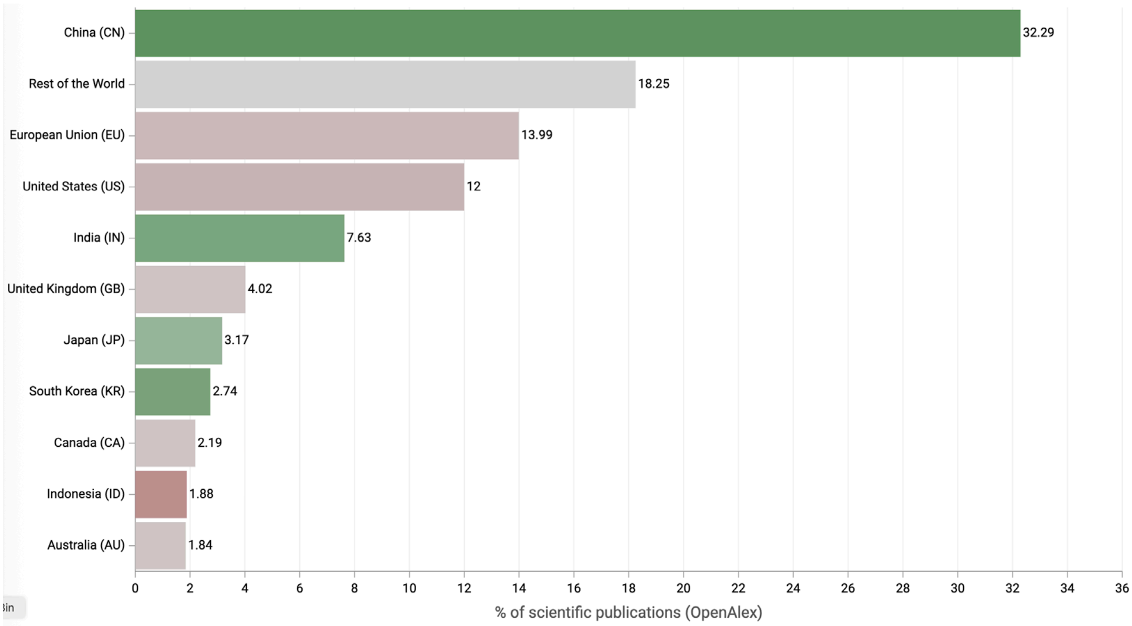
On scientific publications in the fields of computer vision, natural language processing, and object recognition, China clearly dominates, accounting for about 32.3 % of global publications. This strong position reflects the rapid expansion of China's research system in artificial intelligence and data-intensive computing. Chinese universities and research institutes are particularly active in these domains, supported by significant government funding and national AI strategies. Leading institutions such as Tsinghua University, Peking University, and the Chinese Academy of Sciences are among the most prolific contributors to scientific publications in machine learning and computer vision. In addition, major Chinese technology companies, including Baidu and Alibaba, frequently collaborate with academic researchers and publish research results related to artificial intelligence and large-scale data processing.

The European Union holds the second-largest share of publications with about 14 %, slightly ahead of the United States, which accounts for around 12 %. Europe's scientific output reflects the contributions of a wide network of universities and publicly funded research institutions across Member States. Prominent European institutions publishing in artificial intelligence include University of Oxford, Technical University of Munich, and ETH Zurich, which are particularly active in machine learning, computer vision, and data science. In the United States, major research universities such as Stanford University and Massachusetts Institute of Technology remain central actors in the academic development of artificial intelligence. Large technology companies, including Google and Microsoft, also contribute extensively to the scientific literature through collaborations with universities and dedicated research laboratories.

India also holds a significant share of global publications, accounting for about 7.6 % of the total. India's growing role in AI research is linked to its large pool of engineers and computer scientists as well as the expansion of its higher-education system. Institutions such as Indian Institute of Technology have become increasingly active in publishing research on machine learning, computer vision, and natural language technologies.

Overall, the distribution of scientific publications highlights the global expansion of research in artificial intelligence. While China leads in publication volume, Europe, the United States, and India also play important roles through strong academic institutions and collaborations between universities and major technology companies.

Figure 17 – Percentage of scientific publications in computer vision, NLP and object recognition, 2010-2025



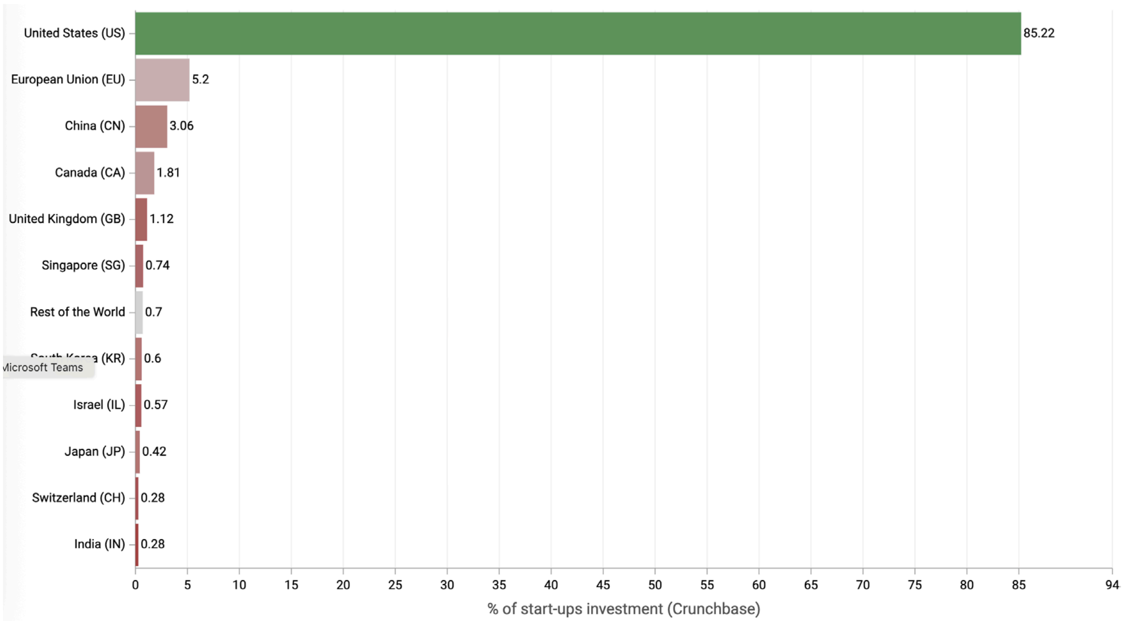
Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/computer-vision-language-processing--object-recognition.html

Data on venture capital investment in start-ups specialising in computer vision, natural language processing, and object recognition show the overwhelming dominance of the United States, which accounts for roughly 85 % of the global value of venture-backed deals. This striking concentration reflects the central role of the US start-up ecosystem in the commercialisation of artificial intelligence technologies. Silicon Valley and other major innovation hubs host many of the world's leading AI start-ups as well as the largest venture capital funds and corporate investors. As a result, the United States captures the vast majority of large funding rounds in AI-related sectors.

A key characteristic of the venture landscape is the presence of extremely large funding rounds for a small number of US-based companies. As reported by Crunchbase Pro, several AI start-ups have raised multi-billion-dollar rounds in recent years. For example, Scale AI, which provides training data for computer vision and machine learning systems, has raised multiple large funding rounds from investors such as Accel and Tiger Global Management. Another example is UiPath, which uses natural language processing and machine learning technologies within automation platforms and attracted major venture investments before its public listing.

Outside the United States, venture investment is significantly smaller but still notable. The European Union accounts for around 5.2 % of global deal value in these domains. European start-ups such as DeepL, which develops advanced neural machine translation systems based on natural language processing, have raised substantial funding and gained global visibility. Meanwhile China accounts for about 3 % of venture capital investment in these sectors. Chinese companies such as SenseTime, known for its work in computer vision and facial recognition technologies, have attracted significant investment from both domestic and international investors.

Figure 18 – Percentage of VC investment in start-ups in computer vision, NLP and object recognition, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/computer-vision-language-processing--object-recognition.html

2.6. CYBERSECURITY TECHNOLOGIES

In the domain of cybersecurity technologies, patent data also reveal a close technological competition between China and the United States. China holds a slightly larger share of patents, accounting for approximately 28.5 % of the global total, while the United States follows closely with around 27 %. China's strong position reflects sustained investment in digital infrastructure, data protection technologies, and secure communication systems. A number of large Chinese technology firms have built extensive cybersecurity-related patent portfolios. Companies such as Huawei and Alibaba are particularly active in patenting innovations related to network security, encryption systems, and cloud-based security solutions. These companies integrate cybersecurity capabilities into telecommunications networks, cloud platforms, and digital services used by millions of users.

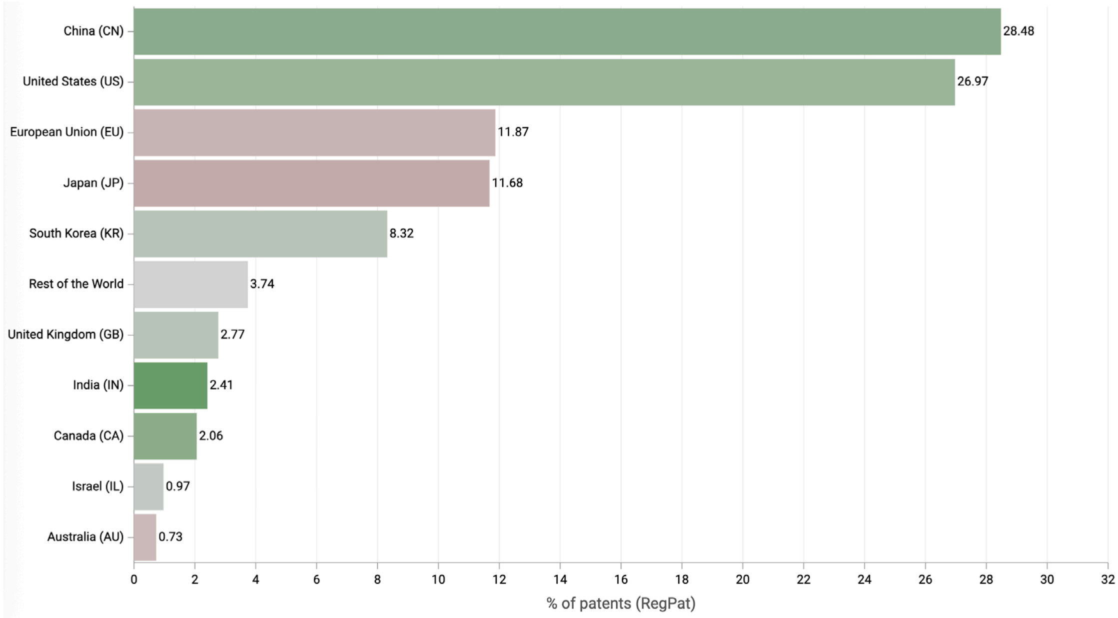
The United States remains one of the most influential innovation ecosystems in cybersecurity technologies. Much of the US patent activity is driven by large technology companies with strong research capabilities and extensive global operations. Firms such as IBM, Microsoft, and Cisco hold large patent portfolios covering areas such as cryptographic systems, secure cloud architectures, network protection technologies, and threat-detection systems. These companies play a key role in shaping cybersecurity standards and technologies used across digital infrastructures worldwide.

The European Union and Japan follow with similar shares of global cybersecurity patents, each holding close to 12 %. In Europe, patent activity is often driven by telecommunications and industrial technology companies. Firms such as Nokia and Ericsson contribute significantly to innovations in network security, secure mobile communications, and encrypted data transmission. In Japan, cybersecurity innovation is supported by large electronics and information-technology firms. Companies including NEC and Fujitsu have developed extensive patent portfolios related to biometric authentication, secure network systems, and advanced encryption technologies.

Finally, South Korea accounts for about 8.3 % of global patents in cybersecurity. South Korea's strong digital economy and advanced telecommunications infrastructure support significant innovation in secure mobile networks and digital services. Major technology firms such as Samsung Electronics play an important role in developing cybersecurity solutions integrated into mobile devices, network equipment, and cloud-based platforms.

Overall, the patent landscape in cybersecurity highlights intense competition among major technological powers. While China currently holds a slight lead in patent volume, the United States, Europe, Japan, and South Korea remain important innovators, with large multinational companies driving the development of technologies essential to securing modern digital systems.

Figure 19 – Percentage of global patents in cybersecurity technologies, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/cybersecurity-technologies.html

On scientific publications in cybersecurity, China holds the leading position with around 19 % of the global output. This strong performance reflects the rapid growth of China's research system and the strategic importance given to cybersecurity and digital sovereignty in national technology policies. Chinese universities and public research institutes are particularly active in publishing work on cryptography, network security, intrusion detection systems, and data protection technologies. Major institutions such as Tsinghua University, Shanghai Jiao Tong University, and the Chinese Academy of Sciences are among the most prolific contributors to the scientific literature in cybersecurity and information security.

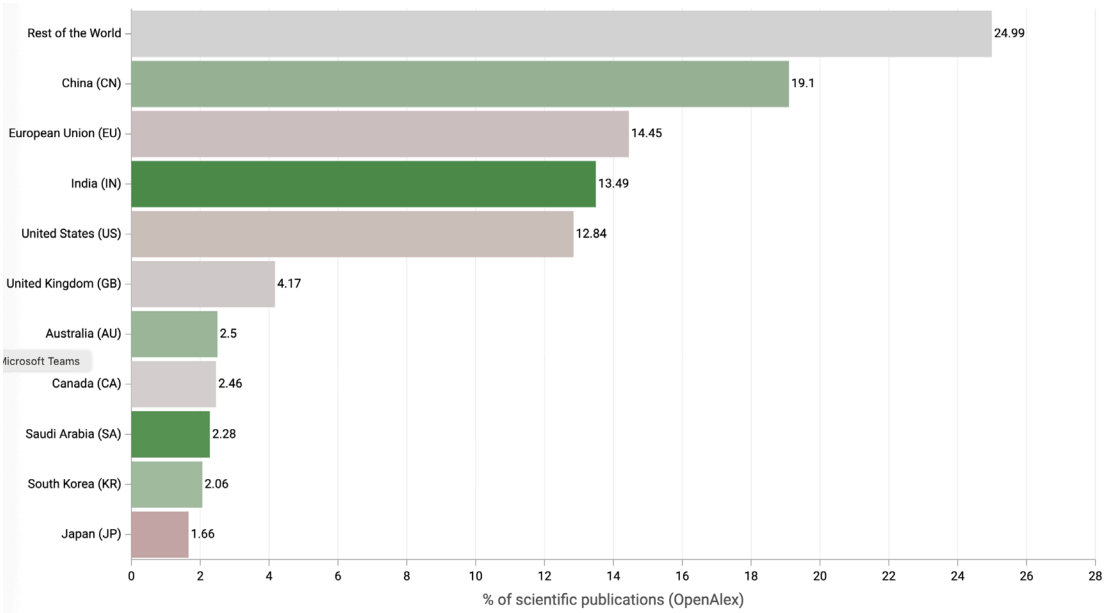
The European Union follows with approximately 14 % of global publications. Europe's research output reflects the contributions of a broad network of universities and publicly funded research centres working on digital security, privacy protection, and secure communication systems. Institutions such as KU Leuven and Technical University of Munich have strong research groups specialising in cryptography, privacy-enhancing technologies, and network security.

India also occupies a prominent position with a share slightly above 14 %, placing it ahead of the United States, which accounts for less than 13 % of global publications. India's strong publication performance reflects the rapid expansion of its higher-education system and the large number of researchers working in computer science and information technology. Leading institutions such as the Indian Institute of Technology network and the Indian Institute of Science contribute significantly to research on secure software systems, network protection mechanisms, and data security.

Despite ranking slightly lower in publication volume, the United States remains highly influential in cybersecurity research through leading universities and strong links between academia and industry. Institutions such as Stanford University, Massachusetts Institute of Technology, and Carnegie Mellon University are globally recognised for their work on cryptography, network security, and privacy technologies. In addition, large technology companies including Microsoft, Google, and IBM frequently collaborate with academic researchers and publish influential work on cybersecurity technologies.

Overall, the distribution of scientific publications in cybersecurity illustrates the increasingly global nature of research in this domain. While China leads in publication volume, Europe and India also play important roles, and the United States continues to exert strong influence through high-impact research institutions and industry–academic collaborations.

Figure 20 – Percentage of scientific publications in cybersecurity technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/cybersecurity.html

In terms of venture capital investment in cybersecurity start-ups, the United States once again dominates the global landscape, accounting for roughly 64 % of the total value of deals. This overwhelming share reflects the scale and maturity of the American venture capital ecosystem as well as the strategic importance of cybersecurity for digital infrastructure, cloud computing, and enterprise software markets. Major technology hubs such as Silicon Valley, Boston, and Washington D.C. host numerous cybersecurity start-ups and specialised venture capital firms. According to data reported by Crunchbase, several large funding rounds have contributed to this dominance. For instance, Wiz raised a multibillion-dollar investment round to expand its cloud security platform, while companies such as Snyk and Tanium have also attracted major venture funding to develop advanced security solutions for enterprise software and cloud environments.

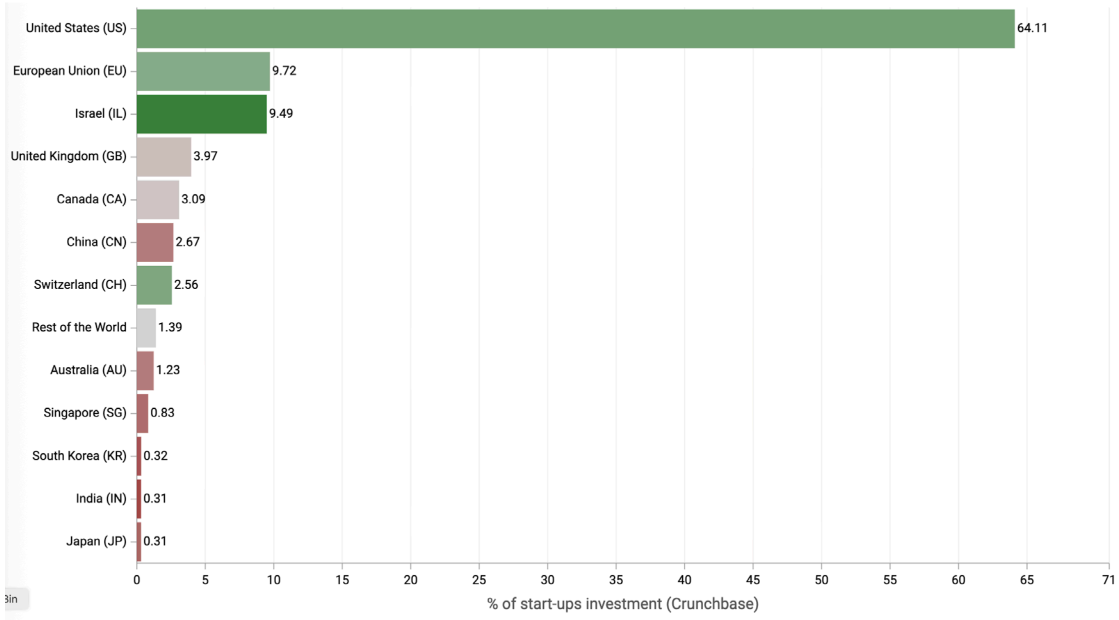
Outside the United States, the European Union and Israel stand out as the most significant venture ecosystems in cybersecurity, each accounting for more than 9 % of the global value of deals. Europe has produced several rapidly growing cybersecurity firms supported by venture funding. For example, Darktrace, based in the United Kingdom, has attracted substantial investment for its artificial intelligence-driven threat-detection technologies, while companies such as Helsing have raised large rounds to develop advanced digital security and defence technologies.

Israel, despite its relatively small size, has developed one of the most dynamic cybersecurity start-up ecosystems in the world. Israeli companies frequently emerge from strong research universities and military technology units, creating a steady pipeline of innovative security start-ups. Firms such as Check Point Software Technologies and CyberArk illustrate the country's long-standing expertise in network security, identity protection, and digital defence technologies.

The United Kingdom and Canada also attract notable venture capital investments in cybersecurity, both ranking ahead of China in terms of deal value. China accounts for only about 2.7 % of global venture capital investment in this field. While Chinese companies are highly active in cybersecurity patents and research publications, venture investment in cybersecurity start-ups has been comparatively limited, partly reflecting the structure of China's technology sector and the greater role of large established firms in developing security technologies.

Overall, the venture capital landscape in cybersecurity highlights a strong concentration of investment in a few innovation hubs. The United States clearly dominates in terms of funding and start-up activity, while Europe and Israel represent important secondary centres of innovation, supported by strong technical expertise and growing venture ecosystems.

Figure 21 – Percentage of VC investment in start-ups in cybersecurity technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/cybersecurity-technologies.html

2.7. DRONES

In the field of drones, patent data reveal a somewhat unexpected distribution of technological activity. The European Union holds a slightly larger share of global drone-related patents than the United States, with around 22.7 % compared with 22.4 %. Although the difference is small, this result may appear surprising given the strong visibility of US drone companies and the central role of American technology firms in advanced aerospace innovation. However, patent statistics often reflect the structure of industrial research and development, where large aerospace manufacturers and engineering companies maintain extensive patent portfolios covering components, control systems, navigation technologies, and sensor integration.

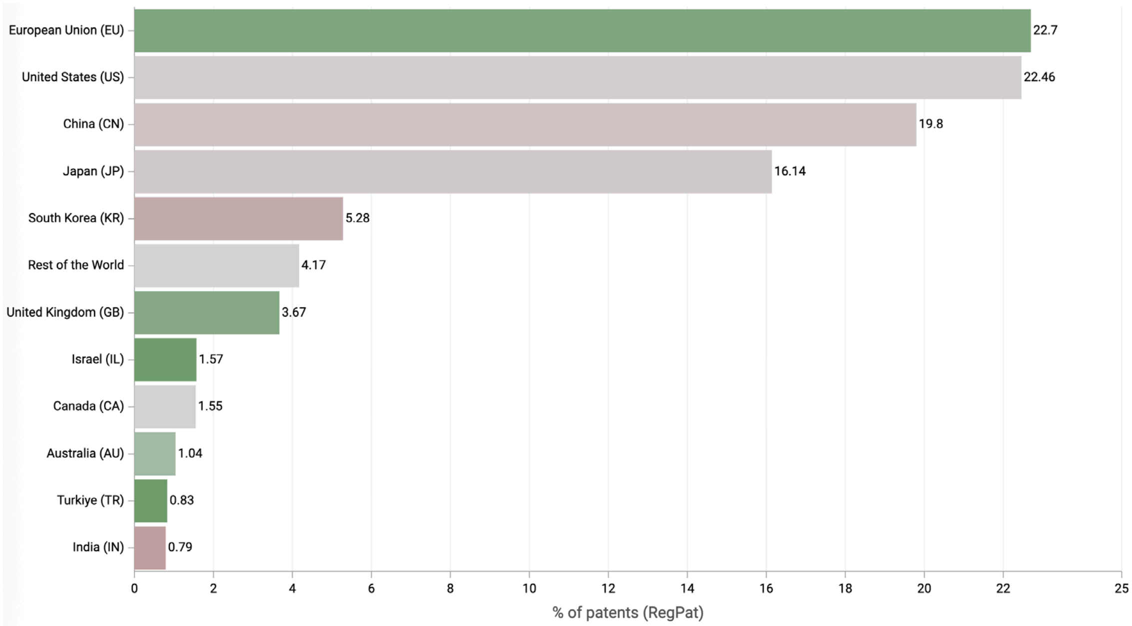
Europe's strong position can be largely explained by the presence of major aerospace and defence companies with long-standing expertise in aeronautics and autonomous systems. Firms such as Airbus, Thales Group, and Leonardo S.p.A. have invested heavily in unmanned aerial systems, particularly for surveillance, security, and industrial applications. These companies often develop complex technological subsystems – including avionics, communication links, and autonomous navigation systems – that generate large numbers of patent filings. In addition, European research programmes and collaborative aerospace initiatives have contributed to sustained patent activity across several EU member states.

The United States follows very closely in terms of patent share. American innovation in drones is driven by both large aerospace contractors and emerging technology companies. Major patent holders include companies such as Boeing and Lockheed Martin, which have long been involved in the development of unmanned aerial systems for military and industrial purposes. US technology firms also contribute to innovation in areas such as autonomous navigation, artificial intelligence for aerial systems, and advanced sensing technologies.

China, while slightly behind the European Union and the United States with a share below 20 %, has rapidly expanded its capabilities in drone technologies over the past decade. Chinese companies such as DJI have become global leaders in commercial drone manufacturing and have accumulated significant patent portfolios related to flight stabilisation, camera systems, and consumer drone platforms. Finally, Japan accounts for about 16.1 % of global drone patents. Japanese innovation is often driven by electronics and robotics companies, including firms such as Sony, which develop advanced sensors and imaging technologies used in unmanned aerial systems.

Overall, the patent landscape in drone technologies reflects the intersection of aerospace engineering, robotics, and digital technologies. Europe’s slight lead is largely linked to the strong patenting activity of its aerospace and defence industries, while the United States remains highly competitive due to its powerful aerospace sector and growing ecosystem of autonomous technology companies. China and Japan also play important roles, particularly through companies specialising in robotics, electronics, and commercial drone platforms.

Figure 22 – Percentage of global patents in drones, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/drones.html

In contrast to the patent landscape, the distribution of scientific publications on drone technologies is dominated by China, which accounts for roughly one third of all publications in this field. This strong position reflects the rapid expansion of China's research system in robotics, autonomous systems, and artificial intelligence, all of which are central to the development of unmanned aerial vehicles. Chinese universities and research institutes are particularly active in publishing work on drone navigation, swarm coordination, remote sensing, and aerial robotics. Leading institutions such as Beihang University, Tsinghua University, and the Chinese Academy of Sciences contribute significantly to the scientific literature on unmanned aerial systems and related technologies.

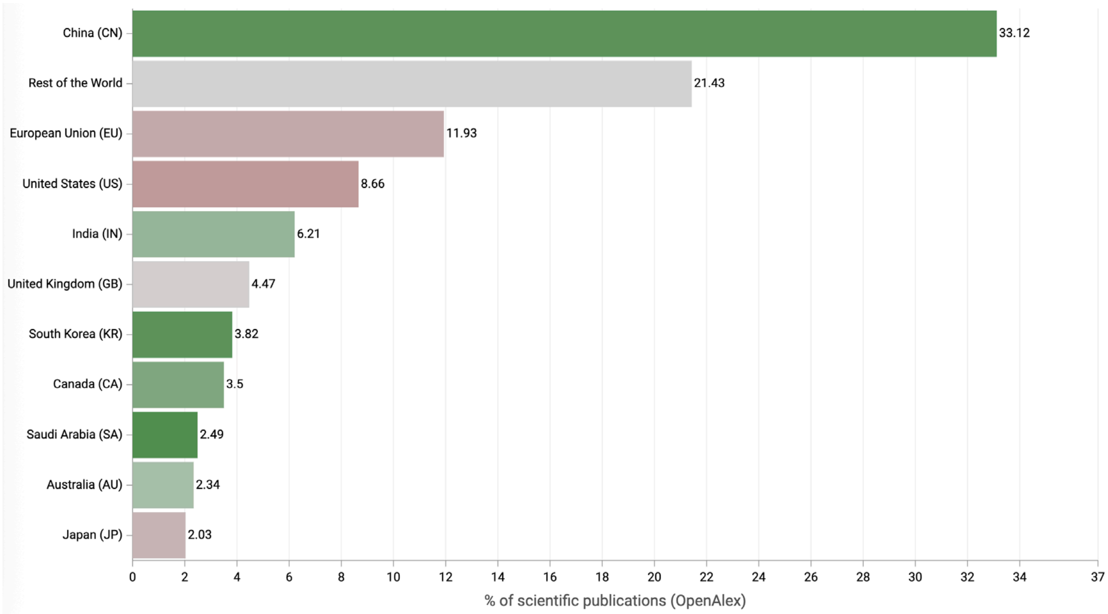
The European Union ranks second with around 12 % of global publications. Europe's research output in drone technologies reflects the contributions of a broad network of universities, engineering schools, and publicly funded research programmes focusing on robotics, autonomous vehicles, and aerial sensing systems. Institutions such as ETH Zurich and Delft University of Technology are particularly active in drone research, especially in areas such as autonomous navigation, swarm robotics, and aerial mapping technologies.

The United States holds a smaller share of publications, accounting for less than 9 % of the global total. While the United States is highly influential in aerospace engineering and autonomous systems, much of its innovation in drone technologies occurs within private companies and defence contractors rather than through academic publications.

Nonetheless, major research universities such as Massachusetts Institute of Technology, Stanford University, and the Georgia Institute of Technology remain important contributors to research on aerial robotics, control systems, and sensor integration.

Finally, India accounts for about 6.2 % of global publications. India's growing presence reflects the expansion of its engineering and robotics research communities as well as increasing interest in drone technologies for applications such as agriculture, infrastructure monitoring, and environmental observation. Institutions such as the Indian Institute of Technology network play an important role in producing research in autonomous aerial systems and related technologies.

Figure 23 – Percentage of scientific publications in drones, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/drones.html

According to data reported in Crunchbase Pro, venture capital investment in drone-related start-ups shows an unusual distribution when the United States, the United Kingdom, and the European Union are not included the dataset. Among the remaining countries, South Korea emerges as the leading location for venture capital investment in drones, accounting for about 36 % of the total value of deals. This strong position reflects South Korea's advanced electronics industry, strong robotics capabilities, and the presence of large technology firms that invest in autonomous systems, sensors, and aerial robotics. Companies such as Samsung Electronics have supported innovation in imaging systems, communications technologies, and embedded electronics that are critical for modern drone platforms.

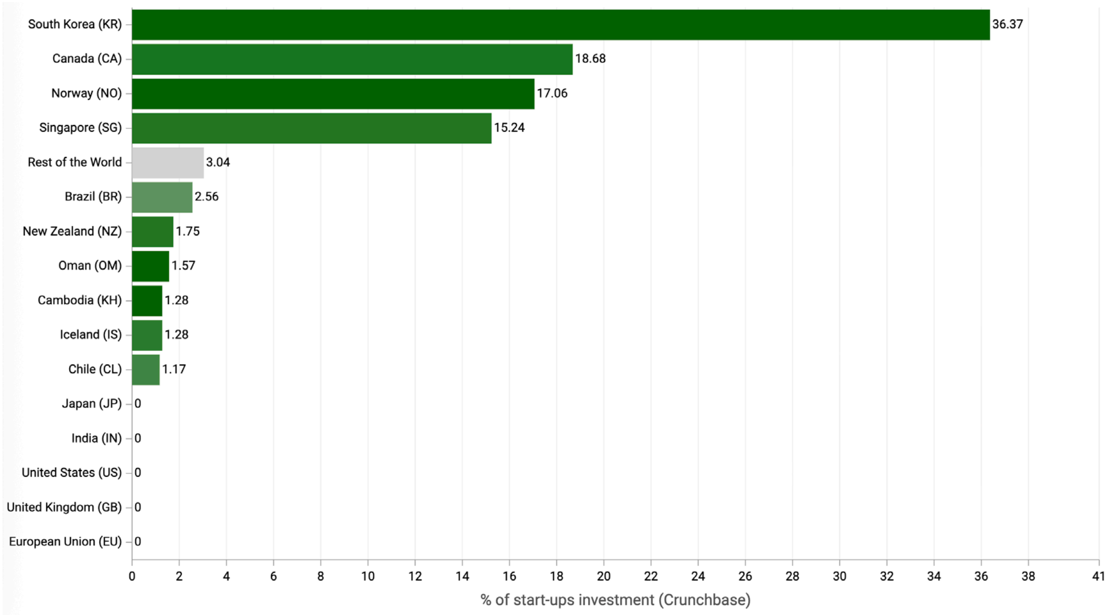
Canada ranks second with close to 19 % of deal value. Canada has developed a dynamic ecosystem of drone start-ups, supported by strong aerospace engineering expertise and a favourable regulatory environment for testing unmanned aerial vehicles. Several Canadian firms focus on specialised applications such as aerial mapping, environmental monitoring, and inspection of industrial infrastructure. The country's aerospace sector and research universities contribute to the development of technologies related to autonomous navigation, sensor integration, and data processing for drone operations.

Norway follows with around 17 % of venture capital investment. Norway's prominence in this area is partly linked to the country's strong maritime and offshore industries, which increasingly rely on drone technologies for inspection, surveillance, and environmental monitoring. Drone start-ups in Norway often focus on industrial applications such as monitoring offshore oil installations, shipping infrastructure, and coastal environments.

Finally, Singapore accounts for about 15 % of the value of deals in the dataset. Singapore has become an important regional hub for drone innovation and venture capital investment in Southeast Asia. The city-state actively promotes the development of autonomous technologies through regulatory experimentation and public support for urban drone applications, including logistics, surveillance, and infrastructure inspection.

Overall, these figures highlight how venture capital investment in drone start-ups can be strongly influenced by national industrial specialisations and regulatory environments. While the absence of the United States, the United Kingdom, and the European Union from the dataset significantly alters the ranking, the remaining data illustrate the growing importance of several smaller but highly specialised innovation ecosystems in the development of drone technologies.

Figure 24 – Percentage of VC investment in start-ups in drones, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/drones.html

2.8. HIGH-PERFORMANCE COMPUTING

The domain of high-performance computing (HPC) has become increasingly pivotal for the development of advanced digital technologies, as it provides the computational power necessary for artificial intelligence, large-scale simulations, and data-intensive scientific research. Patent data suggest that technological leadership in this field currently lies with China, which accounts for about 34.6 % of global patents. This strong position reflects sustained public investment in supercomputing infrastructure and domestic semiconductor technologies, as well as national programmes aimed at reducing dependence on foreign computing hardware. Chinese technology firms and research institutes have built substantial patent portfolios in areas such as parallel computing architectures, high-performance processors, and large-scale data processing systems. Companies such as Huawei and Inspur, together with the Chinese Academy of Sciences, play a central role in developing HPC hardware and systems that support large-scale computing platforms.

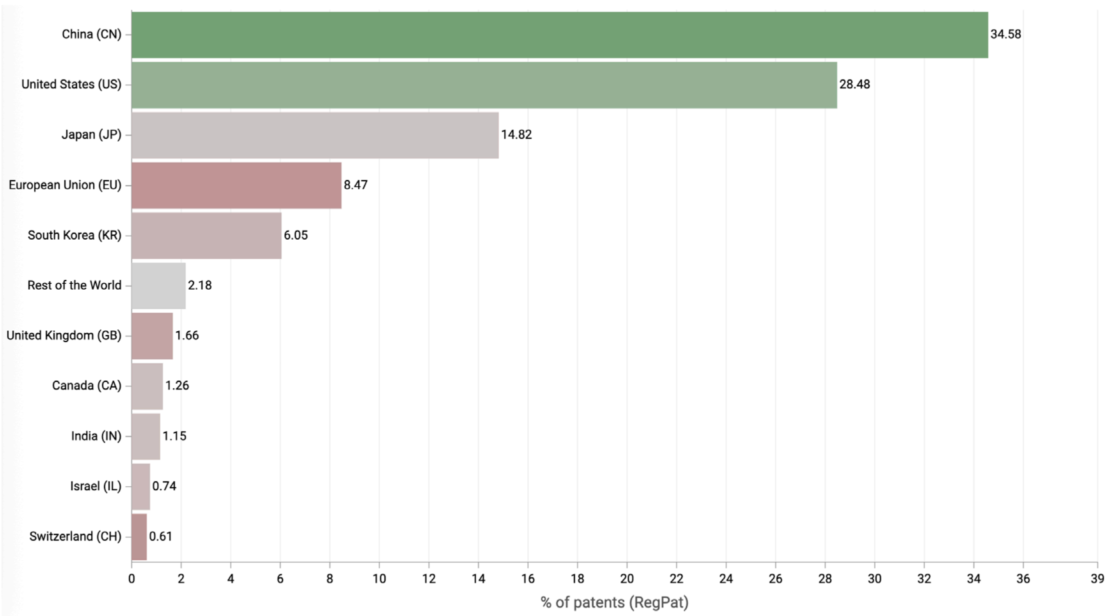
The United States follows with approximately 28.5 % of global patents. Although it ranks second in patent counts, the United States remains a major force in the development of HPC technologies through its powerful ecosystem of technology companies, research laboratories, and government-supported supercomputing initiatives. Leading firms such as IBM, Intel, and NVIDIA have been instrumental in advancing high-performance processors, graphics processing units, and computing architectures used in modern supercomputers and AI workloads.

Japan significantly outperforms the European Union in terms of patent counts in this domain, holding around 14.8 % of global HPC patents compared with about 8.5 % for the EU. Japan's strong performance reflects its long-standing expertise in supercomputing hardware and advanced semiconductor technologies. Companies such as Fujitsu and NEC have developed highly advanced computing systems and processors that power some of the world's fastest supercomputers.

Finally, South Korea accounts for roughly 6 % of global HPC patents. The country's role in this field is largely driven by its strong semiconductor industry and expertise in memory technologies essential for high-performance computing systems. Companies such as Samsung Electronics and SK Hynix contribute significantly to innovations in high-speed memory and advanced chip technologies that underpin modern supercomputing architectures.

Overall, the patent landscape in high-performance computing highlights the importance of semiconductor technologies, computing architectures, and large-scale data processing systems. China's leading share reflects the rapid growth of its domestic supercomputing ecosystem, while the United States, Japan, and South Korea remain key innovators through their powerful technology companies and advanced semiconductor industries.

Figure 25 – Percentage of global patents in HPC, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/highperformance-computing.html

Despite its more limited share of patents, the European Union emerges as a scientific leader in high-performance computing (HPC), accounting for about 19.3 % of global publications. This places the EU slightly ahead of both China and the United States in terms of scientific output. Europe's strong position reflects the presence of a dense network of universities, public research institutes, and collaborative research programmes dedicated to advanced computing technologies. Major academic actors include institutions such as ETH Zurich, Technical University of Munich, and University of Barcelona, which contribute extensively to research on parallel computing architectures, distributed systems, and large-scale simulation techniques. European collaborative initiatives and publicly funded research infrastructures have also played an important role in sustaining high levels of scientific publication in this field.

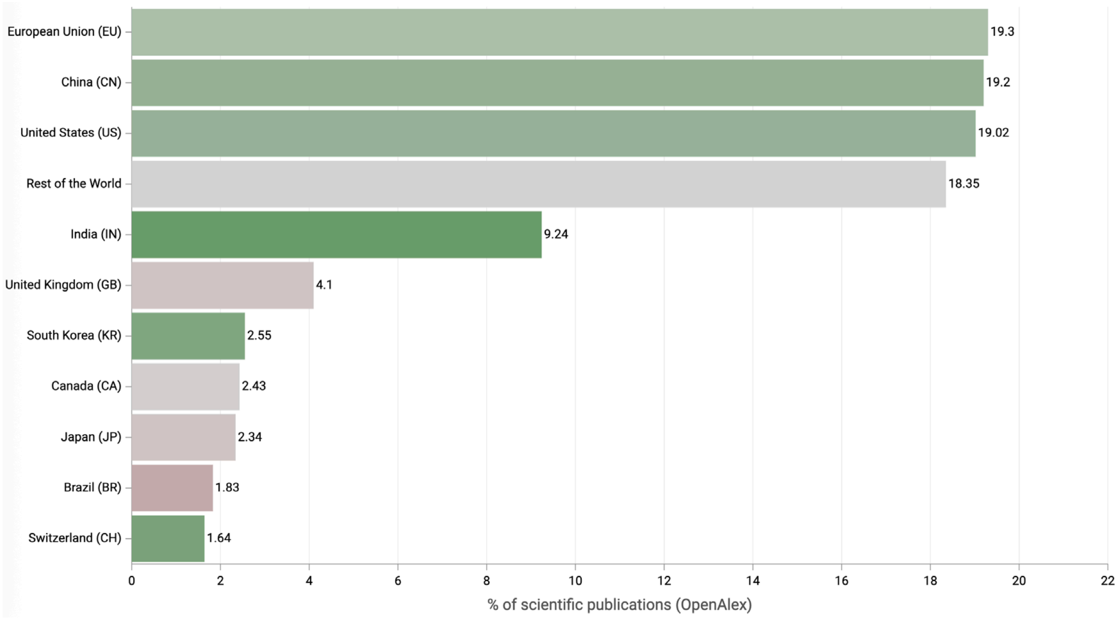
China and the United States follow closely behind Europe in terms of publication share. China's strong scientific output is supported by rapid growth in its research universities and significant national investments in supercomputing capabilities. Institutions such as Tsinghua University, the Chinese Academy of Sciences, and National University of Defense Technology are major contributors to HPC research, particularly in areas such as parallel computing systems, supercomputer architectures, and data-intensive computing for artificial intelligence.

The United States also remains highly influential in scientific research on high-performance computing. Leading universities and national laboratories play a central role in advancing HPC technologies used for scientific modelling, climate simulations, and large-scale data analytics. Institutions such as Massachusetts Institute of Technology, Stanford University, and Lawrence Berkeley National Laboratory contribute extensively to research on advanced computing architectures, parallel algorithms, and energy-efficient supercomputing systems.

Another important contributor to scientific publications in this field is India, which accounts for around 9 % of global output. India's growing role in HPC research reflects the expansion of its engineering and computer science communities as well as national programmes aimed at developing domestic supercomputing capabilities. Research institutions such as the Indian Institute of Technology network and the Indian Institute of Science are particularly active in areas such as parallel programming, distributed computing systems, and high-performance algorithms.

Overall, the scientific landscape in high-performance computing illustrates the complementary roles of different innovation systems. While countries such as China and the United States lead in technological patents and industrial development, Europe and India play a particularly strong role in advancing the academic foundations of HPC through extensive scientific research and international collaboration.

Figure 26 – Percentage of scientific publications in HPC, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/highperformance-computing.html

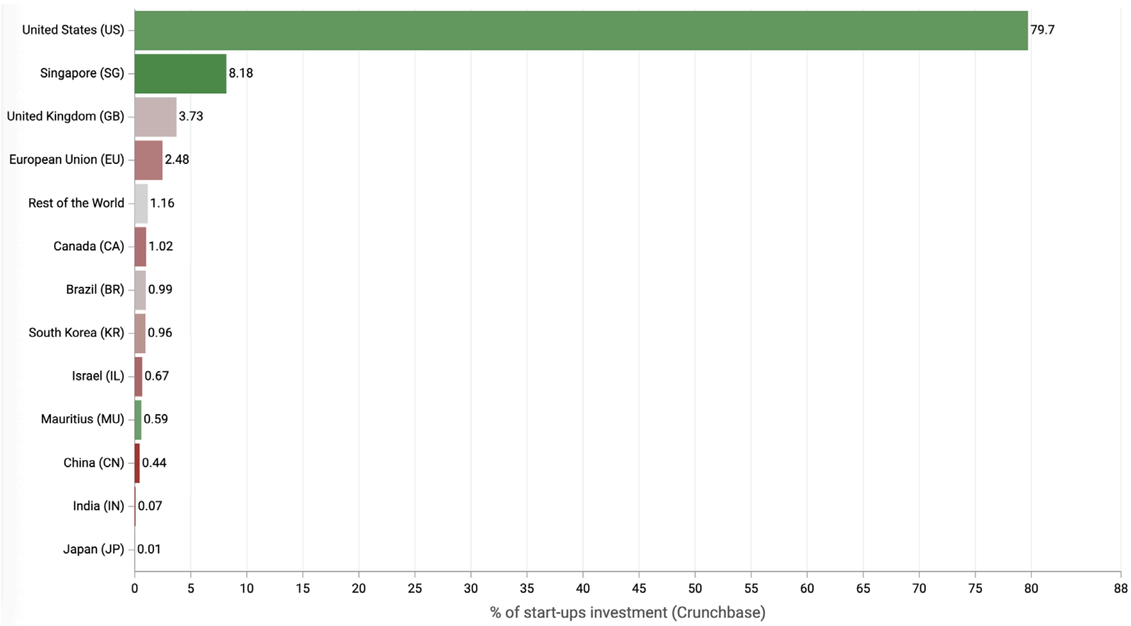
As regards venture capital investment in high-performance computing (HPC)-related start-ups, the distribution differs significantly from the patterns observed for patents and scientific publications. Data reported by Crunchbase show that the United States overwhelmingly dominates this segment, accounting for almost 80 % of the global value of venture capital investment in new start-ups. This leadership reflects the depth of the American venture capital ecosystem, the presence of major technology clusters such as Silicon Valley and Boston, and the strong demand for advanced computing infrastructure driven by artificial intelligence, cloud computing, and data-intensive applications. Several US-based companies working on HPC architectures, specialised processors, and large-scale computing platforms have attracted major investments. Firms such as Cerebras Systems, which develops wafer-scale processors designed for large-scale AI and high-performance computing workloads, and Graphcore, which focuses on advanced accelerator chips for machine learning, illustrate the growing interest of venture capital investors in new computing architectures capable of supporting extremely demanding computational tasks.

The second-largest share of venture investment in this field is associated with Singapore, which accounts for more than 8 % of the total value of deals. Singapore's strong position reflects its role as a regional financial and technology hub in Asia, where venture capital funds and technology companies often establish headquarters for start-ups operating across the region. The country has actively promoted advanced computing technologies through national innovation policies and support for digital infrastructure, which has attracted investment in start-ups working on data processing, cloud infrastructure, and advanced computing solutions.

The European Union holds a more modest share of venture capital investment in HPC-related start-ups, accounting for around 2.5 % of global deal value. Europe's relatively smaller share reflects a venture capital ecosystem that is less concentrated and generally smaller than that of the United States. Nevertheless, several European technology companies are active in developing advanced computing architectures and specialised processors. The United Kingdom, which accounts for about 3.7 % of venture capital investment in this domain, slightly outperforms the EU as a whole in the available data. The UK benefits from a strong research base in computer science and semiconductor design, illustrated by companies such as Graphcore, which has attracted significant venture capital to develop innovative processor architectures for high-performance computing and artificial intelligence.

Overall, venture capital investment patterns in high-performance computing highlight a strong geographical concentration of entrepreneurial financing in a small number of global innovation hubs. While China, Europe, and Japan play important roles in scientific research and patenting activity, the commercialisation of new HPC technologies through venture-backed start-ups remains overwhelmingly concentrated in the United States, with smaller but notable investment hubs emerging in Singapore and the United Kingdom.

Figure 27 – Percentage of VC investment in start-ups in HPC, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/highperformance-computing.html

2.9. INTERNET OF THINGS

Internet of Things (IoT) technologies have become increasingly central to the development of modern digital infrastructures. They enable the interconnection of physical devices, sensors, and machines, making them crucial for applications in logistics and supply chains, industrial automation, physical AI systems, as well as defence and security operations. Patent data indicate that China holds the leading position in this technological domain, accounting for more than 27 % of global patents related to IoT technologies. This strong performance reflects China's large-scale investments in digital infrastructure, telecommunications networks, and smart manufacturing. Major Chinese technology firms have developed extensive patent portfolios in IoT-related technologies, particularly in areas such as connected devices, data transmission, and industrial automation. Companies such as Huawei and ZTE are particularly active in developing network technologies and connected-device ecosystems that underpin large-scale IoT deployments.

The United States follows with approximately 23.5 % of global IoT patents. The United States remains a major innovator in this domain thanks to its strong technology sector and large ecosystem of digital platform companies. Firms such as IBM, Cisco, and Intel hold significant patent portfolios related to cloud-connected devices, edge computing systems, and data processing platforms that support IoT infrastructures. These companies play a key role in developing both the hardware and software components required for large-scale IoT networks.

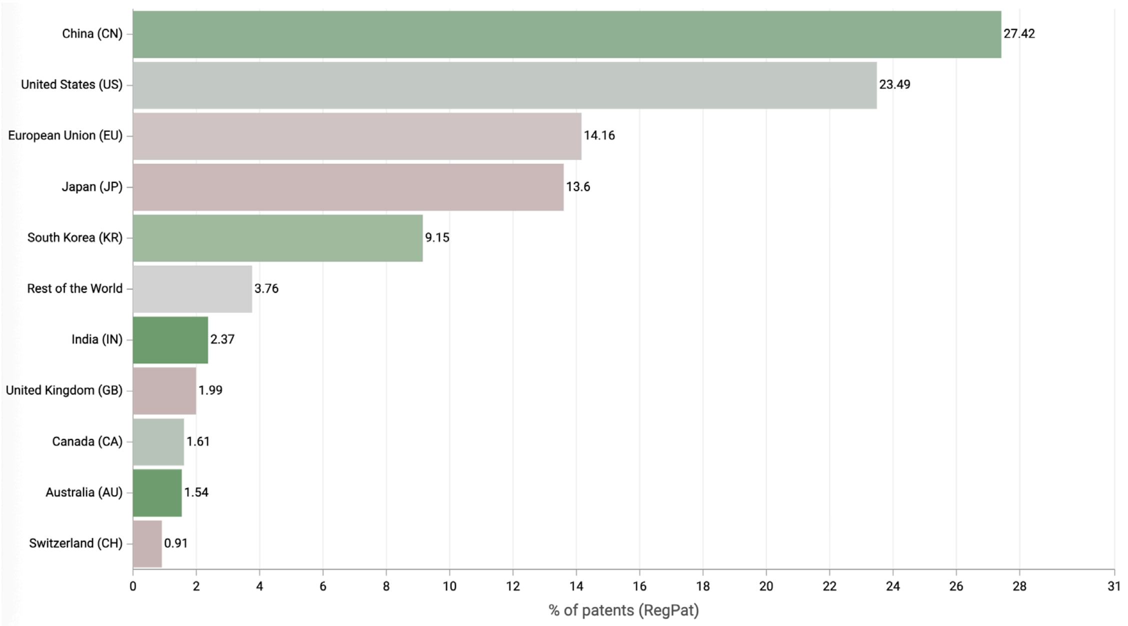
The European Union accounts for about 14.1 % of global IoT patents. Europe's contributions are often driven by industrial and engineering companies specialising in automation technologies, smart manufacturing, and connected industrial systems. Companies such as Siemens and Ericsson are particularly active in developing industrial IoT solutions, communication technologies, and smart infrastructure systems.

Japan follows closely with approximately 13.6 % of global IoT patents. Japan's strong electronics and robotics sectors contribute significantly to IoT innovation, especially in areas related to connected sensors, robotics systems, and industrial automation. Companies such as Sony and Panasonic have developed technologies enabling smart devices and interconnected systems for both consumer and industrial applications.

Finally, South Korea holds around 9.15 % of global patents in this field. South Korea's contributions are closely tied to its strong semiconductor and electronics industries. Companies such as Samsung Electronics and LG Electronics have developed a wide range of connected devices and smart home technologies that form an important part of the broader IoT ecosystem.

Overall, the patent landscape for IoT technologies highlights intense global competition among the world's major technology powers. China currently leads in terms of patent volume, but the United States, Europe, Japan, and South Korea remain key innovators thanks to their strong telecommunications, semiconductor, and industrial technology sectors.

Figure 28 – Percentage of global patents in IoT, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/internet-of-things-iot.html

When examining scientific publications related to Internet of Things technologies, the global distribution of research activity differs significantly from the patent landscape. India slightly leads the field with around 19 % of global publications, narrowly ahead of China, which accounts for approximately 18.8 %. India's strong position reflects the rapid expansion of its higher-education system and the large number of researchers working in computer science, telecommunications, and embedded systems – fields closely linked to IoT technologies. Leading institutions such as the Indian Institute of Technology network and the Indian Institute of Science contribute significantly to research on sensor networks, distributed computing, and connected-device architectures.

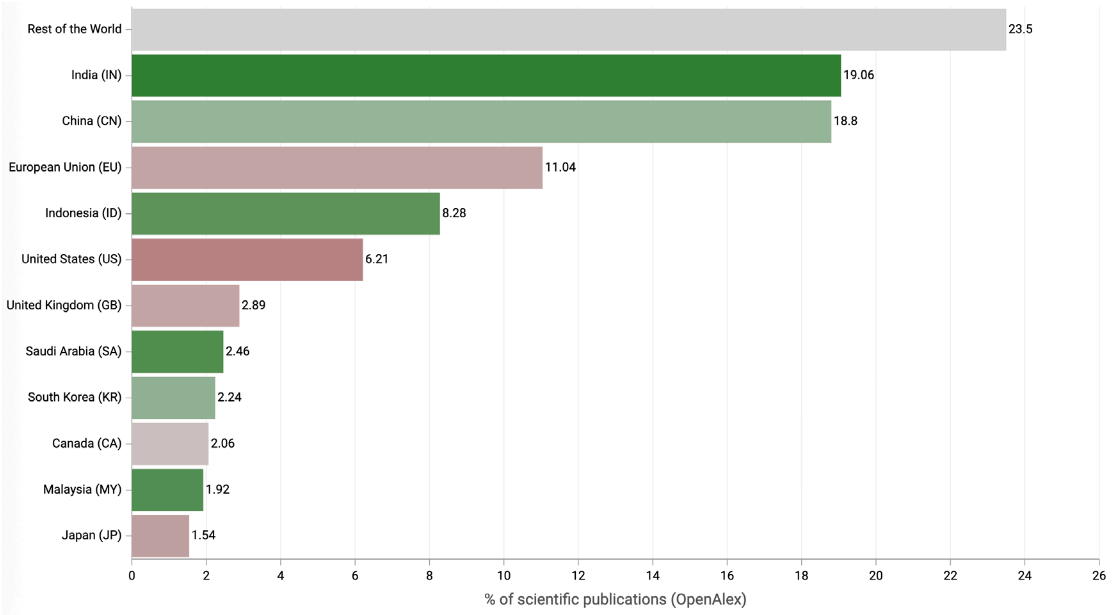
China remains a major contributor to IoT research despite ranking slightly behind India in publication share. Chinese universities and research institutes produce a large volume of work on wireless communication systems, smart infrastructure, and industrial IoT applications. Prominent institutions such as Tsinghua University, Shanghai Jiao Tong University, and the Chinese Academy of Sciences are particularly active in publishing research related to large-scale sensor networks and intelligent connected systems.

The European Union accounts for roughly 11 % of global publications in this field. Europe's contribution reflects a strong network of universities and collaborative research programmes focused on digital infrastructure, smart cities, and industrial automation. Institutions such as Technical University of Munich, Delft University of Technology, and University College London are among the most active in publishing research on IoT architectures, distributed sensing, and cyber-physical systems.

An interesting feature of the publication landscape is the relatively strong position of Indonesia, which accounts for about 8 % of global publications – placing it ahead of the United States, which holds only around 6.2 %. Indonesia's high share partly reflects the rapid growth of its academic publishing activity in computer science and engineering, particularly through conference proceedings and international collaborations. Universities such as Bandung Institute of Technology and University of Indonesia have become increasingly active in publishing work on IoT applications, smart systems, and digital infrastructures.

Although the United States has a smaller share of publication volume, it remains highly influential in the development of IoT technologies through leading universities and strong links between academic research and industry. Institutions such as Massachusetts Institute of Technology and Stanford University continue to produce influential research on embedded systems, edge computing, and cyber-physical infrastructures. Overall, the publication landscape in IoT technologies illustrates the increasingly global nature of digital research, with emerging research systems contributing a growing share of scientific output alongside established technological powers.

Figure 29 – Percentage of scientific publications in IoT, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/internet-of-things-iot.html

In the domain of Internet of Things (IoT) technologies, the usual dominance of the United States in venture capital investment is somewhat less pronounced than in other digital technology sectors. According to data reported by Crunchbase, the United States accounts for around 44 % of the total value of venture-backed deals in IoT-related start-ups. Although this still represents the largest share globally, it is noticeably lower than the levels typically observed in fields such as artificial intelligence or cybersecurity. The US ecosystem nevertheless remains highly dynamic, supported by strong venture capital markets and a dense network of technology start-ups working on connected devices, edge computing, and industrial IoT platforms. Companies such as Samsara, which develops connected sensors and data platforms for industrial and logistics applications, have attracted substantial venture funding to expand large-scale IoT deployments.

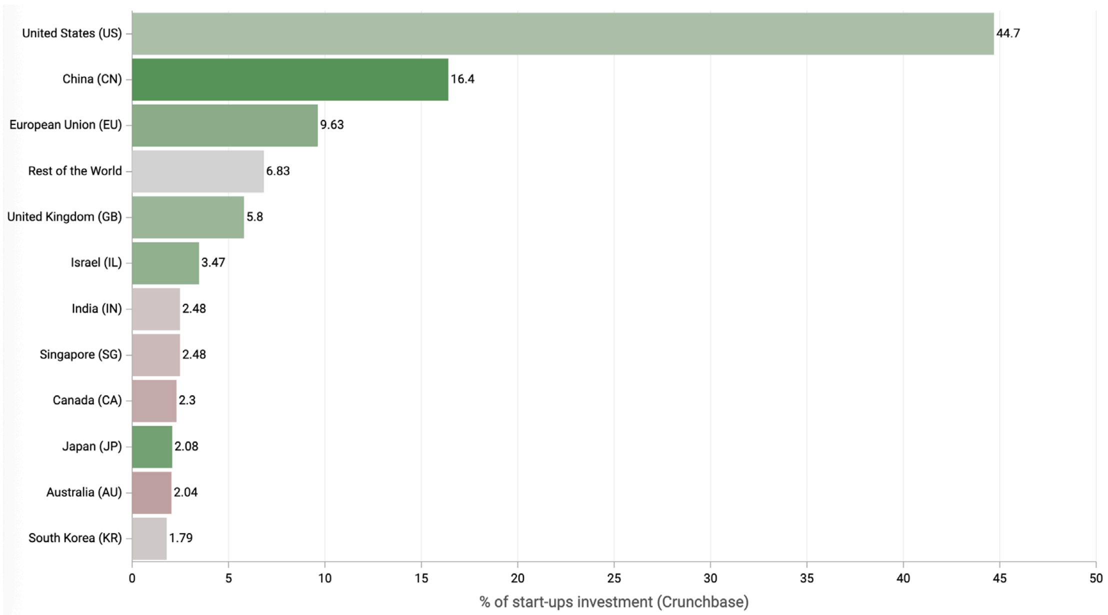
China holds a significant share of venture capital investment in IoT start-ups, accounting for approximately 16.4 % of the value of deals. China's strong position reflects the rapid expansion of its digital economy and the widespread adoption of connected devices across sectors such as manufacturing, logistics, and smart cities. Chinese technology companies and investors have actively supported start-ups developing IoT platforms, industrial automation systems, and smart infrastructure technologies that integrate sensors, data analytics, and cloud computing.

The European Union accounts for almost 10 % of global venture capital investment in this field. Europe's IoT ecosystem benefits from strong industrial sectors, particularly in manufacturing, automotive technologies, and industrial automation. Start-ups often focus on applications such as smart factories, connected logistics systems, and energy management platforms that support the digital transformation of traditional industries.

The United Kingdom also represents an important venture capital market in this domain, accounting for around 5.8 % of global deal value. The UK benefits from a strong research base in computer science and engineering as well as a well-developed venture capital ecosystem centred in London. Finally, Israel accounts for about 3.5 % of venture capital investment in IoT-related start-ups. Israel's strong position reflects its highly innovative technology sector, supported by close links between research institutions, venture investors, and a large number of start-ups specialising in sensors, cybersecurity for connected devices, and embedded systems.

Overall, venture capital investment patterns in IoT technologies appear more geographically distributed than in many other digital technology domains. While the United States still leads, China and Europe hold significant shares of the market, and smaller but highly innovative ecosystems such as the United Kingdom and Israel also play an important role in supporting the growth of IoT start-ups.

Figure 30 – Percentage of VC investment in start-ups in IoT, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/internet-of-things-iot.html

2.10. MOBILE NETWORKS (5G AND 6G)

Mobile networks have traditionally been a strong area of technological competitiveness for the European Union, particularly through its leadership in telecommunications standards and network infrastructure. However, over the past two decades both China and the United States has developed very strong technological capabilities in this field. Patent data for next-generation mobile networks – particularly 5G and emerging 6G technologies – show that China currently holds a dominant position, accounting for approximately 37.6 % of global patents. This strong lead reflects sustained national investment in telecommunications infrastructure and the strategic importance of mobile network technologies for digital economies. Chinese technology companies have been particularly active in patenting innovations related to radio access networks, network architecture, and high-speed wireless communications. Firms such as Huawei and ZTE are among the world's most prolific patent holders in 5G technologies and have played a central role in the development of global telecommunications standards.

The United States follows with roughly 23.8 % of global patents related to 5G and 6G technologies. The US telecommunications ecosystem benefits from strong research capabilities in semiconductor technologies, network software, and wireless communications. Key corporate innovators include Qualcomm, which has built one of the largest patent portfolios in mobile communications, as well as technology companies such as Intel that contribute to advanced wireless chipsets and networking technologies.

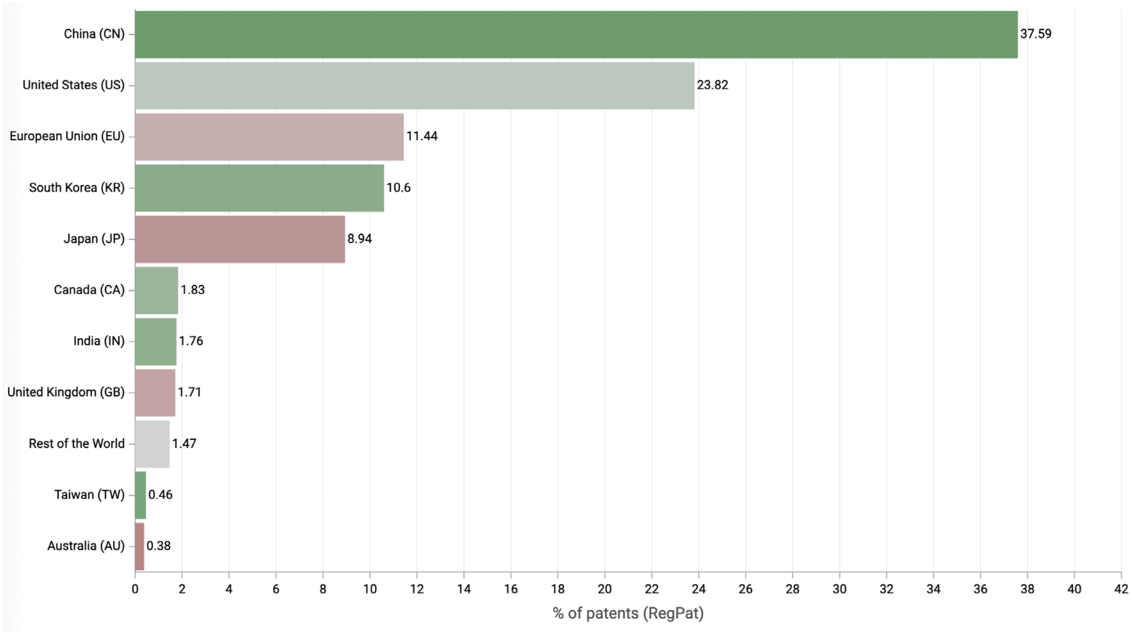
The European Union holds about 11.44 % of global patents in this domain. Although Europe's share is smaller than that of China and the United States, the region remains an important innovator in mobile networks thanks to major telecommunications equipment manufacturers. Companies such as Ericsson and Nokia are key contributors to the development of wireless network technologies and continue to play an influential role in the standardisation of global telecommunications systems.

South Korea ranks fourth with around 10.6 % of global patents. South Korea's strong position is driven by large electronics and telecommunications companies that have invested heavily in next-generation mobile networks. Corporations such as Samsung Electronics have been particularly active in developing 5G infrastructure technologies, advanced wireless devices, and network equipment.

Finally, Japan accounts for approximately 8.9 % of global patents in 5G and 6G technologies. Japanese telecommunications and electronics firms have long contributed to wireless communication systems, particularly in areas related to network hardware and advanced electronics. Companies such as NEC and Fujitsu remain important innovators in mobile network infrastructure and advanced communication technologies.

Overall, the patent landscape for next-generation mobile networks illustrates intense global competition among the world's major technology powers. While China currently holds a significant lead in patent counts, the United States, Europe, South Korea, and Japan remain key players through their powerful telecommunications companies and strong technological capabilities in wireless communications.

Figure 31 – Percentage of global patents in mobile networks (5G/6G), 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/mobile-networks-5g6g.html

A similar distribution can be observed when looking at scientific publications on advanced mobile networks, including 5G and emerging 6G technologies. China leads the global research landscape with close to one quarter of all publications in this field. This strong position reflects the rapid expansion of China's research system and the strategic importance assigned to next-generation telecommunications technologies. Chinese universities and research institutes publish extensively on topics such as radio access networks, spectrum management, network virtualisation, and ultra-low-latency communications. Institutions such as Tsinghua University, Beijing University of Posts and Telecommunications, and the Chinese Academy of Sciences are particularly active in these areas and frequently collaborate with telecommunications companies in the development of new mobile network architectures.

The European Union ranks second with about 14.5 % of global publications. Europe's research strength in telecommunications is supported by a long tradition of academic excellence in electrical engineering and communication systems, as well as by collaborative research initiatives across Member States. Universities such as the

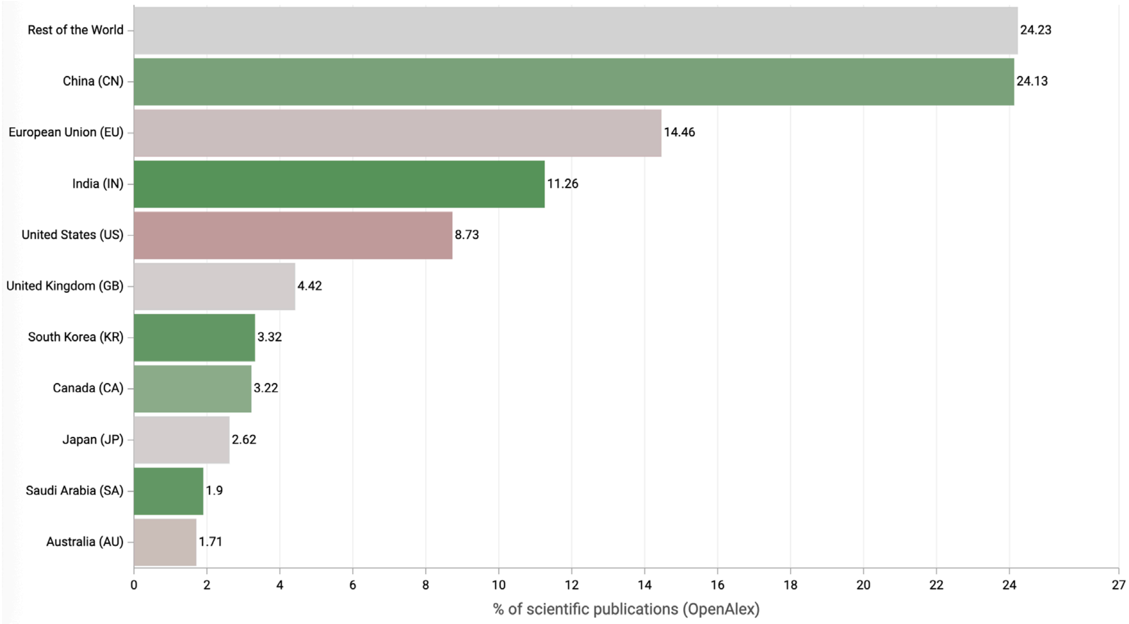
University of Oulu (Finland), which hosts one of the world’s leading research centres on 6G technologies, the Technical University of Munich, and King's College London contribute significantly to research on advanced wireless systems, network architectures, and spectrum technologies.

India follows with approximately 11.26 % of publications, illustrating the growing importance of its research community in telecommunications engineering and computer science. Indian universities and engineering institutes publish extensively on wireless networks, signal processing, and communication protocols. The Indian Institute of Technology network and institutions such as the Indian Institute of Science are particularly active contributors to the global research literature on mobile communication technologies.

The United States ranks somewhat lower in terms of publication share, accounting for around 8.6 % of global output. While the United States produces fewer publications than China, Europe, or India in this domain, it remains highly influential through leading universities and strong industry–academic collaborations. Institutions such as Stanford University, Massachusetts Institute of Technology, and the University of California, Berkeley conduct significant research on wireless communications, network optimisation, and next-generation mobile systems.

Overall, the scientific publication landscape in mobile network technologies reflects the increasingly global nature of telecommunications research. China leads in terms of publication volume, while Europe and India maintain strong academic communities, and the United States continues to exert substantial influence through high-impact research and close collaboration between universities and the telecommunications industry.

Figure 32 – Percentage of scientific publications in mobile networks (5G/6G), 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/openalex/mobile-networks-5g6g.html

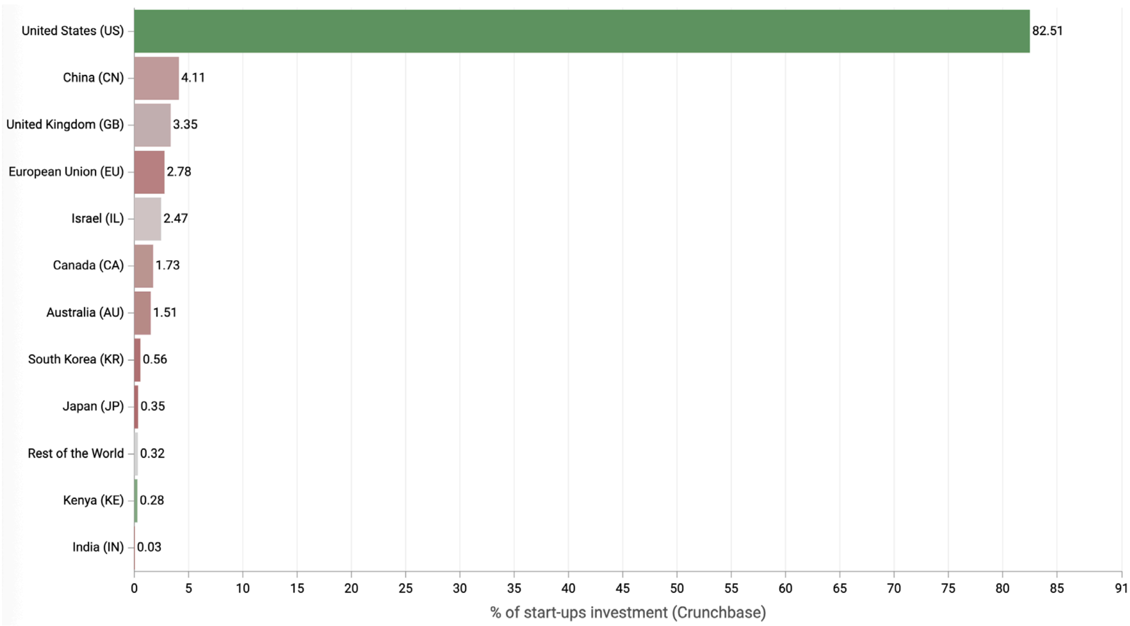
Venture capital investment in mobile network technologies – including 5G infrastructure, network software, and emerging 6G-related solutions – shows a very strong concentration in the United States. According to data reported by Crunchbase, the United States accounts for roughly 82.5 % of the global value of venture-backed deals in start-ups active in this domain. This dominant position reflects the scale of the American venture capital ecosystem and the presence of major technology clusters that support start-ups working on telecommunications software, network virtualisation, and advanced wireless technologies. Many US start-ups focus on next-generation network architectures, including open radio access networks (Open RAN), cloud-native network infrastructure, and specialised semiconductor solutions for mobile communications. Companies such as Mavenir and Celona illustrate the growing role of venture-backed firms developing software-defined networking solutions and private 5G systems for enterprise applications.

In comparison, China accounts for a much smaller share of venture capital investment in this segment, with around 4.1 % of the value of deals. Although China is a global leader in patents and industrial capabilities for mobile network infrastructure – particularly through companies such as Huawei and ZTE – innovation in this domain is often driven by large established corporations rather than venture-backed start-ups. As a result, the role of venture capital is comparatively smaller in China's telecommunications sector.

The United Kingdom, the European Union, and Israel account for smaller but still notable shares of venture capital investment in mobile network technologies. The United Kingdom benefits from a strong telecommunications research base and a dynamic start-up ecosystem centred around London and Cambridge. The European Union hosts a number of technology start-ups developing components for mobile networks, particularly in areas such as network optimisation, edge computing, and secure communications. Israel, meanwhile, has developed a highly innovative telecommunications and cybersecurity start-up ecosystem, supported by strong engineering expertise and close links between research institutions and venture capital investors.

Overall, the venture capital landscape in mobile network technologies differs significantly from the patent and research landscapes. While China and Europe play major roles in patents and scientific publications, the commercialisation of new mobile network technologies through venture-backed start-ups remains overwhelmingly concentrated in the United States.

Figure 33 – Percentage of VC investment in start-ups in mobile networks (5G/6G), 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/mobile-networks-5g6g.html

2.11. QUANTUM TECHNOLOGIES

Patent data on quantum technologies indicate that the United States currently holds the leading position, accounting for more than 29 % of the patents registered in the OECD RegPat dataset. This strong performance reflects the United States'long-standing leadership in advanced physics, semiconductor technologies, and high-performance computing, as well as the presence of a powerful innovation ecosystem linking universities, national laboratories, and technology companies. Major corporate patent holders include companies such as IBM, Google, and Microsoft, which are heavily investing in quantum computing architectures, quantum algorithms, and cloud-based quantum services. In addition, major research institutions and laboratories such as Massachusetts Institute of Technology and the Lawrence Berkeley National Laboratory play an important role in advancing quantum technologies.

China follows closely with around 26.3 % of global patents in quantum technologies. China has significantly expanded its capabilities in this field over the past decade through large public investments and strategic research programmes aimed at developing quantum communication networks, quantum cryptography, and quantum computing systems. Institutions such as the Chinese Academy of Sciences and University of Science and Technology of China have produced groundbreaking research in quantum communication and quantum information science, while technology firms have increasingly contributed to patenting activity in quantum hardware and related technologies.

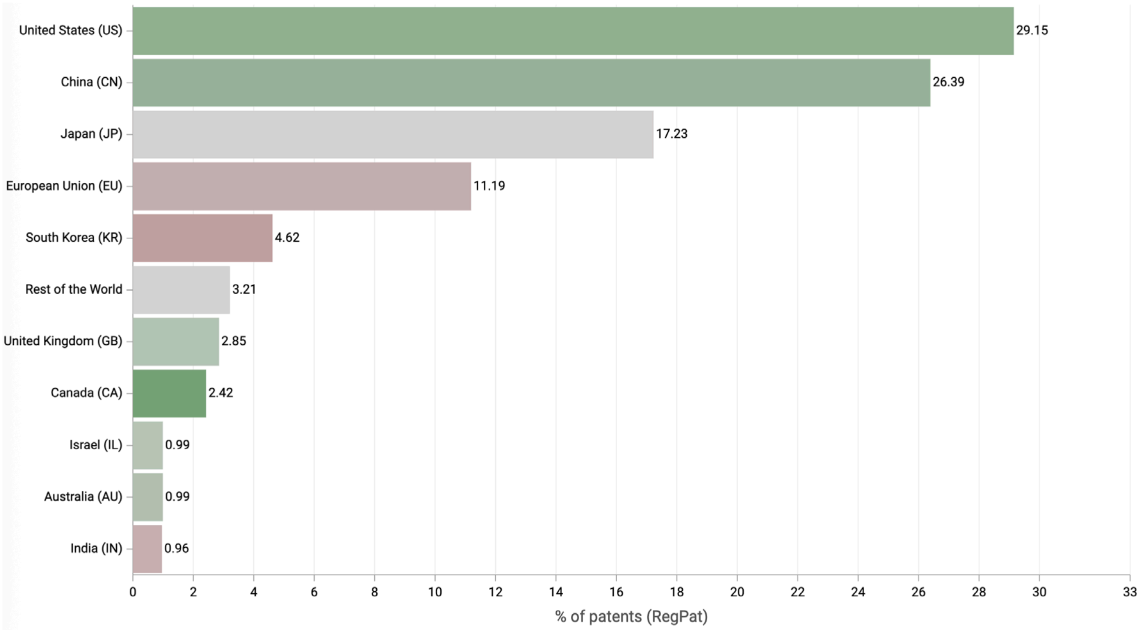
Japan ranks third with about 17.2 % of the patents in this domain. Japan's strong position reflects its expertise in precision electronics, photonics, and semiconductor technologies, which are crucial for the development of quantum computing hardware and quantum sensing systems. Companies such as NEC and Fujitsu are particularly active in developing quantum computing architectures and quantum-inspired optimisation technologies.

The European Union accounts for around 11.2 % of global quantum technology patents. Europe's innovation landscape in quantum technologies is supported by strong academic research programmes and collaborative initiatives across member states. Companies such as Infineon Technologies and Nokia contribute to quantum-related patenting, particularly in areas such as quantum communication, cryptography, and advanced semiconductor components.

Finally, South Korea accounts for about 4.6 % of the patents in this field. South Korea's participation in quantum technologies is closely linked to its strong semiconductor and electronics industries. Major firms such as Samsung Electronics are increasingly investing in quantum computing research and quantum hardware development.

Overall, the patent landscape in quantum technologies illustrates the strategic importance of this emerging field for the future of computing, communications, and secure data processing. While the United States currently leads in patent counts, China and Japan also hold substantial shares, and Europe and South Korea continue to develop important technological capabilities through both industrial innovation and advanced scientific research.

Figure 34 – Percentage of global patents in quantum technologies, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/quantum-technologies.html

Where the European Union stands out in the quantum technology landscape is in scientific publications. Compared with other digital technology domains, the distribution of research output in quantum science appears relatively less concentrated across countries. According to data reported by OpenAlex, the European Union accounts for more than 21 % of global publications related to quantum technologies, placing it clearly ahead of other regions. Europe's strong performance reflects the presence of a large network of leading universities and research institutes specialising in quantum physics, photonics, and quantum information science. Institutions such as TU Delft and TUM contribute extensively to research on quantum computing architectures, quantum communication systems, and quantum sensing technologies. European collaborative initiatives and large-scale research programmes have also played a key role in supporting scientific output in this domain.

China follows with around 18.7 % of global publications. China's growing presence in quantum research reflects sustained national investment in quantum information science and related technologies. Leading research institutions such as the University of Science and Technology of China and the Chinese Academy of Sciences are particularly active in publishing research on quantum communication, quantum cryptography, and quantum computing systems.

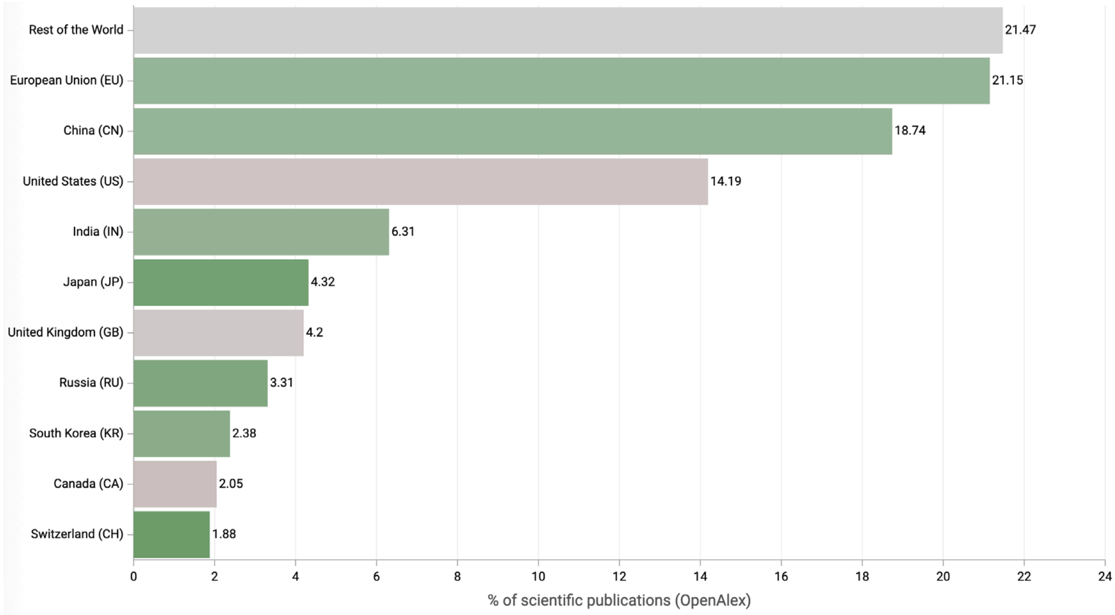
The United States accounts for approximately 14.2 % of global publications in quantum technologies. Although the United States produces a smaller share of publications than Europe or China, it remains highly influential in the field through leading universities and strong links between academia, national laboratories, and technology companies. Institutions such as Massachusetts Institute of Technology, Harvard University, and the University of California, Berkeley are among the most prominent contributors to quantum information science and quantum computing research.

India follows with about 6.3 % of global publications, reflecting the growing scale of its research community in physics, computer science, and advanced computing. Institutions such as the Indian Institute of Science and the Indian Institute of Technology network contribute significantly to research on quantum algorithms, quantum communication, and quantum materials.

Finally, Japan and the United Kingdom each account for slightly above 4 % of global publications in quantum technologies. Both countries maintain strong research traditions in quantum physics and advanced materials science. Universities such as University of Tokyo and Universities of Oxford and Cambridge continue to play important roles in advancing quantum computing, quantum sensing, and quantum communication research.

Overall, the scientific publication landscape in quantum technologies is more geographically balanced than in many other advanced technology domains. While Europe leads in publication volume, China and the United States also maintain strong research capabilities, and countries such as India, Japan, and the United Kingdom contribute significantly to the global development of quantum science.

Figure 35 – Percentage of scientific publications in quantum technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/quantum-technologies.html

Finally, when examining venture capital investment in quantum technologies, the United States clearly remains the leading market, accounting for roughly 55 % of the total value of venture-backed deals. Data reported by Crunchbase indicate that the United States hosts a large number of start-ups developing quantum computing hardware, quantum software platforms, and enabling technologies such as cryogenic systems and photonic processors. The country's leadership reflects the strength of its venture capital ecosystem as well as close links between universities, national laboratories, and technology companies. Start-ups such as IonQ and Rigetti Computing have attracted significant venture funding to develop quantum processors and cloud-based quantum computing platforms.

Compared with many other digital technology domains, the European Union holds a relatively strong position in venture capital investment in quantum technologies, accounting for almost 20 % of the total value of deals. This reflects the presence of a growing ecosystem of quantum start-ups emerging from Europe's strong academic research base in quantum physics and engineering. Companies such as Pasqal in France and IQM Quantum Computers in Finland illustrate the expansion of European quantum technology ventures, often supported by public funding programmes and research collaborations.

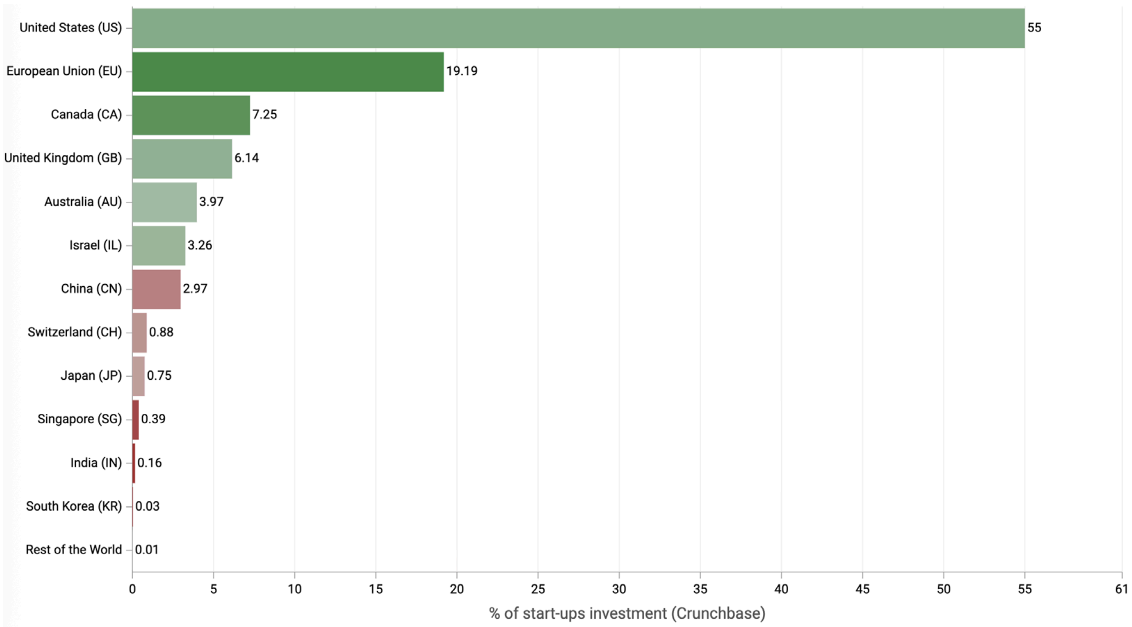
Several partner countries also hold significant shares of venture capital investment in quantum start-ups. Canada accounts for about 7.25 % of the total value of deals, supported by strong academic institutions and a growing ecosystem of quantum technology companies. For example, D-Wave Systems has attracted substantial investment to develop quantum annealing systems and related computing technologies.

The United Kingdom also represents an important venture capital market in this domain, accounting for approximately 6.1 % of global investment. The UK benefits from a strong scientific base in quantum physics and national initiatives aimed at developing quantum technologies. Companies such as Oxford Quantum Circuits have secured venture funding to develop superconducting quantum computing architectures.

Finally, Australia accounts for about 4 % of venture capital investment in quantum start-ups. Australia's position reflects the presence of leading research groups in quantum computing and the emergence of spin-off companies such as Silicon Quantum Computing, which focuses on silicon-based quantum processor technologies.

The venture capital landscape in quantum technologies appears more geographically diversified than in many other advanced technology domains. While the United States still leads in terms of investment value, Europe and several partner countries play a more significant role in supporting quantum start-ups than is typically observed in fields such as artificial intelligence or cloud computing.

Figure 36 – Percentage of VC investment in start-ups in quantum technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/quantum-technologies.html

2.12. ROBOTICS

The robotics landscape is rapidly evolving as artificial intelligence becomes increasingly integrated into machines that interact with the physical world, giving rise to what is often described as 'physical AI.'These systems combine sensing, machine learning, and advanced control technologies to enable robots to operate autonomously in complex environments. Patent data reported in the OECD RegPat indicate that leadership in this domain is relatively distributed among several major technological powers. The United States currently holds a narrow lead with around 22.3 % of global robotics patents. This strong position reflects the country's dynamic innovation ecosystem linking universities, start-ups, and major technology companies. Firms such as Boston Dynamics and Amazon, which deploys large fleets of warehouse robots, contribute to the development of advanced robotic systems integrating artificial intelligence, machine vision, and automated manipulation.

China follows extremely closely with about 21.42 % of global patents. China has significantly expanded its robotics industry over the past decade through major industrial policies aimed at upgrading manufacturing capabilities and promoting automation. Chinese companies have developed extensive patent portfolios related to industrial robots, service robots, and autonomous systems used in logistics and manufacturing.

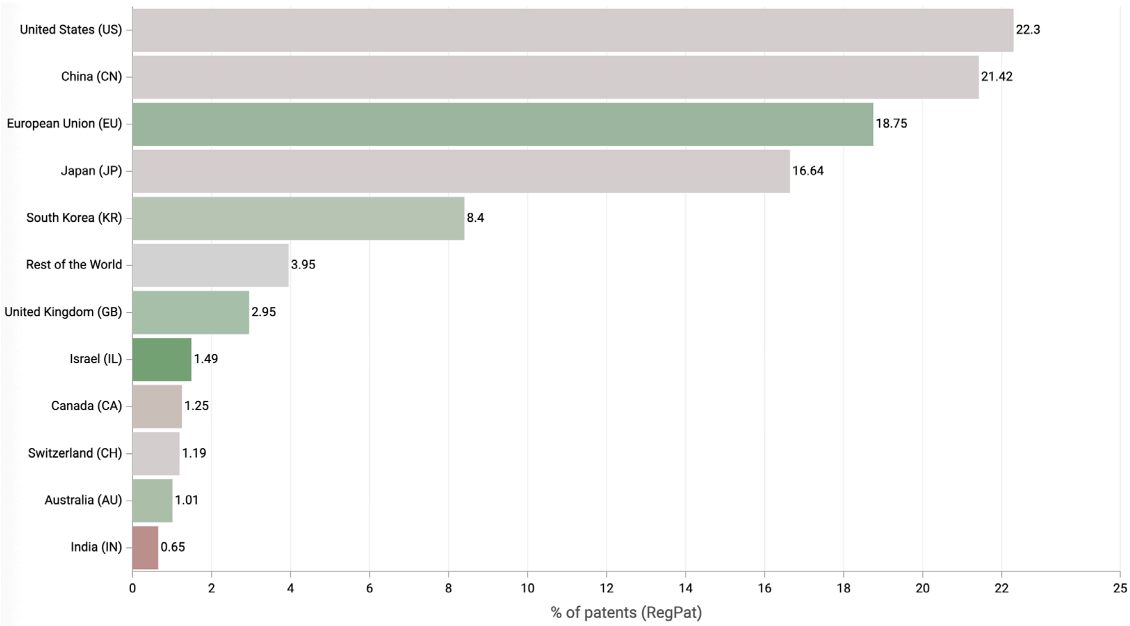
The European Union has traditionally been strong in robotics and accounts for roughly 18.75 % of all patents reported in the dataset. Europe's robotics ecosystem is supported by a strong industrial base in automation and mechanical engineering. Companies such as ABB, KUKA, and Siemens have long been leaders in industrial robotics and automated manufacturing systems. When combined with the United Kingdom, which accounts for almost 3 % of global robotics patents, Europe's overall share approaches that of the leading countries.

Japan remains one of the most prominent actors in robotics with approximately 16.64 % of global patents. Japan has a long-standing tradition in robotics, particularly in industrial automation and precision engineering. Companies such as Fanuc and Yaskawa Electric are among the world's largest manufacturers of industrial robots used in automotive production, electronics manufacturing, and other high-precision industries.

Finally, South Korea accounts for around 8.4 % of global robotics patents. South Korea's strong electronics and manufacturing sectors support innovation in robotics and automation technologies. Large technology firms such as Samsung Electronics and Hyundai Motor Company are increasingly investing in robotics and autonomous systems, particularly in areas related to smart manufacturing and mobility.

Overall, the patent landscape in robotics reflects intense global competition and a convergence of technologies including artificial intelligence, sensors, and advanced manufacturing systems. While the United States and China currently lead in patent counts, Europe, Japan, and South Korea remain major innovators thanks to their strong industrial robotics sectors and long-standing expertise in automation technologies.

Figure 37 – Percentage of global patents in robotics, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/robotics.html

In terms of scientific publications on robotics and related technologies, China clearly dominates the global research landscape, accounting for almost 30 % of all publications. This strong position reflects the rapid expansion of China's research system in robotics, artificial intelligence, and automation technologies. Chinese universities and research institutes publish extensively on topics such as autonomous robotics, machine perception, human–robot interaction, and intelligent manufacturing systems. Institutions such as Tsinghua University, Harbin Institute of Technology, and the Chinese Academy of Sciences are particularly active contributors to the scientific literature in robotics and intelligent systems.

The European Union ranks second with approximately 18.5 % of global publications. Europe's strong position reflects a dense network of universities, engineering schools, and publicly funded research centres working on robotics, autonomous systems, and advanced manufacturing technologies. Universities such as ETH Zurich, Technical University of Munich, and Delft University of Technology are among the most active institutions publishing research on robotics, machine learning for robotics, and cyber-physical systems. European collaborative research programmes have also contributed to maintaining a strong publication output in this domain.

The United States accounts for about 11.2 % of global publications. Although its share of publications is lower than that of China and Europe, the United States remains highly influential in robotics research through leading universities and strong connections between academia and industry. Institutions such as Massachusetts Institute of Technology, Stanford University, and Carnegie Mellon University are globally recognised centres for robotics research, particularly in areas such as autonomous navigation, robotic manipulation, and machine perception.

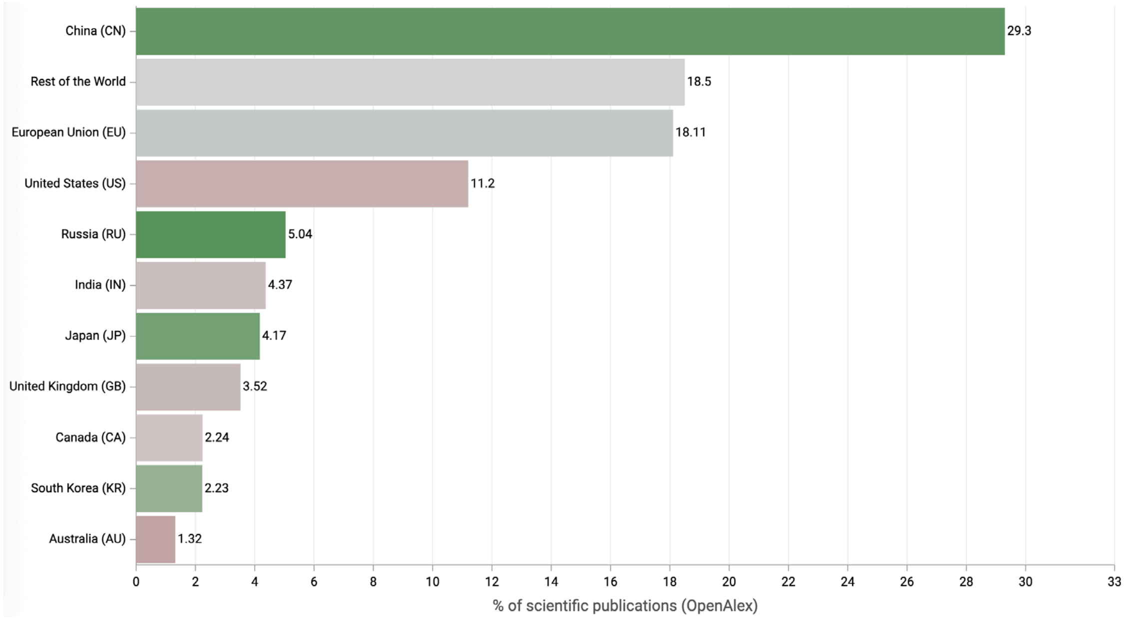
A notable share of scientific publications is also produced by Russia, which accounts for around 5 % of global output. Russia has a long-standing tradition in robotics, control systems, and applied mathematics, with institutions such as Moscow Institute of Physics and Technology contributing to research on intelligent robotic systems and automation.

India follows with about 4.17 % of global publications. India's growing role in robotics research reflects the expansion of its engineering and computer science communities. Institutions such as the Indian Institute of Technology network contribute significantly to research on robotic perception, automation technologies, and intelligent control systems.

Finally, the United Kingdom accounts for roughly 3.5 % of global robotics publications. British universities maintain strong research programmes in robotics and artificial intelligence, with institutions such as University of Oxford and Imperial College London producing influential work on autonomous systems, machine learning for robotics, and human–robot interaction.

Overall, the scientific publication landscape in robotics illustrates the increasingly global nature of research in intelligent machines and autonomous systems. While China leads by a significant margin in publication volume, Europe maintains a strong research base, and several other countries – including the United States, Russia, India, and the United Kingdom – contribute actively to the advancement of robotics and physical AI technologies.

Figure 38 – Percentage of scientific publications in robotics, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/robotics.html

Data on venture capital investment in robotics start-ups present a more fragmented picture than in other technology domains. According to information reported by Crunchbase, specific data are missing for several major economies – including the European Union, the United Kingdom, the United States, Japan, Canada, India, Russia, and South Korea – which makes it difficult to draw direct comparisons with the patent and scientific publication landscapes. The absence of these major innovation ecosystems suggests that the available venture capital data capture only a partial segment of the global robotics start-up market.

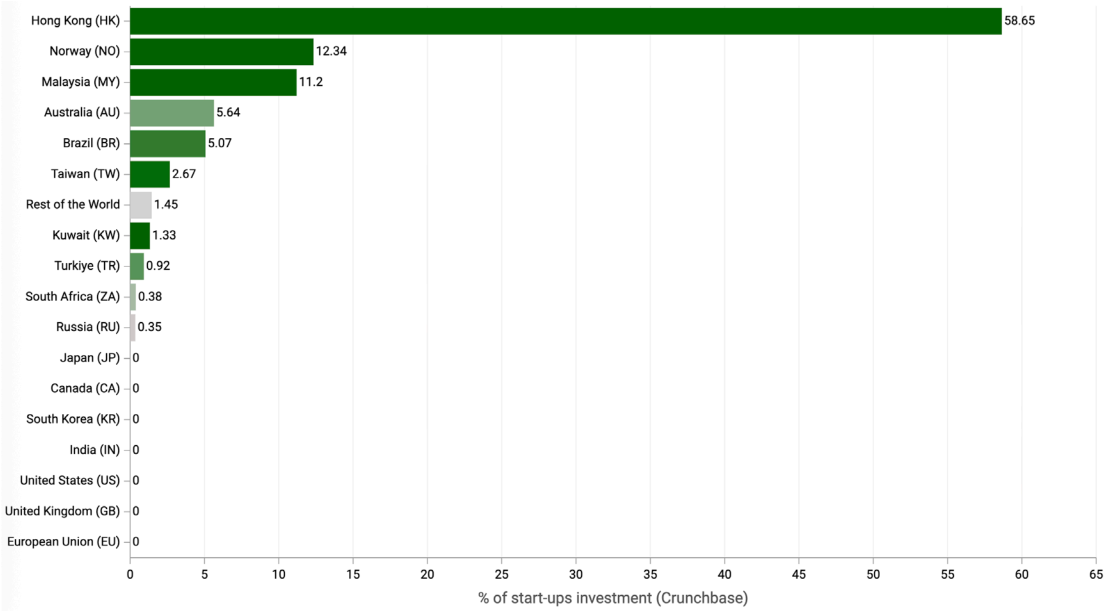
Among the countries for which venture capital investments are reported, Hong Kong holds by far the largest share, accounting for approximately 58.7 % of the total value of deals in the dataset. Hong Kong's strong position reflects its role as an important financial and investment hub for technology start-ups operating across the Asia-Pacific region. Venture capital funds and investors based in Hong Kong frequently finance robotics and automation companies whose operations may span multiple countries, which can lead to investment deals being attributed to Hong Kong in venture capital databases.

Norway follows with around 12.34 % of the value of deals. Norway's relatively strong position in this subset of the data may be linked to the country's technological specialisation in maritime robotics, offshore inspection systems, and autonomous vehicles used in the oil, shipping, and energy industries. Robotics start-ups in Norway often develop autonomous systems for industrial and environmental monitoring applications.

Finally, Malaysia accounts for roughly 11.2 % of the total value of venture capital investments in the available dataset. Malaysia has been expanding its technology start-up ecosystem in recent years, particularly in sectors related to manufacturing automation, electronics, and robotics for industrial applications.

Overall, the venture capital landscape for robotics appears more difficult to interpret due to incomplete coverage of several major innovation economies. The available data highlight the role of certain financial hubs and specialised industrial ecosystems, but they likely represent only a partial view of global venture investment in robotics and physical AI technologies.

Figure 39 – Percentage of VC investment in start-ups in robotics, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/robotics.html

2.13. SATELLITE CONNECTIVITY

Satellite connectivity is becoming increasingly foundational and strategic for countries around the world, as it supports global telecommunications, navigation, Earth observation, and secure communications for both civilian and defence applications. Patent data indicate that China currently leads the global landscape in satellite connectivity technologies, accounting for almost one third of all patents in this domain. China's strong position reflects sustained national investments in space infrastructure, satellite communications, and launch capabilities. Major Chinese state-owned and technology organisations contribute to this innovation effort, including the China Aerospace Science and Technology Corporation, which develops satellite platforms and launch systems, and Huawei, which has been active in developing communication technologies related to satellite-enabled networks and integrated space–terrestrial communication systems.

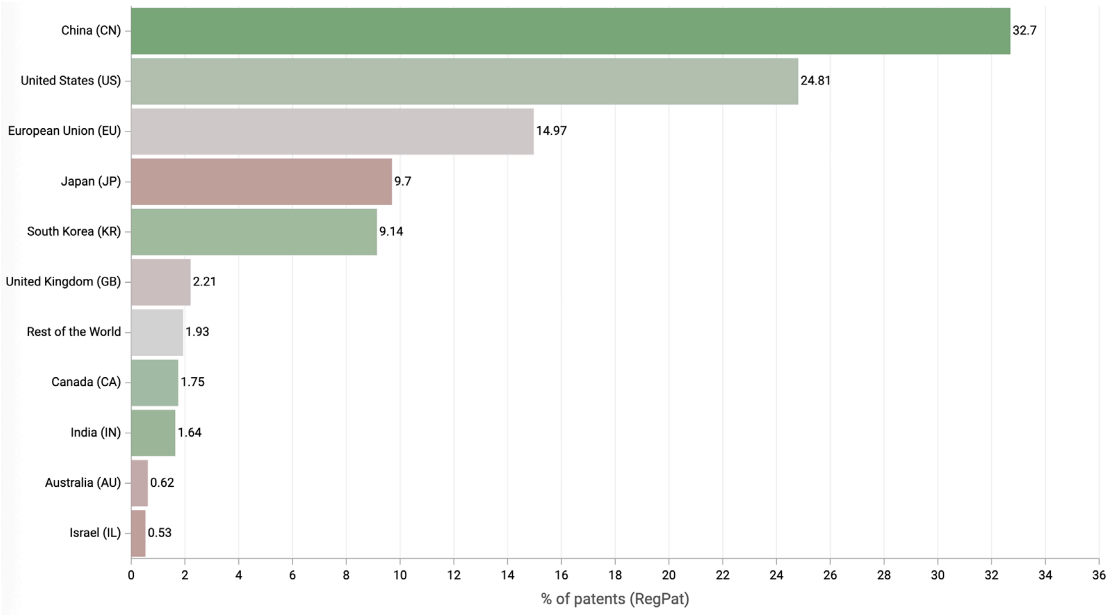
The United States follows with approximately 24.8 % of global patents in satellite connectivity technologies. The United States benefits from a highly advanced space industry combining government agencies, defence contractors, and innovative private companies. Firms such as SpaceX, which operates the Starlink broadband satellite network, and Boeing, a major satellite manufacturer, play a central role in advancing technologies related to satellite communications, low-Earth-orbit constellations, and global broadband connectivity.

The European Union ranks third with about 15 % of global patents. Europe's space and telecommunications industries have long-standing expertise in satellite technologies. Companies such as Airbus and Thales Alenia Space are key actors in the development of satellite platforms, communications payloads, and integrated space systems used for telecommunications and Earth observation.

Japan and South Korea are also important innovators in satellite connectivity technologies, each accounting for roughly 9 % of global patents. Japan's space and electronics industries support the development of advanced satellite communications and navigation technologies through organisations such as Japan Aerospace Exploration Agency and companies like Mitsubishi Electric, which manufactures satellite systems and communication technologies. South Korea's contributions are closely linked to its strong electronics and telecommunications industries, with companies such as Samsung Electronics investing in satellite communication technologies and next-generation connectivity systems.

Overall, the patent landscape in satellite connectivity highlights the strategic importance of space-based communication infrastructures for national technological competitiveness. China currently leads in patent counts, but the United States, Europe, Japan, and South Korea remain major innovators thanks to their advanced aerospace industries and growing investments in satellite networks and space-based digital infrastructure.

Figure 40 – Percentage of global patents in satellite connectivity, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/satellite-connectivity.html

A similar pattern can be observed in the scientific publication landscape for satellite connectivity technologies. China clearly dominates the field, accounting for roughly 29 % of global publications. This strong research output reflects China's rapid expansion in space technologies, telecommunications engineering, and satellite systems. Chinese universities and research institutes are particularly active in areas such as satellite communications, low-Earth-orbit constellations, signal processing, and integrated space–terrestrial networks. Institutions such as Beijing University of Posts and Telecommunications, Tsinghua University, and the Chinese Academy of Sciences contribute extensively to research on next-generation satellite communications and space-based connectivity.

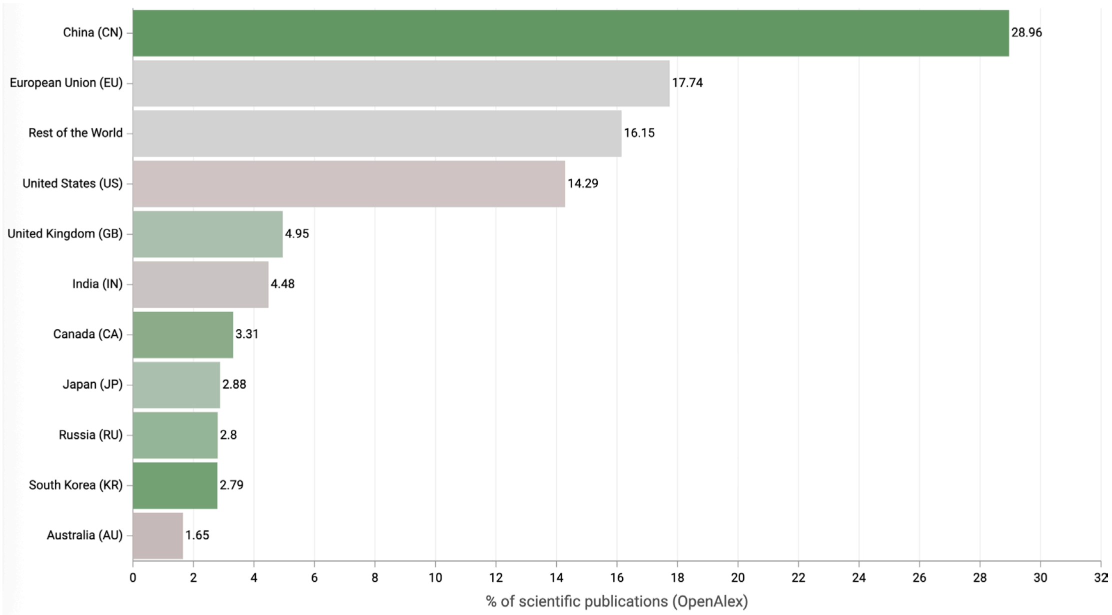
The European Union ranks second with approximately 17.7 % of global research output. Europe's strong presence reflects a combination of leading aerospace companies, public research institutions, and collaborative space programmes. Universities and research centres such as Delft University of Technology and Technical University of Munich are particularly active in research on satellite communications systems, orbital networks, and integrated communication infrastructures. European research initiatives in space and telecommunications also contribute significantly to the continent's publication output.

The United States follows with about 14.3 % of global publications. Although the United States holds a smaller share of scientific publications compared with China and Europe, it remains highly influential in the development of satellite technologies through a strong combination of academic research, national laboratories, and private aerospace companies. Universities such as Massachusetts Institute of Technology and Stanford University conduct important research on satellite communications, orbital systems, and space networking technologies.

Smaller but still notable shares of global publications are accounted for by the United Kingdom, with about 5 % of total output, and India, which holds approximately 4.5 %. The United Kingdom benefits from strong expertise in satellite engineering and small satellite technologies, particularly through institutions such as University of Surrey, which has pioneered research in small satellites and space communications. India's presence reflects the growing capabilities of its space and telecommunications sectors, supported by institutions such as the Indian Institute of Technology network and the Indian Space Research Organisation.

Overall, the scientific publication landscape in satellite connectivity shows a strong concentration of research activity in China, while Europe and the United States remain important contributors. The presence of additional players such as the United Kingdom and India highlights the increasingly global nature of research efforts aimed at developing next-generation space-based communication infrastructures.

Figure 41 – Percentage of scientific publications in satellite connectivity, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/satellite-connectivity.html

Venture capital investment in satellite connectivity technologies presents a somewhat different picture from patents and scientific publications. According to data reported by Crunchbase, the United States leads the global landscape, accounting for around 30 % of the total value of venture-backed deals in this domain. The United States benefits from a highly dynamic space technology ecosystem supported by strong venture capital markets and close connections between aerospace start-ups, research institutions, and large technology companies. Firms such as SpaceX, which operates the Starlink broadband network, and Planet Labs, which deploys large constellations of Earth-observation satellites, illustrate the growing role of venture-backed companies in shaping the satellite connectivity ecosystem.

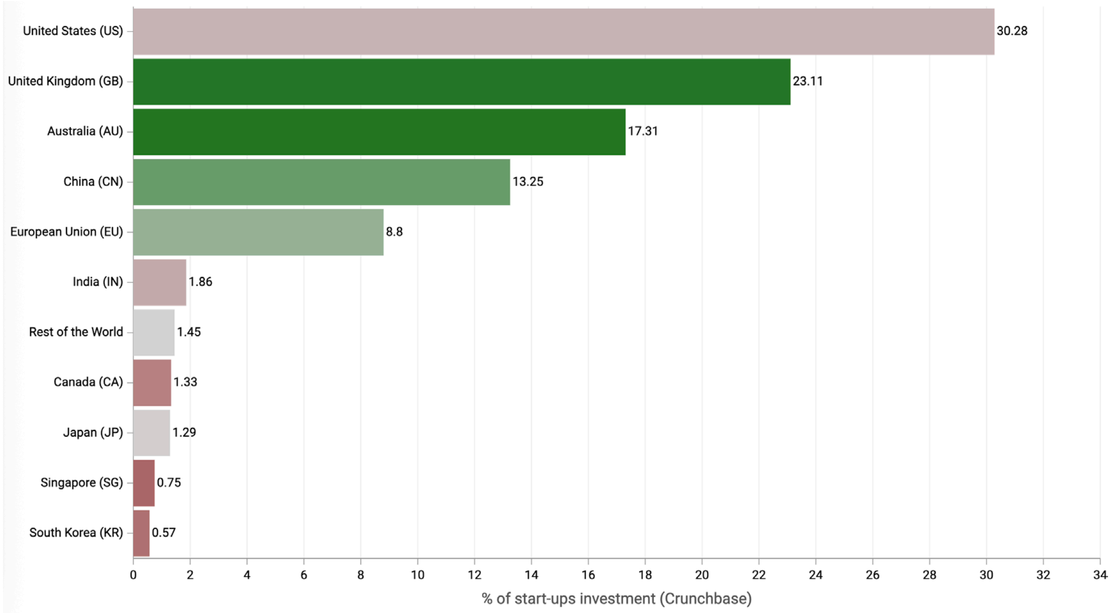
The United Kingdom follows closely with approximately 23.1 % of global venture capital investment. The UK has developed a strong commercial space sector supported by specialised venture funds and a favourable regulatory environment for satellite start-ups. Companies such as OneWeb, which is building a global low-Earth-orbit satellite constellation to deliver broadband connectivity, have attracted substantial investment and positioned the country as one of the leading markets for satellite connectivity ventures.

Australia also holds a notable share of venture capital investment in this field, accounting for around 17.3 % of the total value of deals. Australia's strong position reflects the emergence of a dynamic space technology ecosystem supported by research institutions and new space start-ups. Companies such as Fleet Space Technologies focus on satellite-based connectivity solutions for applications such as mining, environmental monitoring, and industrial data transmission.

China accounts for roughly 13.3 % of global venture capital investment in satellite connectivity start-ups. Although China leads in patents and scientific publications in this domain, venture capital plays a somewhat smaller role in the country's space industry, where many major projects are driven by state-owned enterprises and government programmes rather than private venture funding.

Finally, the European Union accounts for around 8.8 % of venture capital investment in this domain. Europe's relatively smaller share reflects the still-developing nature of its venture capital ecosystem in the space technology sector, despite the presence of strong aerospace companies and research institutions. Overall, the venture capital landscape in satellite connectivity highlights the growing importance of private investment in the commercialisation of space-based communication systems, with the United States and several partner countries playing particularly prominent roles in supporting new satellite connectivity start-ups.

Figure 42 – Percentage of VC investment in start-ups in satellite connectivity, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/satellite-connectivity.html

2.14. Semiconductors and Chips

In the domain of semiconductors and microchips, which constitute the backbone of modern digital technologies and advanced computing systems, the patent landscape reveals a distribution of technological capabilities across several major industrial powers. According to patent data, Japan holds the leading position with approximately 31.7 % of all patents in this field. Japan's strong performance reflects its long-standing expertise in semiconductor manufacturing equipment, materials science, and precision electronics. Major Japanese companies have developed extensive intellectual property portfolios related to semiconductor fabrication processes, lithography technologies, and chip design. Firms such as Tokyo Electron and Renesas Electronics are particularly influential in the development of semiconductor manufacturing technologies and integrated circuits.

China follows with around 24.3 % of global semiconductor patents. Over the past decade China has significantly expanded its capabilities in chip design, semiconductor manufacturing, and electronic components, supported by large national industrial policies aimed at strengthening technological self-sufficiency. Chinese technology companies and research institutions have increasingly filed patents related to chip architectures, manufacturing processes, and semiconductor materials.

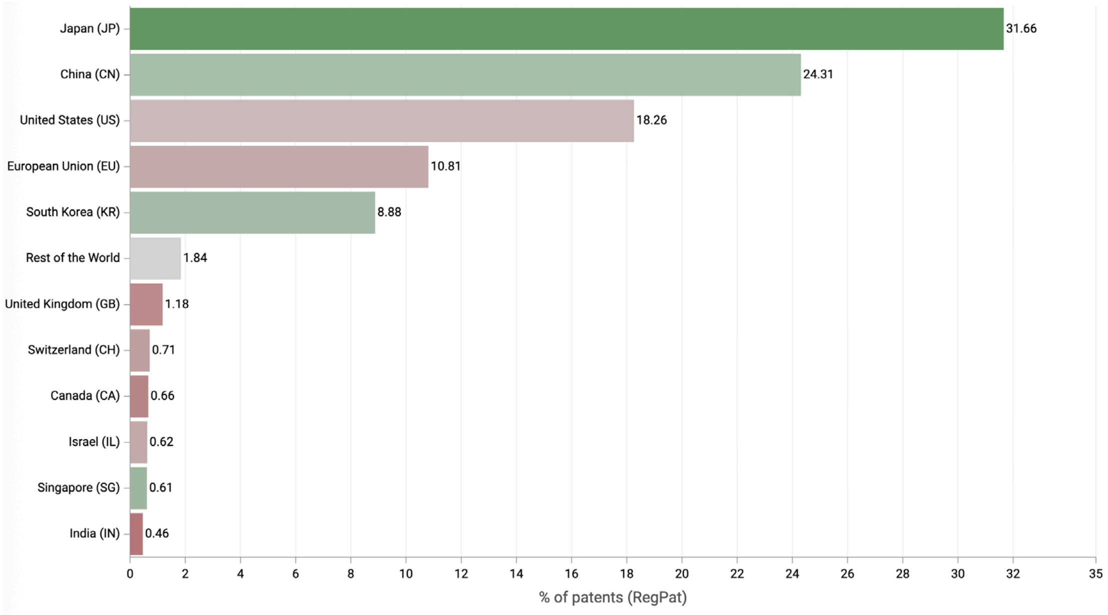
The United States accounts for about 18.3 % of global semiconductor patents. While the United States ranks behind Japan and China in terms of patent counts, it remains a central actor in semiconductor innovation through its powerful ecosystem of chip designers and technology companies. Firms such as Intel, NVIDIA, and Qualcomm play a crucial role in developing advanced microprocessors, graphics processors, and specialised chips used in artificial intelligence, telecommunications, and high-performance computing.

The European Union accounts for slightly below 11 % of global patents in semiconductors and chips. Europe's contribution is strongly linked to its expertise in semiconductor equipment, power electronics, and specialised chip technologies. Companies such as Infineon Technologies and STMicroelectronics are important innovators in power semiconductors, automotive electronics, and industrial applications.

Finally, South Korea accounts for approximately 8.9 % of global semiconductor patents. South Korea's semiconductor industry is dominated by large electronics companies with strong manufacturing capabilities. Firms such as Samsung Electronics and SK Hynix play a key role in the development of advanced memory chips and semiconductor manufacturing technologies used in data centres, consumer electronics, and mobile devices.

Overall, the patent landscape in semiconductors highlights the strategic importance of chip technologies for global technological competitiveness. Japan leads in patent counts thanks to its strong expertise in semiconductor manufacturing technologies, while China, the United States, Europe, and South Korea remain major contributors to innovation across different segments of the semiconductor value chain.

Figure 43 – Percentage of global patents in semiconductors and chips, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/semiconductorsandchips.html

Japan's leadership in semiconductor patents is not mirrored in the scientific publication landscape. In terms of research output, China leads the field with approximately 22.9 % of global publications related to semiconductors and chip technologies. This strong position reflects the rapid expansion of China's research ecosystem in electronics, materials science, and microelectronics engineering. Chinese universities and research institutes publish extensively on topics such as semiconductor materials, chip architectures, and advanced fabrication techniques. Institutions such as Tsinghua University, Shanghai Jiao Tong University, and the Chinese Academy of Sciences are among the most active contributors to the global literature in semiconductor technologies.

The European Union ranks second with around 17.3 % of global publications. Europe benefits from a strong academic tradition in electrical engineering, materials science, and nanoelectronics, supported by a network of universities and publicly funded research centres. Institutions such as IMEC, ETH Zurich, and Technical University of Munich contribute significantly to research on semiconductor devices, chip fabrication technologies, and advanced materials for microelectronics.

The United States follows with about 12.9 % of global publications. Although its share of academic publications is smaller than that of China and Europe, the United States remains highly influential in semiconductor research through leading universities and strong links between academia and the semiconductor industry. Institutions such as Massachusetts

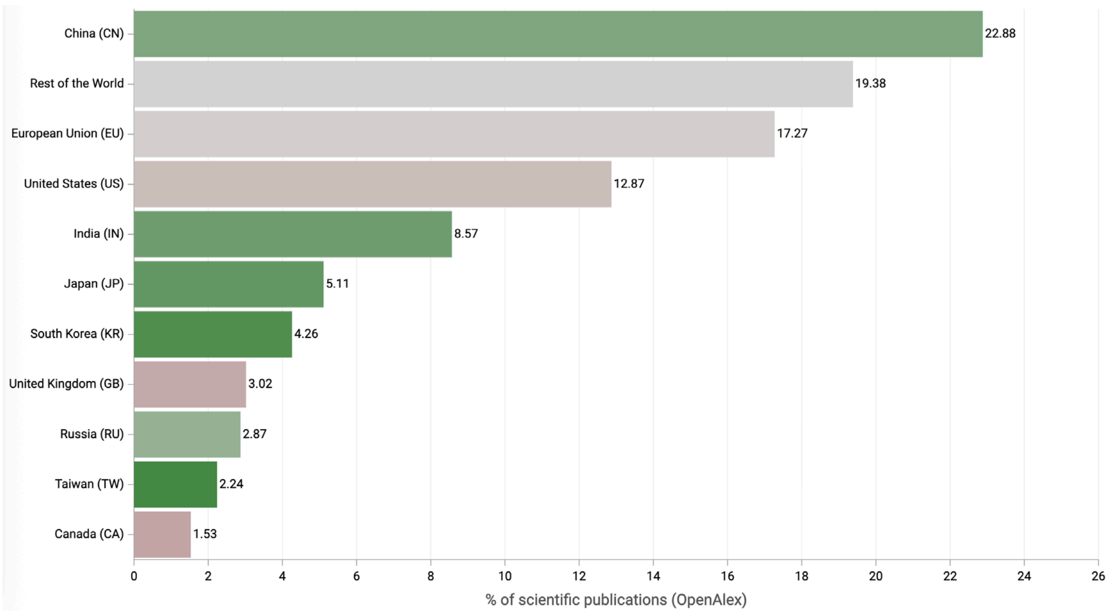
Institute of Technology, Stanford University, and the University of California, Berkeley conduct important research on semiconductor devices, nanoelectronics, and chip design.

A notable share of scientific publications is also produced by India, which accounts for approximately 8.6 % of global output in this field. India's growing presence reflects the expansion of its research community in electronics and computer engineering. Institutions such as the Indian Institute of Technology network contribute to research on semiconductor devices, chip design, and integrated circuits.

By contrast, Japan, despite leading in patent counts, accounts for only about 5 % of global scientific publications related to semiconductors. A similar share is held by South Korea. In both countries, innovation in semiconductor technologies is often driven primarily by industrial research and development rather than academic publishing. Large electronics companies play a central role in advancing semiconductor technologies through corporate laboratories and proprietary research, which is more frequently reflected in patents than in scientific publications.

Overall, the publication landscape in semiconductor research highlights a contrast between academic research output and industrial innovation. While China and Europe lead in publication volume, Japan and South Korea play a particularly strong role in technological development through their powerful semiconductor industries and extensive patent portfolios.

Figure 44 – Percentage of scientific publications in semiconductors and chips, 2010-2025



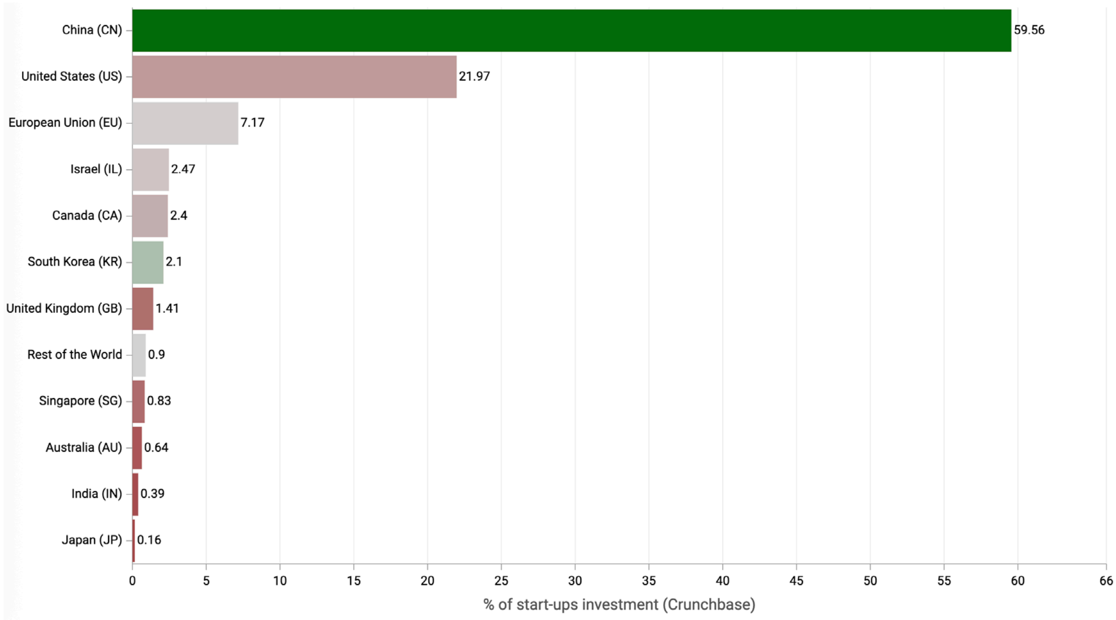
Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/semiconductorsandchips.html

In the semiconductor and chip sector, the venture capital landscape differs markedly from that observed in many other digital technology domains. According to data reported by Crunchbase, China holds the largest share of venture capital investment in semiconductor-related start-ups, accounting for close to 60 % of the total value of deals. This dominant position reflects the strategic priority that China assigns to semiconductor technologies, which are considered essential for technological sovereignty and the development of advanced digital industries. Over the past decade, Chinese public policies and investment funds have strongly supported the creation and expansion of domestic semiconductor companies, particularly in areas such as chip design, fabrication equipment, and advanced packaging technologies.

By contrast, the United States, despite hosting the largest venture capital market in the world, accounts for around 22 % of global investment in semiconductor start-ups. While this share is significant, it is lower than in many other advanced technology domains such as artificial intelligence or cloud computing. The US semiconductor ecosystem is dominated by large, established firms with substantial internal research and development capabilities, including companies such as Intel, NVIDIA, and Qualcomm. As a result, innovation in this sector is often driven by corporate R&D rather than by venture-backed start-ups.

The European Union accounts for a relatively small share of venture capital investment in semiconductor start-ups, at approximately 7.1 % of the global total. Europe nevertheless maintains important capabilities in specialised segments of the semiconductor value chain, particularly in areas such as power electronics, automotive semiconductors, and semiconductor manufacturing equipment. Companies such as Infineon Technologies and STMicroelectronics remain key players in these areas, although the European start-up ecosystem in semiconductor technologies remains more limited compared with that of China or the United States.

Figure 45 – Percentage of VC investment in start-ups in semiconductors and chips, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/semiconductorsandchips.html

2.15. SOFTWARE ENGINEERING AND SYSTEM DEVELOPMENT

The domains of Software Engineering and Systems Development refer to the methods, tools, and technologies used to design, build, test, deploy, and maintain software systems. These domains are foundational to the digital economy because they enable the creation of applications, platforms, and infrastructures that support virtually all modern technologies, from cloud computing and AI to mobile applications and embedded systems.

Software engineering focuses on the systematic and disciplined development of software. It includes activities such as requirements analysis, software architecture design, programming, testing, debugging, and maintenance. The goal is to produce reliable, efficient, and scalable software systems using structured development methodologies. This field encompasses practices such as agile development, continuous integration and deployment (CI/CD), software quality assurance, and version control. It also involves the development of programming languages, development frameworks, and software tools used by programmers.

Systems development is a broader concept that covers the design and implementation of complete information systems that integrate software, hardware, networks, and data. It often involves methodologies such as the Systems Development Life Cycle, which organises the stages of planning, analysis, design, implementation, and maintenance of complex systems. Systems development therefore includes areas such as database systems, enterprise software platforms, distributed systems, operating systems, and large-scale digital infrastructures.

In practice, the two domains are closely intertwined. Software engineering provides the technical methods and tools used to write and maintain code, while systems development focuses on the broader architecture and integration of software components within larger technological systems. Together they form the backbone of modern digital innovation, enabling the development of complex applications, cloud platforms, and large-scale digital services that support businesses, governments, and everyday digital activities.

In the crucial domain of software engineering and systems development, the patent landscape reflects the technological leadership of several advanced digital economies. The United States holds the leading position with more than one quarter of all patents in this field. This strong performance reflects the central role of the United States in the global software industry and the presence of major technology companies that develop large-scale software platforms, operating systems, and cloud infrastructures. Firms such as Microsoft, IBM, and Oracle Corporation have accumulated extensive patent portfolios related to software architectures, database systems, enterprise software platforms, and distributed computing technologies.

Japan ranks second with close to 19 % of global patents in this domain. Japan's strong position reflects its long-standing expertise in computing systems, enterprise software, and embedded systems used in electronics and industrial automation. Companies such as Fujitsu and NEC have developed important technologies related to enterprise software platforms, system integration, and large-scale information systems.

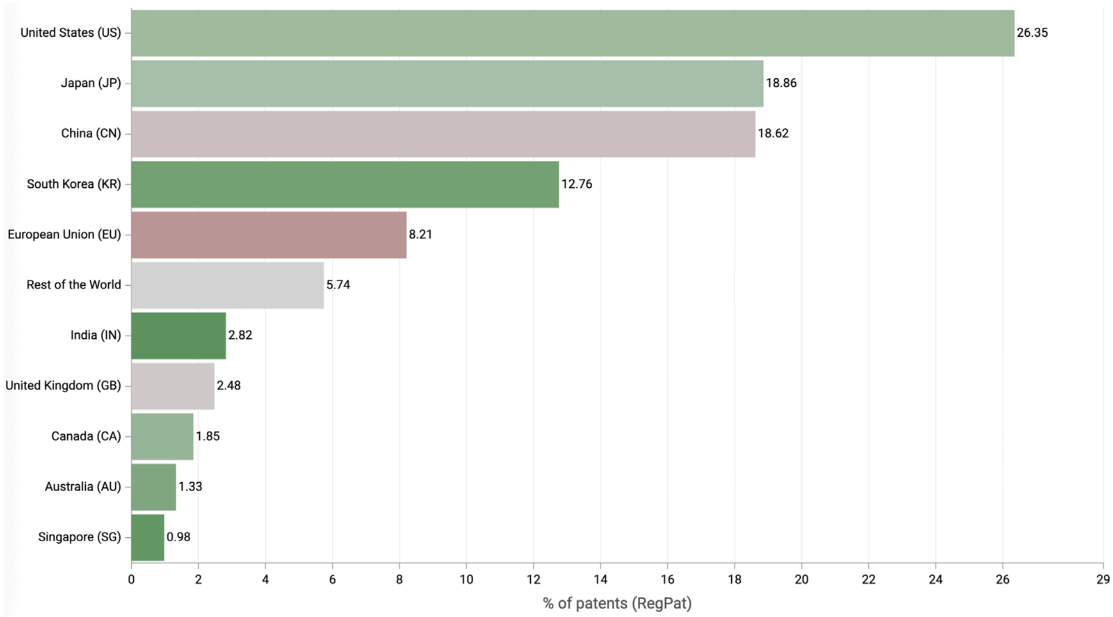
China follows closely with approximately 18.6 % of the patents. China's growing presence in software engineering reflects the rapid expansion of its digital economy and the rise of large internet and technology companies. Firms such as Alibaba and Tencent contribute to innovations in cloud platforms, distributed computing systems, and large-scale software infrastructures.

South Korea is also a major player, accounting for around 12.8 % of global patents in software engineering and systems development. The country's strong electronics and digital services industries support significant innovation in software platforms and integrated digital systems. Companies such as Samsung Electronics play a key role in developing software systems integrated into consumer electronics, mobile devices, and digital services.

Finally, the European Union accounts for about 8.2 % of global patents in this domain. Europe's contributions are often linked to enterprise software, industrial software systems, and digital infrastructure technologies. Companies such as SAP and Siemens have developed important software platforms used in enterprise management systems, industrial automation, and large-scale information systems.

Overall, the patent landscape in software engineering and systems development highlights the strategic importance of software technologies for global technological competitiveness. The United States leads thanks to its dominant software industry, while Japan, China, South Korea, and Europe remain significant innovators through their strong technology companies and digital infrastructure capabilities.

Figure 46 – Percentage of global patents in software engineering and systems development, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/software-engineering--system-development.html

In contrast to the patent landscape, the scientific publication landscape in software engineering and systems development is clearly dominated by the European Union, which accounts for more than one quarter of global research output in this domain. Europe's strong position reflects the presence of a dense network of universities and research institutions specialising in computer science, software engineering methodologies, distributed systems, and large-scale information infrastructures. Institutions such as the University of Oxford, the Technical University of Munich, and ETH Zurich contribute significantly to research on software architecture, programming systems, and large-scale distributed computing.

The United States ranks second in terms of scientific publications, with a share roughly 10 percentage points below that of the EU. Despite this lower share of total publications, the United States remains highly influential in the field thanks to leading research universities and strong connections between academia and the software industry. Institutions such as Massachusetts Institute of Technology, Stanford University, and Carnegie Mellon University are widely recognised for their research on software engineering, distributed systems, and advanced computing infrastructures.

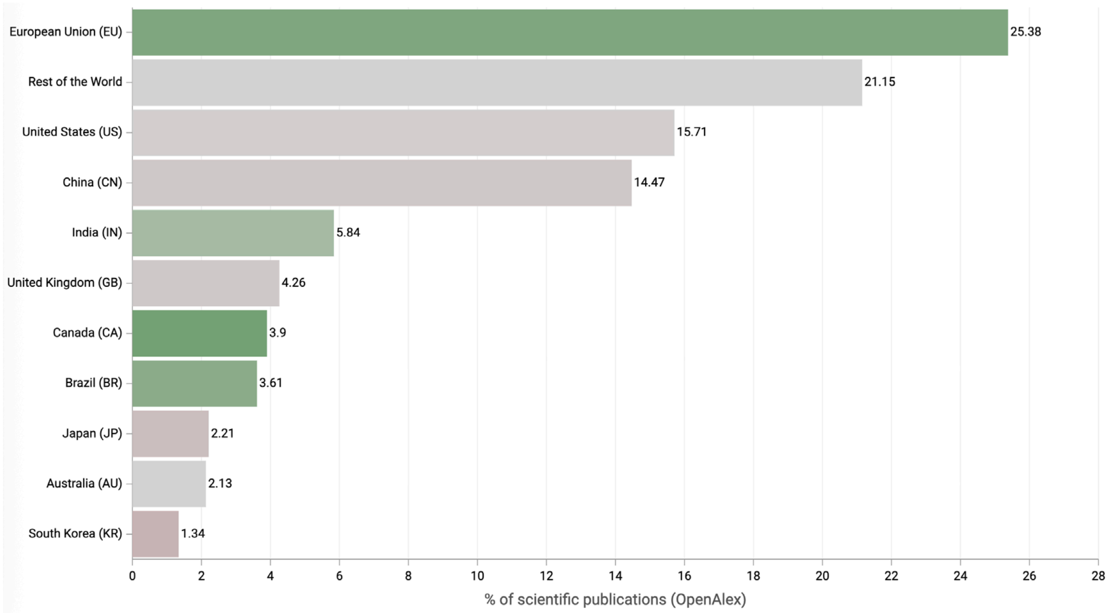
China follows with a share of approximately 14.5 % of global publications. China's presence reflects the rapid expansion of its research community in computer science and information technologies. Universities such as Tsinghua University and Shanghai Jiao Tong University publish extensively on topics such as cloud computing architectures, software systems engineering, and large-scale digital platforms.

Other countries also hold notable shares of scientific publications in this domain. India accounts for around 5.8 % of global output, reflecting the large number of researchers working in computer science and software development across institutions such as the Indian Institute of Technology network. The United Kingdom contributes about 4.3 % of global publications, supported by strong research universities including the University of Cambridge and Imperial College London.

Interestingly, Canada and Brazil also feature among the significant contributors to the global research output in software engineering and systems development, each with shares slightly below 4 %. Canada benefits from strong research programmes in software systems and distributed computing, particularly at universities such as University of Toronto, while Brazil's presence reflects the growth of its computer science research community and the increasing internationalisation of its academic institutions.

Overall, the publication landscape in software engineering highlights the particularly strong academic presence of Europe, while the United States, China, and several other countries maintain active research communities contributing to the advancement of software systems and digital infrastructures.

Figure 47 – Percentage of scientific publications in software engineering and systems development, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/OpenAlex/software-engineering--system-development.html

In the domain of venture capital investment for software engineering and systems development start-ups, the United States clearly dominates the global landscape. According to data reported by Crunchbase, the United States accounts for almost 79 % of the total value of venture-backed deals in this sector. This overwhelming leadership reflects the scale and maturity of the American technology ecosystem, where large venture capital funds, technology hubs such as Silicon Valley and Seattle, and strong links between universities and industry support the creation of numerous software start-ups. Many of these companies focus on areas such as enterprise software, cloud-native applications, developer tools, and large-scale digital platforms.

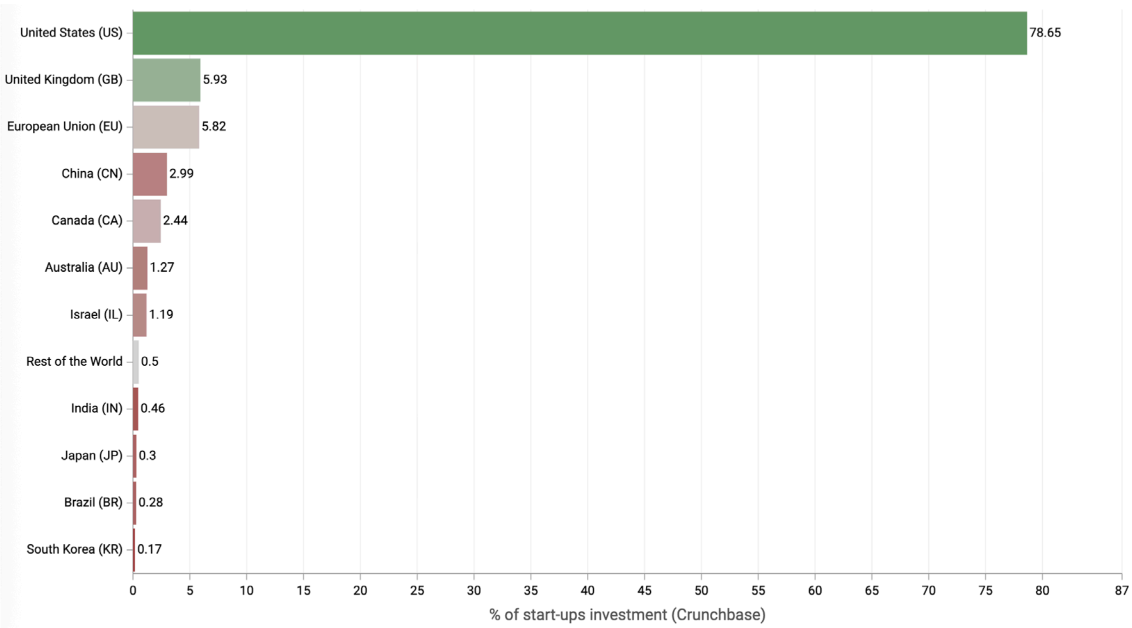
The United Kingdom ranks second, although far behind the United States, with around 6 % of global venture capital investment in this field. The UK benefits from a dynamic start-up ecosystem centred around London and Cambridge, as well as strong research institutions in computer science and software engineering. British start-ups frequently develop enterprise software platforms, financial technology solutions, and cloud-based services that attract international investors.

The European Union follows closely with approximately 5.8 % of global venture capital investment in software engineering and systems development start-ups. Europe's venture capital ecosystem remains more fragmented than that of the United States, but it has been growing steadily in recent years. European start-ups often specialise in enterprise software, industrial digitalisation, and secure digital infrastructures.

Finally, China accounts for less than 3 % of global venture capital investment in this domain. While China hosts a large and rapidly expanding digital economy, many major software innovations in the country are driven by large technology companies rather than venture-backed start-ups. Firms such as Alibaba and Tencent play a central role in developing large-scale software platforms and digital services, which may partly explain the relatively smaller share of venture capital investment in early-stage software start-ups.

Overall, the venture capital landscape in software engineering and systems development highlights the extraordinary concentration of entrepreneurial financing in the United States, while the United Kingdom and the European Union maintain smaller but still significant start-up ecosystems in this crucial digital technology domain.

Figure 48 – Percentage of VC investment in start-ups in software engineering and systems development, 2010-2025



Source: https://www.paballand.com/ceps/ttd/position/crunchbase/software-engineering--system-development.html

2.16. SUMMARY OF MAIN FINDINGS

The analysis of technological activity across 15 advanced digital technology sectors reveals a complex and increasingly multipolar innovation landscape. Across the indicators considered – patents, scientific publications, and venture capital investment – three major innovation systems repeatedly emerge as dominant actors: the United States, China, and the European Union. However, their relative strengths vary significantly depending on the stage of the innovation cycle examined. While China often leads in patenting activity and scientific publications, the United States maintains a decisive advantage in venture capital investment and entrepreneurial innovation. The European Union, for its part, stands out primarily in scientific research output, although this strength is not always matched by equivalent performance in patents or venture capital financing.

In the domain of artificial intelligence, which underpins many other emerging technologies, the United States and China dominate the patent landscape, accounting for roughly 29.3 % and 27.5 % of global patents respectively. Japan follows with a share above 11 %, slightly ahead of the European Union, while South Korea also emerges as a significant contributor. However, the scientific publication landscape presents a different picture: China leads with about one fifth of global publications, followed by the European Union and the United States. India also appears as an increasingly important research contributor. Venture capital investment in AI start-ups is overwhelmingly concentrated in the United States, which accounts for nearly 70 % of the global value of deals, illustrating the country's strong advantage in transforming technological breakthroughs into commercial ventures.

Across many other sectors, a similar pattern emerges. China frequently appears as the leading actor in patents, particularly in infrastructure-related technologies such as mobile networks, cybersecurity, Internet of Things systems, and satellite connectivity. These sectors reflect areas where large-scale industrial policy and strong domestic technology companies have supported rapid technological development. China also leads the scientific publication landscape in several engineering domains, including robotics, satellite communications, and telecommunications technologies.

The European Union often appears as one of the strongest actors in scientific research output. In fields such as high-performance computing, quantum technologies, and software engineering, Europe produces a substantial share of global publications. This reflects the strength of its academic institutions and collaborative research programmes. However, this strong research base does not always translate into equivalent performance in patents or venture capital investment. In several domains – such as artificial intelligence and software engineering – Europe's strong publication output contrasts with more modest shares in technological patents and start-up financing.

The United States consistently dominates the venture capital landscape across most technology sectors examined. In areas such as cloud computing, artificial intelligence, cybersecurity, mobile networks, and software engineering, American start-ups attract most of the global venture capital investment. In some domains, the US share exceeds 80 % of the total value of deals. This dominance reflects the scale and maturity of the American venture capital ecosystem, particularly in major technology hubs such as Silicon Valley, New York, and Boston. Venture capital plays a crucial role in scaling technological innovations and translating research breakthroughs into commercially viable products and services.

Other countries also appear as significant actors in specific technological domains. Japan maintains strong technological capabilities in sectors such as semiconductors, robotics, and electronics, where its industrial base remains globally competitive. South Korea also plays an important role in several technology sectors, particularly in semiconductors, mobile networks, and electronics-related technologies. Meanwhile, countries such as India increasingly appear among the major contributors to scientific publications, particularly in computing-related fields.

Interestingly, several smaller innovation hubs also appear prominently in venture capital investment in specific sectors. Countries such as the United Kingdom, Israel, Canada, Australia, and Singapore emerge as significant actors in venture capital investment in technologies such as satellite connectivity, cybersecurity, quantum technologies, and artificial intelligence. These countries benefit from strong research institutions, dynamic start-up ecosystems, and favourable investment environments that allow them to compete with larger economies in certain technological niches.

The semiconductor sector provides a particularly interesting example of differentiated global leadership. Japan leads the patent landscape thanks to its strong expertise in semiconductor manufacturing technologies, while China plays a major role in venture capital investment in semiconductor start-ups as part of its broader industrial strategy aimed at strengthening domestic chip production capabilities. Meanwhile, the United States continues to dominate in chip design and advanced computing architectures through major technology companies.

Overall, the evidence points to an increasingly diversified global technological landscape. Rather than a single technological hegemon dominating all stages of innovation, different regions specialise in different segments of the innovation cycle. China appears particularly strong in patents and scientific publications, reflecting large-scale investments in research and industrial development. The European Union stands out in academic research, supported by a dense network of universities and public research programmes. The United States retains a decisive advantage in venture capital investment and entrepreneurial innovation, allowing it to convert technological breakthroughs into globally competitive digital companies.

Taken together, these patterns illustrate the emergence of a multipolar technological system in which several major innovation ecosystems coexist and compete. The balance between research production, technological invention, and commercialisation will likely play a central role in shaping the future trajectory of global technological leadership.

Table 1 summarises our main findings.

Table 1 – Summary of competitiveness results for 15 Key Strategic Technologies in select countries

Technology Domain	Patent	Scientific Publications	VC Investment	Notable Players
Artificial Intelligence	US (29.3 %), China (27.5 %)	China (20.4 %)	United States (68.5 %)	EU, India
Blockchain	China / US strong	China dominant	United States	EU, India
Generative AI	China strong in research	China	United States	Singapore, UK
Cloud/Edge Computing	China (>33 %)	China / India strong	United States (~60 %)	EU, UK, Israel
CV/ NLP/OR	China (27.7 %)	China (~30 %)	United States (~85 %)	Japan
Cybersecurity	China (28.5 %)	China (~19 %)	United States (~64 %)	EU, Israel
Drones	China (>27 %)	China (~33 %)	Incomplete data	EU, US
HPC	China (34.6 %)	EU (~19 %)	United States (~80 %)	China
Internet of Things	China (>27 %)	India (~19 %)	United States (~44 %)	EU, China
Mobile Networks (5G/6G)	China (37.6 %)	China (~25 %)	United States (~82 %)	EU, South Korea

Quantum Technologies	United States (~29 %)	EU (~21 %)	United States (~55 %)	Canada, UK
Robotics	United States (~22 %)	China (~30 %)	Partial data	EU, Japan
Satellite Connectivity	China (~33 %)	China (~29 %)	United States (~30 %)	UK, Australia
Semiconductors	Japan (~31.7 %)	China (~22.9 %)	China (~60 %)	US, South Korea
Software Engineering	United States (>25 %)	EU (>25 %)	United States (~79 %)	UK

Source: authors'elaboration.

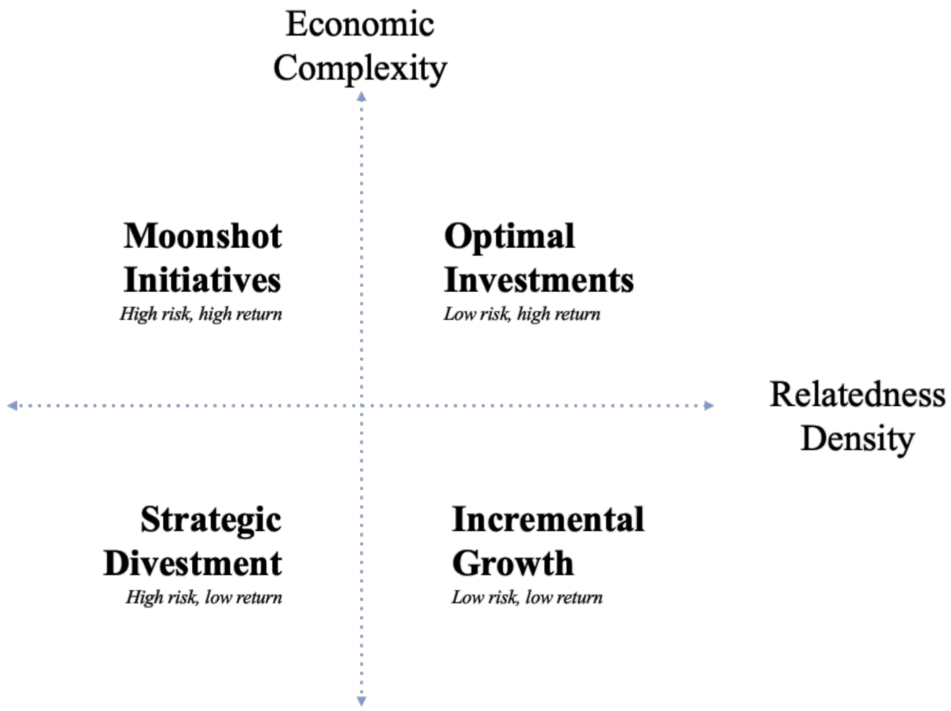
3. INVESTMENT OPPORTUNITIES IN THE SELECTED 15 KSTS

In this section, we briefly describe the results of our data analysis for all selected countries, in terms of the investment opportunities in the 15 KSTs. In particular, we present a graph with four quadrants, in which the horizontal axis measures the feasibility for a given country to invest in a specific KST in the future, based on current capabilities. Feasibility is measured by relatedness density, quantifying how closely related a country's capabilities in a given domain are to potential new domains. It is calculated as the share of related domains (already present in the country) out of all possible related domains for that target. A higher relatedness density means the region has a stronger foundation to lead (now and in the future) in that new domain.

On the vertical axis is the technology's complexity. Importantly, we take complexity as a proxy for the prospective economic impact of a given technological domain. This is due to the original method of 'reflections' (and its eigenvector reformulation), which measures complexity by capturing how diverse locations are and how exclusive the activities or technologies they host are, using iterative network metrics. Here we use a variation that is more robust to smaller techs: instead of using RCA or eigenvector centrality, we use a drop-shares scaling coefficient based on how quickly a technology's presence drops across top locations.

Figure 49 shows the legend for our resulting four-quadrant graph. The north-west quadrant includes domains for which investment, based on patent data, would be rather risky given that the country does not seem to possess a comparative advantage at the moment, but the potential added value of an investment would be significant ('moonshots', i.e. high-risk, high-return initiatives). The north-east quadrant, to the contrary, shows areas where the country is well-equipped to invest, given its current capabilities, and where technologies are complex and difficult to replicate, leading to a significant economic impact ('Optimal investments,' i.e. low-risk, high-return areas). In the bottom part of the graph, the south-east graph showcases domains in which the country has important capabilities, but where technologies are less complex and more replicable, and as such the prospective impact would be comparatively lower ('incremental investment,' i.e. low-risk, low-return investment). Finally, the south-west quadrant shows areas in which complexity and economic value are low, and the country has no comparative advantage, so absent a major strategic effort, the recommendation would be to divest ('Strategic divestment,' i.e. high-risk, low-return areas).

Figure 49 – How to read our four-quadrant investment opportunity graph

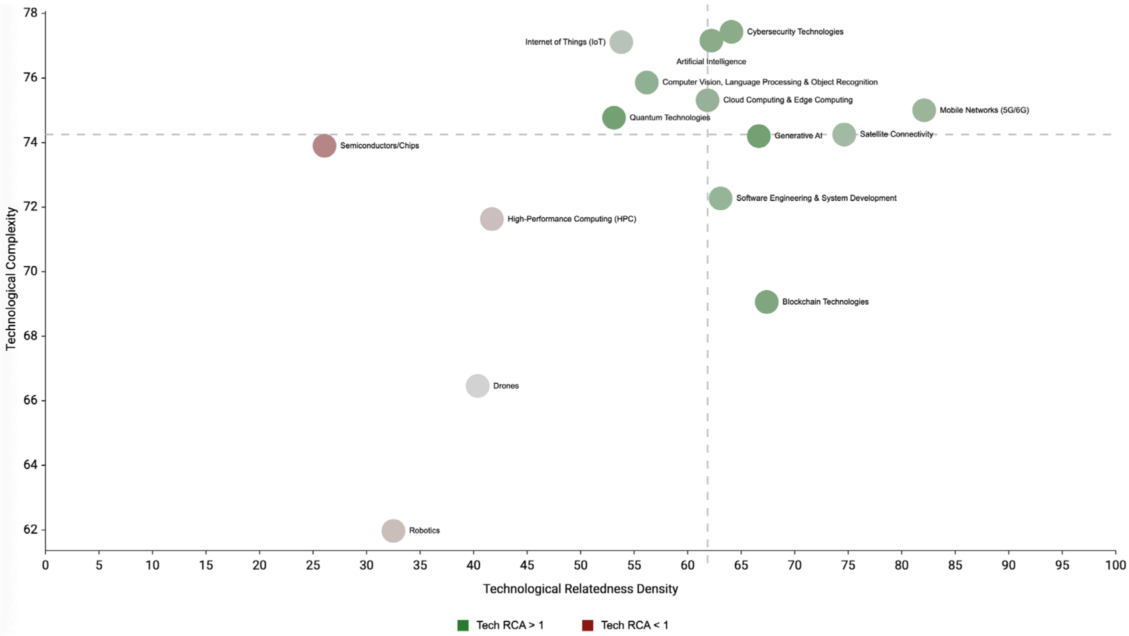


Source: Authors.

3.1. CANADA

Figure 50 analyses Canada from a technological perspective, highlighting areas in which complexity and relatedness density are both high, and as such would deserve to be prioritised as investments with relatively low risk and high return. KSTs that stand out in the optimal investment area include mobile networks (5G/6G), Cybersecurity, AI, Generative AI, Satellite Connectivity and Cloud & Edge computing. The technology RCA of all these KSTs is also positive, as shown by the colour scheme. Other areas, such as IoT, quantum and computer vision, NLP and object recognition fall in the high-risk, high reward area that denominate 'moonshot' quadrant.

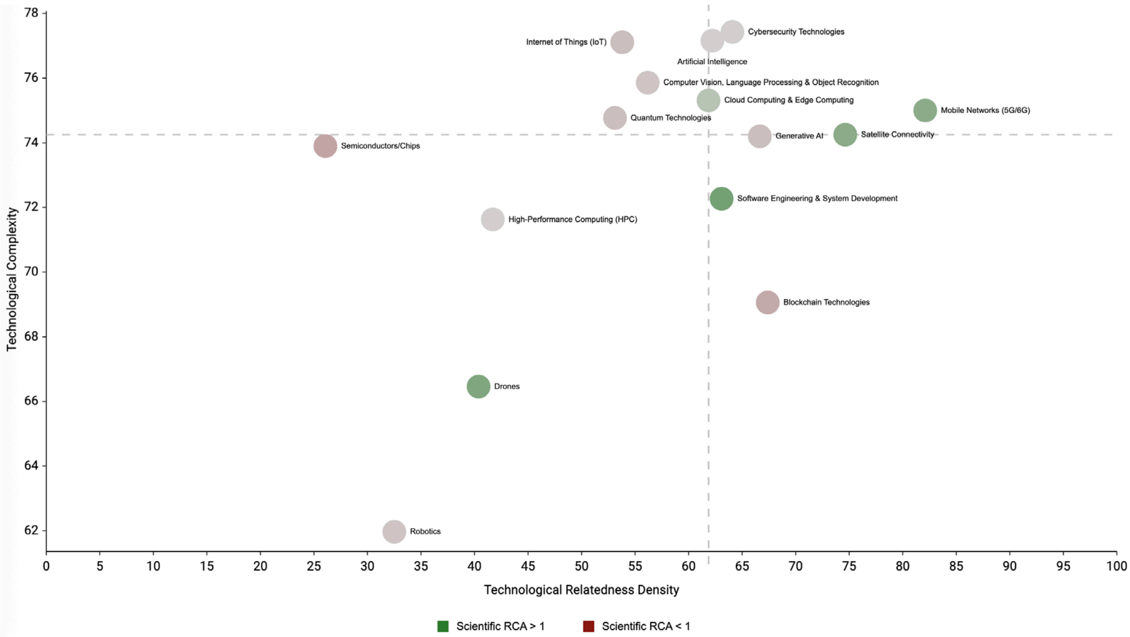
Figure 50 – Technological opportunities in Canada



Source: https://www.paballand.com/ceps/ttd/smart/regpat/canada-ca.html

Figure 51 below repeats the exercise by looking at the Scientific Competitive Advantage index. Seen from the lens of scientific publications, Canada appears as a leading performer in mobile networks and satellite connectivity; whereas its scientific leadership is less pronounced in other areas located in the optimal investment quadrant.

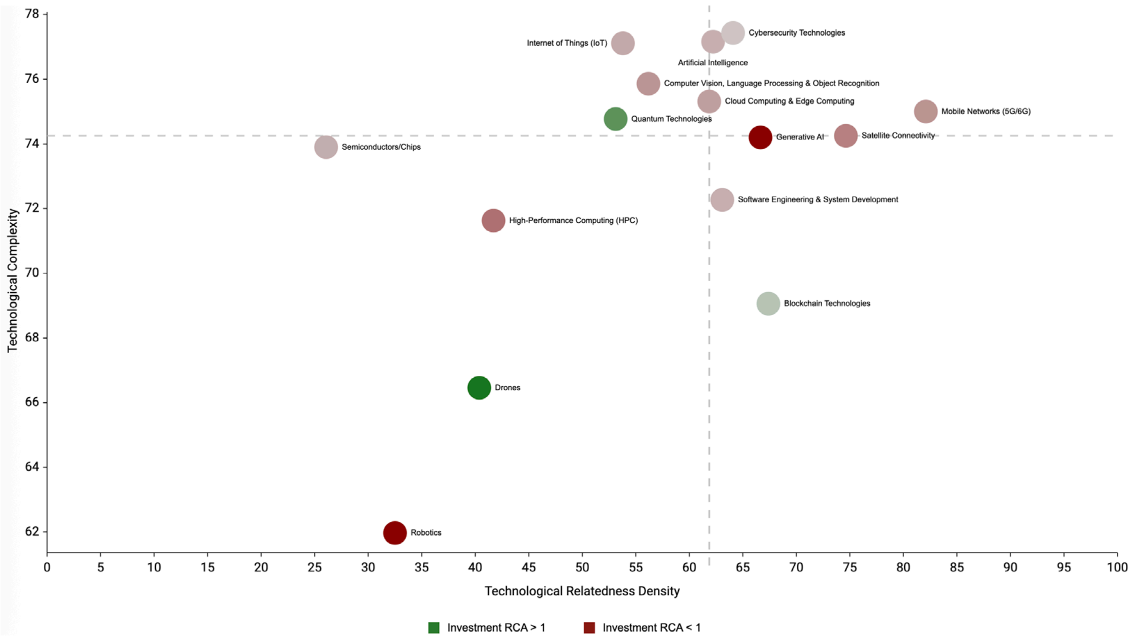
Figure 51 – Scientific opportunities in Canada



Source: https://www.paballand.com/ceps/ttd/smart/openalex/canada-ca.html

Finally, Figure 52 shows the results with a colour scheme that refers to the investment RCA. Here, the dominance of the US in terms of venture capital investment in start-ups makes almost all areas perform lower in terms of relative competitive advantage. Yet the figure shows that Canada would need to boost investment and research in optimal investment areas, and would be well positioned to launch a moonshot on quantum computing.

Figure 52 – Funding opportunities in Canada



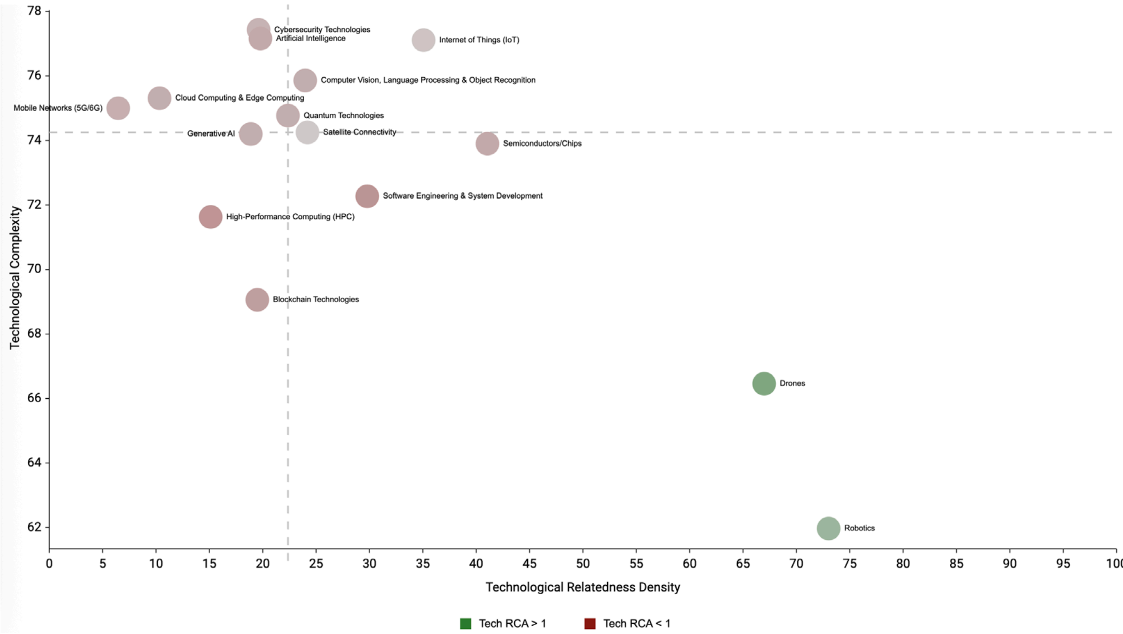
Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/canada-ca.html

3.2. EUROPEAN UNION

Figure 53 analyses the European Union from a technological diversification perspective by combining two key dimensions of the technological space: complexity and relatedness density. These indicators provide insight into how difficult a technology is to develop and how closely it is connected to the existing technological capabilities of the region. Technologies that score high on both dimensions can be interpreted as particularly attractive strategic opportunities. High complexity generally reflects technologies that are knowledge-intensive and associated with high value creation, while high relatedness density indicates that the capabilities required to develop them are already partially present in the region's technological portfolio. When both conditions are satisfied, investments in these technologies are likely to present relatively low diversification risk and potentially high economic returns, as existing capabilities can be leveraged to enter complex technological domains.

In the case of the European Union, a few KSTs appear in this optimal investment area. Notably, the Internet of Things, technologies related to computer vision, natural language processing and object recognition, as well as quantum technology, emerge as promising areas where Europe's existing technological capabilities appear closely aligned with future opportunities. These domains combine strong technological complexity with a relatively high degree of relatedness to Europe's current innovation portfolio. This suggests that further investment in these areas could allow the European innovation system to move into technologically sophisticated sectors while building on capabilities that are already partially established across European industries and research institutions. Satellite connectivity technologies also appear partly within this favourable zone, reflecting Europe's long-standing expertise in aerospace engineering and space infrastructure.

Figure 53 – Technological opportunities for the European Union



Source: https://www.paballand.com/ceps/ttd/smart/regpat/european-union-eu.html

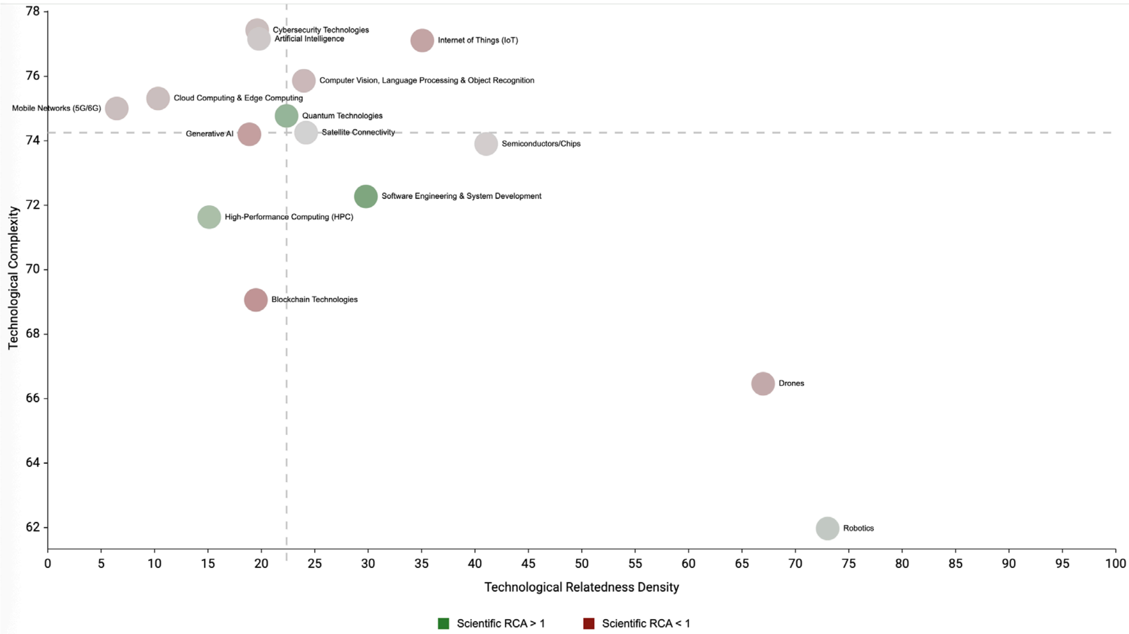
Figure 54 presents a complementary perspective on the technological positioning of the European Union by focusing on the Scientific Competitive Advantage (RCA) rather than technological patents. While the previous analysis emphasised technological specialisation based on patent activity, this figure highlights the structure of Europe's scientific research capabilities across KSTs. By combining complexity, relatedness density, and scientific RCA, the analysis identifies areas where Europe's scientific strengths align with promising technological opportunities.

In this framework, Quantum Technology emerges as one of the most promising investment opportunities. The sector combines high technological complexity with strong relatedness to existing European capabilities, while also displaying a scientific revealed comparative advantage greater than one. This means that European research institutions produce a disproportionately large share of scientific publications in this field compared with the global average. Such a configuration suggests that Europe possesses a strong scientific base capable of supporting future technological development in quantum computing, quantum communication, and quantum sensing. Given the strategic importance of quantum technologies for secure communications, advanced computing, and scientific simulation, this alignment between complexity, relatedness, and scientific excellence indicates a particularly attractive domain for long-term investment and policy support.

The analysis also identifies areas suitable for incremental investment, where the European Union already exhibits a strong scientific specialisation and where the technological barriers to further development are relatively manageable. In particular, Software Engineering and Systems Development appear as domains with favourable characteristics. Europe's scientific research output in these fields is substantial, resulting in a scientific RCA greater than one. At the same time, these domains display significant relatedness to other areas of the digital technology ecosystem, such as cloud computing, artificial intelligence, and distributed computing infrastructures. Strengthening investments in these areas could therefore reinforce Europe's broader digital capabilities while leveraging existing research strengths.

These findings highlight a structural feature of the European innovation system: strong scientific performance in several digital technologies that has not always translated into equivalent technological or industrial leadership. By identifying domains where scientific excellence aligns with favourable diversification conditions, the analysis provides valuable insights into potential strategic priorities. In particular, quantum technologies represent a high-potential frontier where Europe's scientific leadership could be translated into future technological and industrial advantages. Meanwhile, reinforcing established research strengths in software engineering and systems development could support incremental technological progress and contribute to the broader competitiveness of Europe's digital economy.

Figure 54 – Scientific opportunities in the EU



Source: https://www.paballand.com/ceps/ttd/smart/openalex/european-union-eu.html

Finally, Figure 55 presents the results using a colour scheme based on the investment revealed comparative advantage (investment RCA), which reflects the relative strength of venture capital investment across the different KSTs. This indicator captures the extent to which the European Union attracts venture capital investment in specific technological domains compared with the global average. In this sense, it provides a complementary perspective to the previous analyses based on patents and scientific publications by focusing on the commercialisation and scaling phase of innovation, where start-ups and entrepreneurial ecosystems play a crucial role.

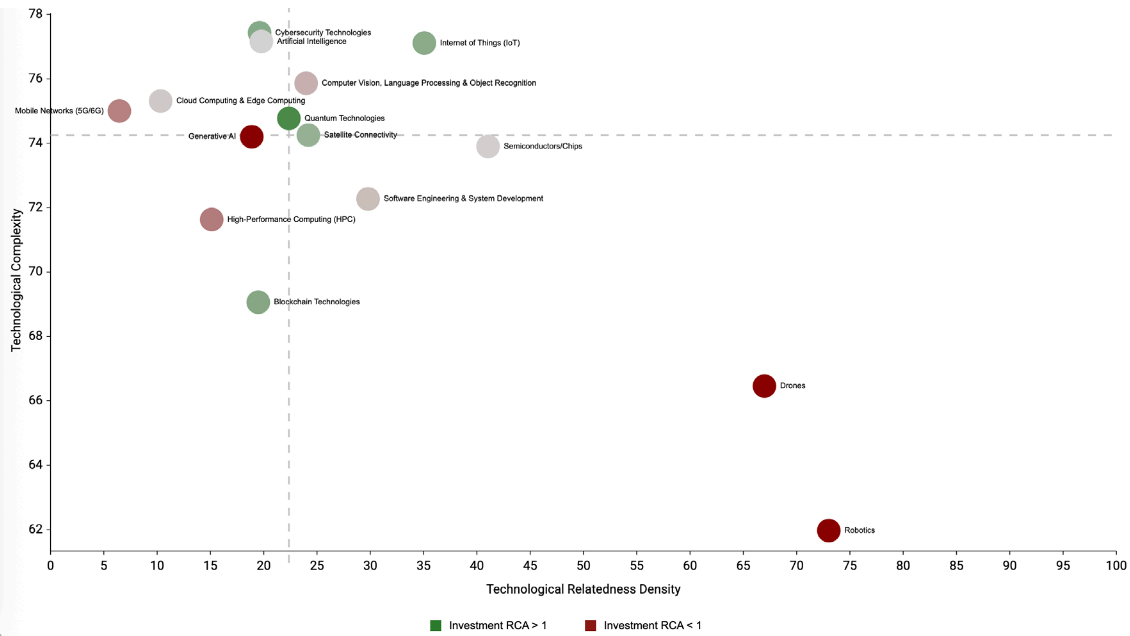
The results indicate that the European Union performs relatively well in several strategic areas, particularly in the Internet of Things, quantum technology, and Satellite Connectivity. These domains combine favourable investment dynamics with strategic relevance for Europe’s long-term technological competitiveness. The relatively strong investment RCA observed in these sectors suggests that the European start-up ecosystem and venture capital markets are able to mobilise financial resources for technologies that are critical to the development of next-generation digital infrastructures and advanced computing systems.

In the case of the Internet of Things, investment activity reflects the strong industrial base present in Europe, particularly in sectors such as manufacturing, automotive technologies, logistics, and industrial automation. European companies and start-ups are increasingly developing connected-device platforms, sensor networks, and industrial IoT applications that support the digital transformation of traditional industries. The presence of a strong industrial ecosystem provides fertile ground for venture capital investment in these technologies.

Quantum technologies also stand out as a particularly important domain for Europe's technological sovereignty. The relatively strong position of Europe in venture capital investment in this field complements its already significant scientific leadership in quantum research. European start-ups emerging from academic laboratories are increasingly developing quantum computing hardware, quantum communication systems, and specialised quantum software platforms. This alignment between scientific capabilities and growing venture investment creates favourable conditions for the development of a competitive quantum technology ecosystem in Europe.

Satellite connectivity represents another area where Europe appears comparatively well positioned from an investment perspective. Satellite communication systems are becoming increasingly central to global digital infrastructure, supporting applications such as broadband connectivity, Earth observation, navigation systems, and secure communications. Europe's long-standing expertise in aerospace engineering and satellite systems, supported by companies and research institutions across the continent, provides a strong technological foundation that can attract venture capital investment in emerging space technology start-ups.

Figure 55 – Funding opportunities in the European Union



Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/european-union-eu.html

3.3. INDIA

Figure 56 presents the technological opportunity landscape for India, revealing a particularly promising configuration across several KSTs. The analysis combines technological complexity, relatedness density, and the technological revealed comparative advantage (tech RCA) to identify areas where the country already possesses significant capabilities and where further diversification would involve relatively low risk. In this case, the technologies located in the optimal investment quadrant all display a tech RCA above 1, indicating that India already holds a degree of technological specialisation in these fields compared with the global average. This suggests that additional investments could build upon existing capabilities and generate strong returns in terms of technological development and industrial competitiveness.

Among the technologies that stand out in this favourable quadrant are Artificial Intelligence and Generative AI, both of which have become central to the current wave of digital innovation. India's growing capabilities in artificial intelligence are supported by a large pool of engineers, strong academic institutions, and an expanding digital services sector. The presence of these technologies in the optimal investment area indicates that India possesses both the technological capabilities and the knowledge proximity required to further expand its role in these rapidly evolving domains.

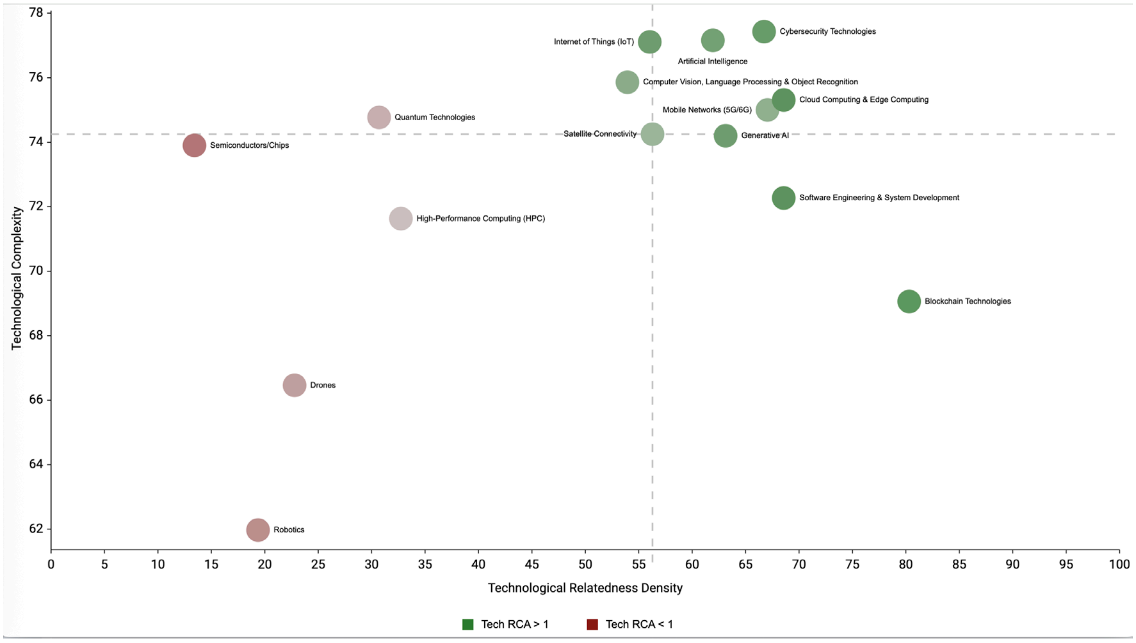
Other technologies appearing in the same quadrant include Cybersecurity, Cloud Computing, and Mobile Networks. These areas are closely linked to the digital infrastructure that supports modern information economies. India's specialisation in these domains reflects the growth of its information technology services sector and the increasing integration of digital technologies into both domestic and global markets. The presence of these technologies within the optimal investment zone suggests that India could strengthen its position in global digital value chains by expanding capabilities in digital infrastructure, secure computing environments, and advanced communication networks.

To a somewhat lesser extent, Internet of Things and Satellite Connectivity also appear as promising areas for technological development. Although the country's specialisation in these sectors is somewhat lower, the relatedness of these technologies to India's existing capabilities indicates that further investments could facilitate diversification into these domains with manageable levels of risk.

In addition to these high-potential technologies, the analysis also highlights opportunities for incremental investment in areas where India already demonstrates strong technological capabilities. In particular, Software Engineering and Systems Development – traditionally among the country's strongest technological domains – continue to display favourable characteristics for further development. India’s global reputation as a major hub for software development and digital services provides a strong foundation for continued innovation and expansion in these areas.

Finally, Blockchain also appears as a promising area for incremental investment. The technology’s connections with digital platforms, financial technologies, and distributed computing systems make it closely related to India’s existing strengths in software engineering and information technology services.

Figure 56 – Technological opportunities for India



Source: https://www.paballand.com/ceps/ttd/smart/regpat/india-in.html

Figure 57 looks at the relative competitive advantage in scientific terms, showing once again a very promising outlook. We examine India’s technological opportunity landscape from the perspective of scientific competitive advantage, using the scientific RCA indicator. This measure evaluates whether a country produces a disproportionate share of scientific publications in a given technological domain compared with the global average. The results show a remarkably favourable picture for India, with almost all KSTs displaying a scientific RCA above 1. This suggests that India possesses a strong and diversified research base across a wide range of digital and emerging technologies, providing a solid foundation for future technological development and industrial innovation.

In the domain of Artificial Intelligence and Generative AI, India has rapidly emerged as one of the most active contributors to global research output. The country benefits from a large pool of computer scientists and data scientists working across universities and research institutes. Institutions such as the Indian Institute of Technology network and the Indian Institute of Science publish extensively on machine learning, deep learning architectures, natural language models, and data-driven algorithms. Research from these institutions frequently addresses applications in areas such as healthcare diagnostics, financial technologies, and language technologies adapted to multilingual environments.

A similarly strong research presence can be observed in Cybersecurity, where Indian researchers contribute to topics such as cryptography, secure distributed systems, intrusion detection, and privacy-preserving data analysis. The growing importance of digital services and online platforms in India has stimulated research on secure software architectures and digital infrastructure resilience. Universities and technology institutes collaborate with industry to address challenges related to digital security in large-scale online systems.

India also displays strong scientific activity in Cloud Computing, an area closely linked to its globally significant IT services industry. Researchers publish extensively on distributed computing architectures, resource management in large-scale data centres, edge computing systems, and cloud-native software infrastructures. These research activities often support the development of scalable digital services and computing platforms.

Another domain where India shows substantial scientific capabilities is Mobile Networks. Research groups across the country investigate wireless communication protocols, network optimisation, spectrum management, and next-generation telecommunications infrastructures. The presence of these research capabilities reflects the growing importance of digital connectivity in India’s economic development strategy.

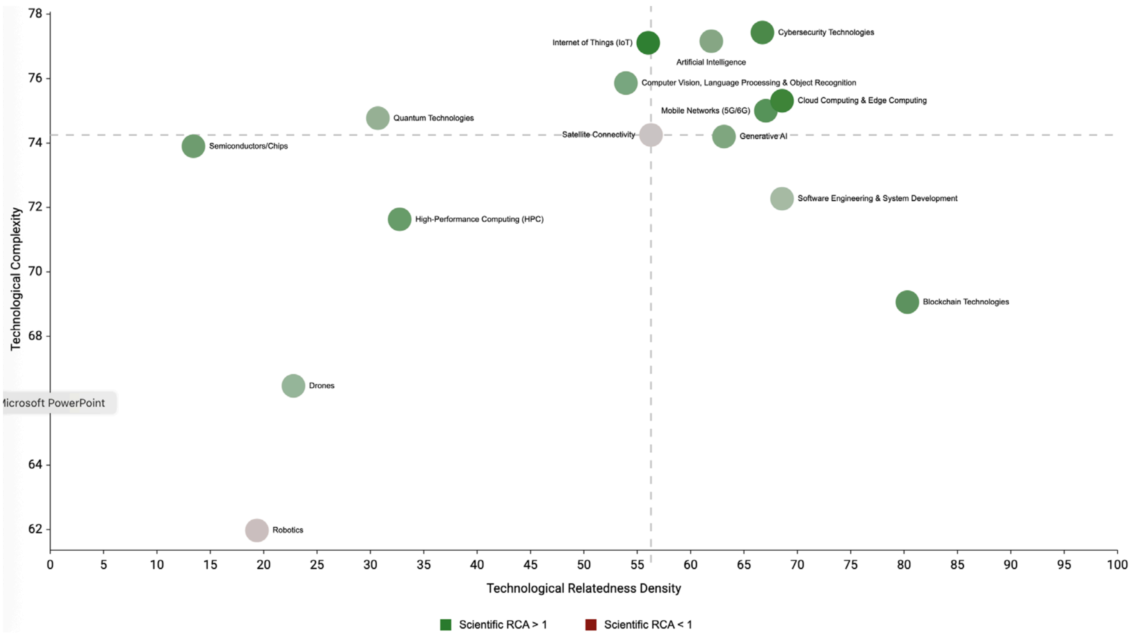
In the fields of Internet of Things and Satellite Connectivity, India also demonstrates notable research strengths. Scientific work in IoT focuses on sensor networks, smart city applications, industrial monitoring systems, and connected-device architectures. Meanwhile, research in satellite connectivity benefits from the country’s long-standing space capabilities and the activities of the Indian Space Research Organisation, which has contributed significantly to satellite communication technologies and space-based digital infrastructure.

India’s long-standing strength in Software Engineering and Systems Development is also reflected in the strong scientific RCA values observed in these domains. Indian universities and research centres publish extensively on software architectures, distributed systems, software reliability, and large-scale digital platforms. These research activities underpin the country’s global role as a major provider of software development and digital services.

Finally, research activity in Blockchain further illustrates the diversification of India's scientific capabilities. Academic institutions investigate topics such as decentralised systems, secure digital transactions, and blockchain-based applications for supply chains, financial systems, and public administration.

Taken together, the results suggest that India possesses a broad and well-developed scientific base across most key strategic technologies. The presence of a scientific RCA above 1 in many domains indicates that the country's research community is highly active and internationally competitive. This strong scientific foundation provides favourable conditions for technological diversification and suggests that India is well positioned to translate scientific knowledge into technological capabilities and industrial innovation in the coming years.

Figure 57 – Scientific opportunities in India



Source: https://www.paballand.com/ceps/ttd/smart/openalex/india-in.html

Finally, Figure 58 presents the same technological opportunity landscape using a colour scheme based on the investment revealed comparative advantage (investment RCA). This indicator reflects the relative intensity of venture capital investment across KSTs, comparing the share of investment attracted by India in a given domain with the corresponding global share. Unlike the analyses based on patents or scientific publications, the results here appear less encouraging. This outcome largely reflects the still-limited development of venture capital markets in India compared with other major global innovation hubs such as the United States, China, and the European Union.

Although India has developed a dynamic start-up ecosystem in recent years, venture capital investment remains relatively concentrated in sectors such as e-commerce, digital platforms, and financial technologies rather than in deep-tech domains. As a result, many of the key strategic technologies identified in the previous analyses – where India shows strong technological and scientific potential – still display relatively low investment intensity. This gap highlights an important structural feature of India's innovation system: a strong base in human capital and scientific research that has not yet been fully matched by equivalent levels of venture capital financing in advanced technology sectors.

In the domain of Artificial Intelligence and Generative AI, venture capital investment has begun to increase in recent years, reflecting the growing importance of AI applications across industries such as finance, healthcare, and digital services. Indian start-ups are developing machine learning platforms, data analytics tools, and AI-enabled business solutions. However, the scale of investment in these areas remains significantly smaller than that observed in major global innovation ecosystems, particularly in the United States, where venture capital funding for AI start-ups dominates the global landscape.

A similar pattern can be observed in Cybersecurity and Cloud Computing. While India hosts a growing number of start-ups developing cybersecurity tools, digital identity solutions, and cloud-based software platforms, the volume of venture capital investment in these areas remains modest compared with global leaders. The development of these sectors is often closely linked to India's large IT services industry, where innovation tends to occur within established firms rather than through heavily venture-backed start-ups.

In the case of Mobile Networks, venture capital investment is also relatively limited. Telecommunications infrastructure development in India is typically driven by large telecom operators and public-sector initiatives rather than by venture-backed start-ups. As a result, despite strong research activity in wireless communications and network technologies, the start-up ecosystem in this field remains relatively small.

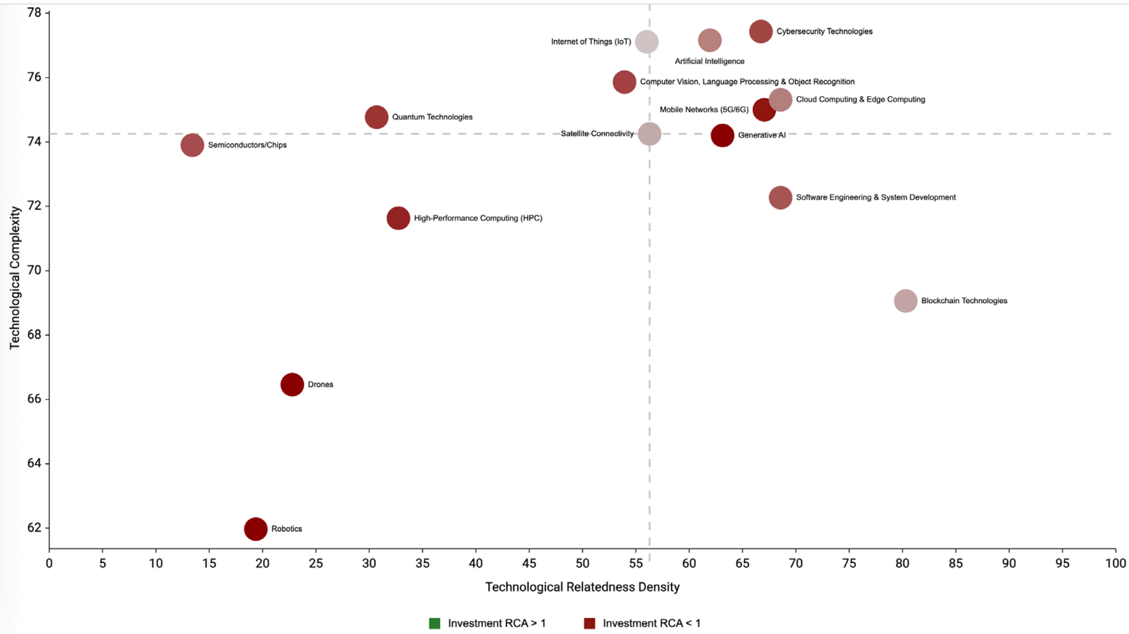
Investment activity in Internet of Things technologies is somewhat more visible, particularly in applications related to smart manufacturing, logistics, and urban infrastructure. Several start-ups are developing sensor networks, industrial monitoring systems, and connected-device platforms. Nevertheless, venture capital-investment levels remain modest compared with leading global ecosystems where IoT start-ups attract significantly larger funding rounds.

In Satellite Connectivity, venture capital investment has historically been limited but is gradually increasing as India's space sector opens to private participation. The presence of the Indian Space Research Organisation has historically shaped the development of satellite technologies through public investment. More recently, a growing number of private space start-ups have begun to emerge, attracting venture capital funding for satellite communication systems and space-based digital services.

India's strongest investment dynamics continue to appear in domains closely connected to its traditional strengths in Software Engineering and Systems Development. The country's large digital services industry and extensive pool of software developers support a vibrant start-up ecosystem focused on enterprise software, digital platforms, and software-as-a-service solutions. Venture capital investment in these areas is therefore relatively more developed compared with other deep-tech sectors.

Finally, emerging areas such as Blockchain have begun to attract increasing attention from venture capital investors, particularly in applications related to financial technologies, digital identity, and decentralised platforms. However, the overall scale of investment remains relatively modest in comparison with global innovation hubs.

Figure 58 – Funding opportunities in India



Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/india-in.html

3.4. Japan

Figure 59 examines the technological opportunity landscape of Japan, highlighting the areas where the country's existing technological capabilities align with promising opportunities for further development and investment. The analysis combines measures of technological complexity, relatedness density, and technological revealed comparative advantage (tech RCA) in order to identify domains where diversification would involve relatively low risk while offering potentially significant technological and economic returns.

In Japan's case, the optimal investment quadrant – which captures technologies characterised by high complexity, strong relatedness to existing capabilities, and positive technological specialisation – appears relatively limited compared with some other innovation systems. The technologies that clearly stand out in this favourable area include the Internet of Things and Quantum Technology. Both fields are closely connected to Japan's established strengths in electronics, advanced manufacturing, and precision engineering. The country's strong capabilities in sensor technologies, embedded systems, and semiconductor components provide a solid technological base for further development in IoT applications, particularly in areas such as smart manufacturing, industrial automation, and connected infrastructure.

Quantum technologies also appear as a promising investment domain. Japan has developed important capabilities in areas such as quantum materials, photonics, and advanced computing systems through collaborations between universities, research institutes, and major technology companies. The presence of these capabilities suggests that additional investment could allow Japan to strengthen its position in emerging quantum computing and quantum communication technologies.

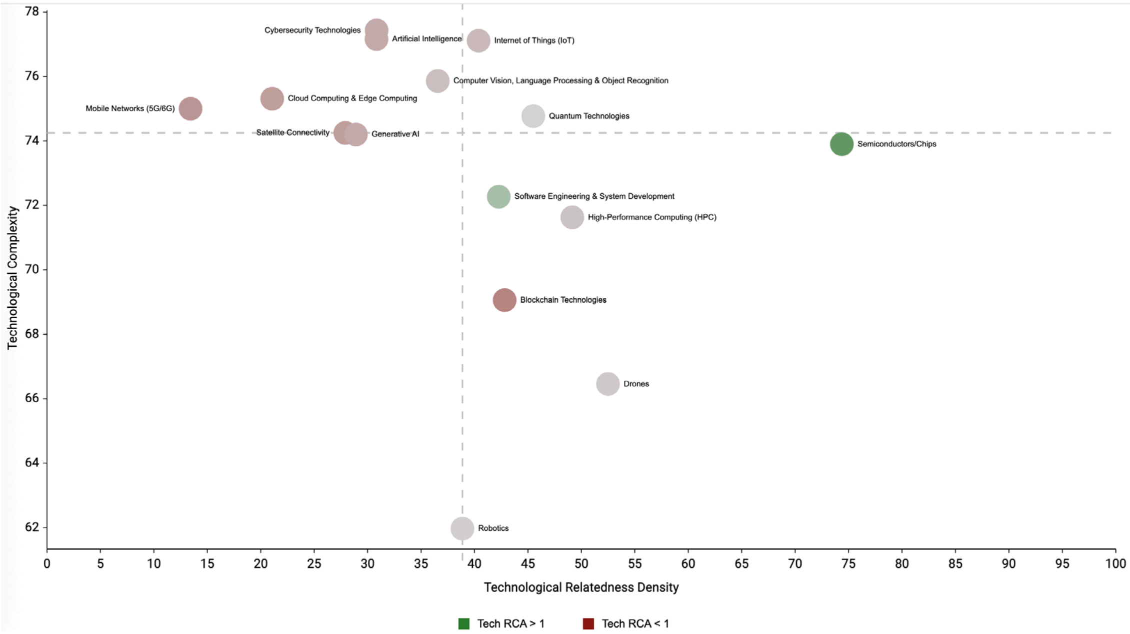
To some extent, Semiconductors and microchips may also fall within this favourable zone. Japan remains one of the world's leading producers of semiconductor manufacturing equipment, materials, and specialised electronic components. These capabilities continue to play a crucial role in the global semiconductor value chain and provide a strong technological foundation for further innovation in advanced chip technologies.

At the same time, many other key strategic technologies appear in what can be described as the 'moonshot' quadrant, characterised by high technological complexity but lower relatedness to Japan's existing technological portfolio. These technologies represent potentially high-impact opportunities but also involve greater diversification risks. Among them are Artificial Intelligence, Generative AI, Computer Vision, Natural Language Processing, and object recognition technologies. These fields are currently experiencing rapid global growth and are central to the development of next-generation digital systems, yet Japan's patent specialisation in these areas remains comparatively weaker than that of other leading innovation systems such as the United States and China.

Similarly, Cybersecurity and Mobile Networks also appear within the moonshot category. These domains are technologically complex and strategically important for digital infrastructure and national security. However, Japan's current technological portfolio appears less strongly connected to these sectors compared with other countries that have invested heavily in digital platforms and telecommunications technologies.

Overall, the analysis suggests that Japan's most promising opportunities for relatively low-risk technological investment remain closely linked to its traditional industrial strengths, particularly in electronics, semiconductor technologies, and advanced engineering systems. At the same time, the presence of several digital technologies in the moonshot quadrant highlights areas where Japan could pursue more ambitious long-term strategies in order to strengthen its position in the evolving landscape of artificial intelligence and digital infrastructure technologies.

Figure 59 – Technological opportunities for Japan



Source: https://www.paballand.com/ceps/ttd/smart/regpat/japan-jp.html

Figure 60 presents the same analysis for Japan using the scientific RCA as the reference indicator. This perspective highlights the structure of Japan's research strengths across KSTs and allows the identification of areas where scientific excellence could support future technological development. By combining scientific specialisation with measures of technological complexity and relatedness density, the analysis helps distinguish between fields where Japan's research capabilities may generate significant technological opportunities and those where further investments may yield more incremental benefits.

The results appear particularly encouraging in the domains of Semiconductors and Advanced chip technologies. Japan has long maintained a strong scientific and technological tradition in semiconductor materials, microelectronics engineering, and manufacturing processes. Universities and research institutions collaborate closely with major industrial actors to advance knowledge in areas such as semiconductor fabrication, lithography technologies, and new chip architectures. The presence of a scientific RCA above 1 in this domain indicates that Japan continues to produce a disproportionately large share of scientific publications related to semiconductor technologies. Given the strategic importance of semiconductors for computing, artificial intelligence, and digital infrastructure, this scientific strength provides a solid foundation for continued technological leadership.

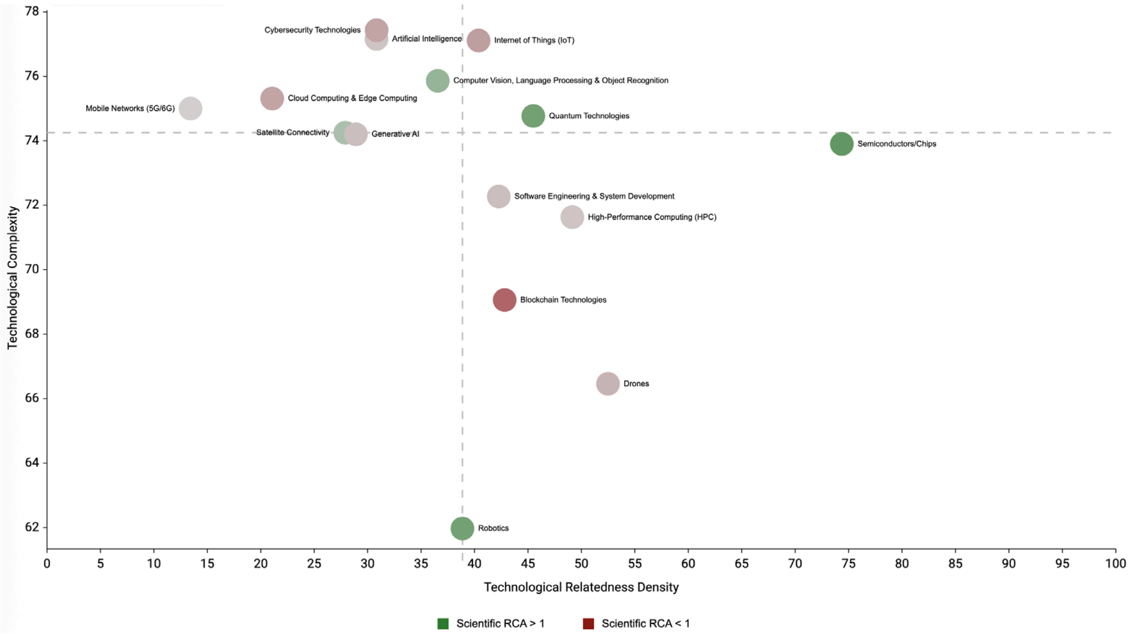
Another domain where Japan's scientific capabilities appear particularly strong is Quantum Technology. Research in quantum materials, photonics, and quantum information science has been an important component of Japan's scientific landscape for many years. Strong research groups in universities and national laboratories contribute to advances in quantum computing architectures, quantum sensing technologies, and secure quantum communication systems. The combination of scientific specialisation and relatively high technological complexity makes quantum technologies a promising area for future investment and technological development.

The analysis also highlights encouraging signals in fields related to Computer Vision, Natural Language Processing, and Object Recognition. Although Japan's technological specialisation in artificial intelligence-related patents may not match that of the United States or China, the country nevertheless demonstrates important scientific capabilities in these domains. Research in machine perception, pattern recognition, and intelligent systems benefits from Japan's strong traditions in robotics, electronics, and computational engineering.

Japan's scientific excellence in Robotics is particularly well established and widely recognised. Japanese universities, research institutes, and industrial laboratories have played a central role in advancing robotic systems, autonomous machines, and intelligent control systems for decades. However, the analysis also suggests that part of the robotics technology domain displays relatively low levels of technological complexity, meaning that the knowledge required to develop these technologies is relatively more accessible and easier for other countries to replicate. In technological diversification terms, this implies that further investments in robotics may generate incremental improvements rather than transformative breakthroughs.

As a result, robotics appears primarily within the category of incremental investment opportunities, characterised by relatively low diversification risk but also more limited potential returns in terms of technological differentiation. Continued investment in this field may still be important for maintaining Japan's industrial competitiveness and reinforcing its leadership in advanced manufacturing and automation. However, the potential for major new technological advantages may be smaller than in more complex and emerging domains such as quantum technologies or advanced semiconductor systems.

Figure 60 – Scientific opportunities in Japan



Source: https://www.paballand.com/ceps/ttd/smart/openalex/japan-jp.html

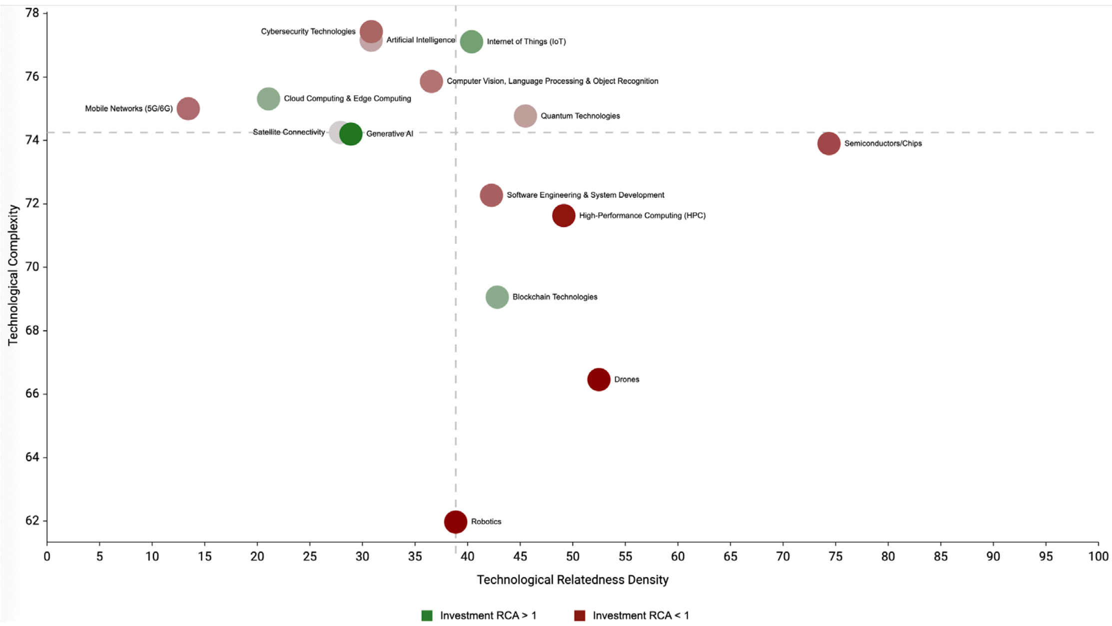
Finally, in Figure 61 we present the results using a colour scheme based on the investment revealed comparative advantage (investment RCA), highlighting the relative strength of venture capital investment across KSTs for Japan. This indicator captures whether Japan attracts a disproportionate share of venture capital investment in specific technological domains compared with the global average. By focusing on the financing dimension of innovation, the analysis complements the previous perspectives based on patents and scientific publications and sheds light on the capacity of Japan's start-up ecosystem to support the commercialisation of emerging technologies.

The results show that Japan displays a particularly strong investment RCA in the Internet of Things. This reflects the country's well-established industrial base in electronics, sensors, robotics, and advanced manufacturing systems, all of which provide fertile ground for IoT-related innovation. Venture capital investment in this domain often targets applications in industrial automation, smart infrastructure, connected mobility, and manufacturing optimisation. Japan's strong integration between industrial firms, technology companies, and research institutions helps support the development of IoT solutions that enhance productivity and enable the digital transformation of manufacturing processes.

Interestingly, the analysis also highlights relatively high investment RCA values in certain moonshot technologies, particularly Generative AI and Cloud Computing. These technologies are characterised by high technological complexity and rapid global growth, yet Japan's existing technological specialisation in them remains more limited compared with leading innovation systems such as the United States or China. The presence of relatively strong venture capital investment in these areas suggests that Japanese investors and start-ups are beginning to position themselves in these rapidly evolving sectors, even though the technological capabilities required to compete globally are still developing. Investments in these moonshot areas may therefore reflect a strategic effort to build capabilities in digital technologies that are becoming central to the global digital economy.

In the category of incremental investment opportunities, Blockchain stands out with a relatively high investment RCA. Blockchain technologies are closely related to Japan's existing strengths in digital services, financial technologies, and secure digital infrastructures. Venture capital investment in this domain often focuses on applications such as digital payments, decentralised platforms, and secure transaction systems. Because blockchain technologies are strongly related to existing digital capabilities, further investments in this field are likely to involve relatively low diversification risk while reinforcing Japan's broader digital ecosystem.

Figure 61 – Funding opportunities in Japan



Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/japan-jp.html

3.5. SOUTH KOREA

Figure 62 examines the technological opportunity landscape of South Korea by combining technological complexity, relatedness density, and technological revealed comparative advantage (tech RCA). This approach identifies domains where the country's existing technological capabilities align closely with emerging opportunities for diversification and investment. In this case, the results reveal a particularly favourable configuration, with many KSTs appearing within the optimal investment quadrant. These technologies combine high complexity with strong relatedness to South Korea's existing technological portfolio and display a tech RCA above 1, indicating that the country already holds a degree of technological specialisation in these domains.

Among the technologies that stand out most clearly are the Internet of Things and Mobile Networks. South Korea's strong position in these sectors reflects its globally competitive telecommunications industry and advanced electronics manufacturing capabilities. Large technology companies and telecommunications providers have played a key role in developing next-generation communication infrastructures, smart device ecosystems, and connected digital platforms. These capabilities create a favourable technological environment for further expansion in IoT applications, including smart cities, industrial automation, and connected mobility systems.

The analysis also points to promising opportunities in several other strategic digital technologies. Satellite Connectivity appears as a domain with positive prospects, benefiting from South Korea's growing capabilities in aerospace engineering, telecommunications infrastructure, and advanced electronics. Similarly, Generative AI and broader Artificial Intelligence applications represent areas where the country's strong digital infrastructure and semiconductor industry could support further technological development.

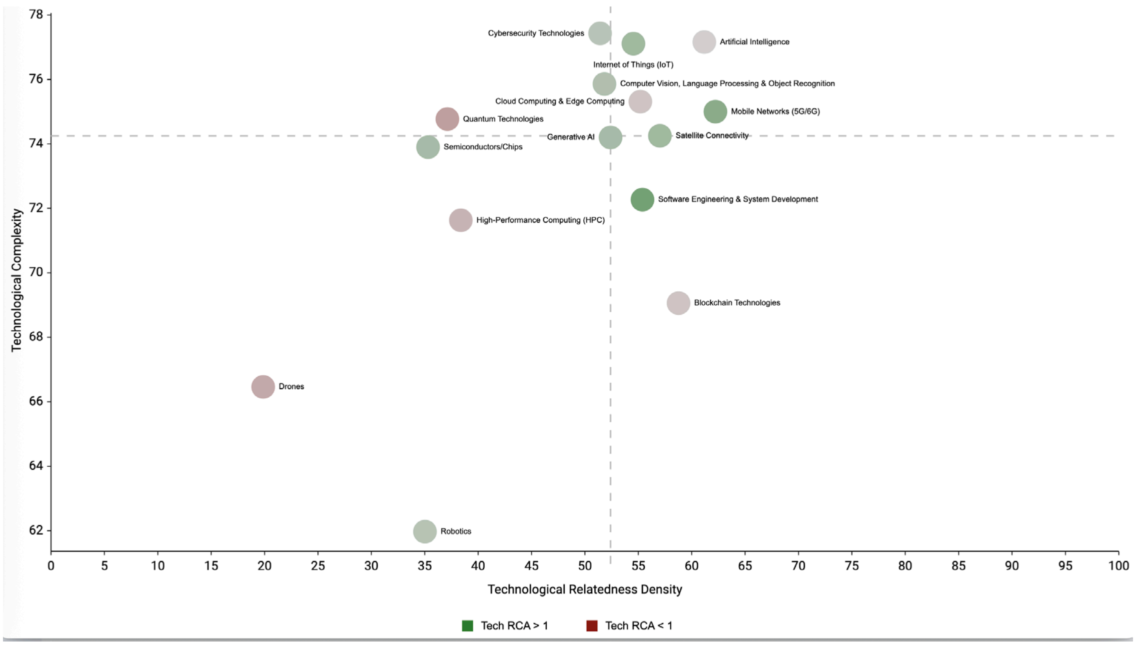
Additional promising domains include Cybersecurity, Cloud Computing, and AI-related technologies such as Computer Vision, Natural Language Processing, and object recognition. These technologies are strongly connected to South Korea's existing strengths in semiconductors, consumer electronics, and digital services. The presence of these domains within the optimal investment area suggests that South Korea is well positioned to leverage its technological base to expand into advanced digital platforms and intelligent computing systems.

Beyond these high-potential technologies, the analysis also highlights several areas suitable for incremental investment, where diversification risks are relatively low but potential returns may be more moderate. In particular, Software Engineering and Systems Development appear as domains where South Korea already possesses strong technological capabilities. Continued investment in these areas could strengthen the country's broader digital ecosystem and support innovation in related technologies such as cloud computing, artificial intelligence, and digital platforms.

Similarly, Blockchain appears as a domain where incremental investment may be particularly promising. Blockchain technologies are closely linked to digital financial systems, secure transaction infrastructures, and decentralised digital platforms – areas where South Korea's advanced digital economy and strong fintech sector provide a supportive environment for innovation.

Overall, the analysis suggests that South Korea possesses a particularly favourable technological landscape across a wide range of key strategic technologies. The presence of many KSTs within the optimal investment quadrant reflects the country's strong technological capabilities in digital infrastructure, electronics, and advanced manufacturing. By building on these strengths, South Korea appears well positioned to further expand its technological leadership in several critical domains of the global digital economy.

Figure 62 – Technological opportunities for South Korea



Source: https://www.paballand.com/ceps/ttd/smart/regpat/south-korea-kr.html

Figure 63 presents the same technological opportunity landscape for South Korea, this time highlighting the scientific RCA. This indicator measures whether a country produces a disproportionately large share of scientific publications in a given technological field relative to the global average. By combining this measure with indicators of technological complexity and relatedness density, the analysis identifies areas where strong scientific capabilities may support future technological development and diversification.

The results show a particularly favourable picture for South Korea. All the KSTs located in the optimal investment quadrant display a scientific RCA above 1, indicating that the country's research community is highly active and internationally competitive across these domains. This alignment between scientific specialisation and technological opportunity suggests that South Korea possesses a strong knowledge base capable of supporting further innovation and industrial development in several advanced digital technologies.

In particular, research activity related to the Internet of Things and Mobile Networks appears especially strong. South Korean universities and research institutes contribute extensively to work on wireless communication systems, sensor networks, and connected-device architectures. These research efforts are closely linked to the country's advanced telecommunications infrastructure and strong electronics sector, which together provide a fertile environment for translating scientific advances into technological applications.

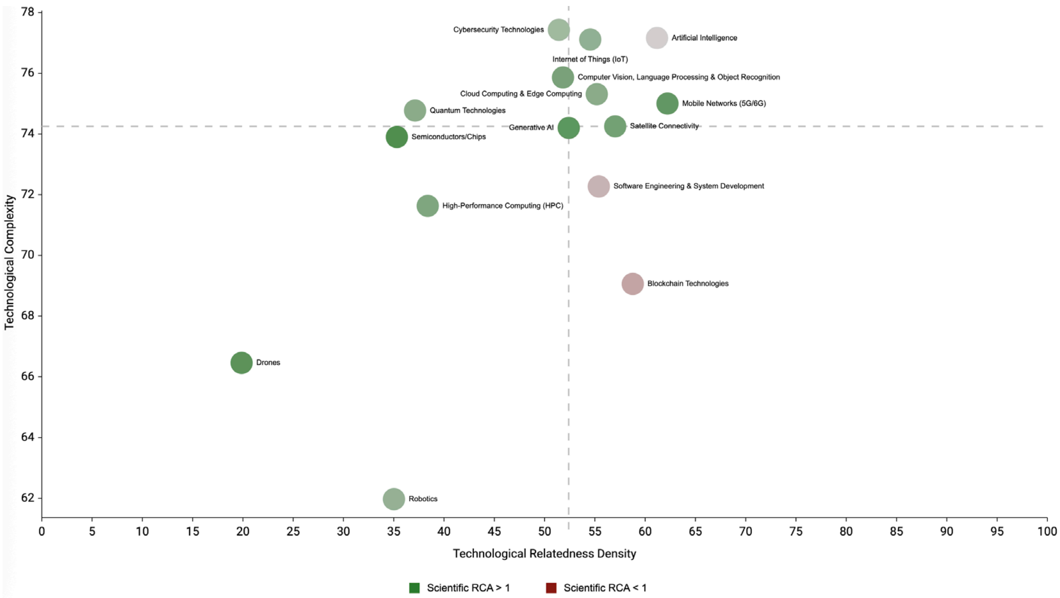
Similarly, the analysis highlights strong scientific capabilities in several fields related to artificial intelligence, including Generative AI, Computer Vision, Natural Language Processing, and object recognition. Research in these areas benefits from South Korea's broader strengths in computer science, data processing, and semiconductor technologies. The country's universities and research laboratories publish widely on machine learning algorithms, pattern recognition systems, and AI applications across fields such as robotics, healthcare technologies, and smart devices.

South Korea also demonstrates significant research activity in Cybersecurity and Cloud Computing, two domains that are becoming increasingly critical to the development of secure and scalable digital infrastructures. Scientific work in these areas focuses on topics such as secure network architectures, data protection systems, distributed computing frameworks, and large-scale cloud infrastructures.

The analysis further indicates promising scientific capabilities in Satellite Connectivity, reflecting South Korea's growing interest in space technologies and advanced communication systems. Research institutions are increasingly contributing to developments in satellite communications, space-based networks, and integrated terrestrial–satellite communication infrastructures.

Overall, the scientific RCA analysis confirms the strong research foundations underlying South Korea's technological ecosystem. The presence of a scientific RCA above 1 across many key strategic technologies suggests that the country's universities and research institutions are well positioned to support further technological diversification and innovation. Combined with its strong industrial base in electronics, telecommunications, and semiconductor technologies, this robust scientific landscape provides favourable conditions for South Korea to continue strengthening its role in the global digital technology ecosystem.

Figure 63 – Scientific opportunities in South Korea



Source: https://www.paballand.com/ceps/ttd/smart/openalex/south-korea-kr.html

Finally, Figure 64 presents the technological opportunity landscape for South Korea using a colour scheme based on the investment revealed comparative advantage (investment RCA). This indicator measures whether the country attracts a disproportionately large share of venture capital investment in specific technological domains relative to the global average. By introducing the investment dimension, the analysis complements the previous perspectives based on technological patents and scientific publications, allowing an assessment of whether South Korea's technological capabilities are also supported by an active venture capital ecosystem.

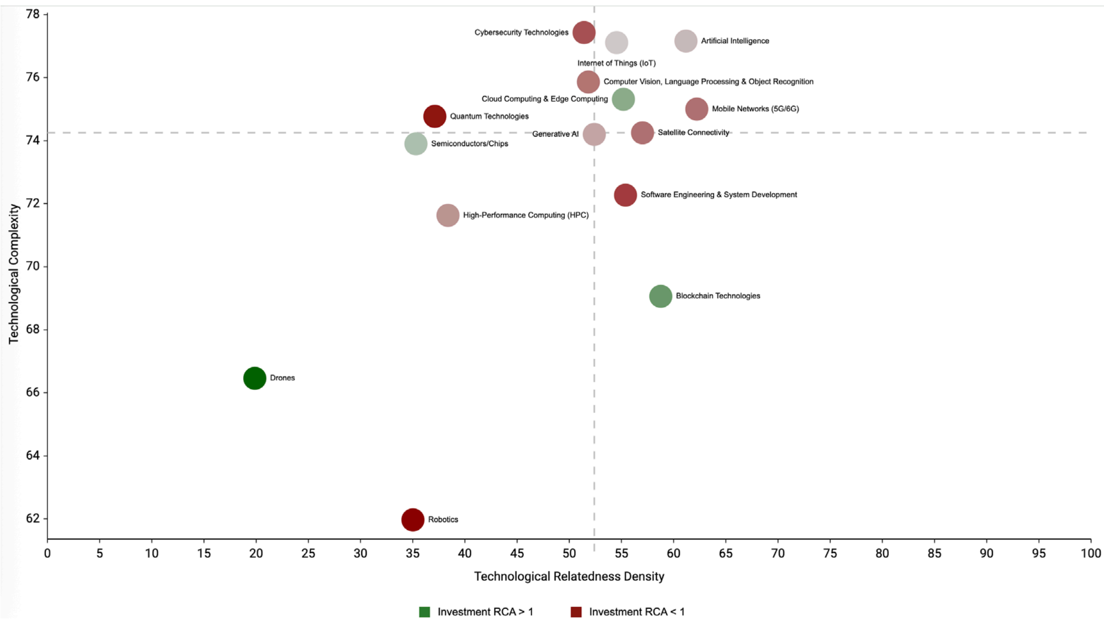
The results show that some of the KSTs located in the optimal investment quadrant – where complexity and relatedness density are both high – also display an investment RCA above 1. This alignment suggests that South Korea's technological capabilities in these domains are increasingly supported by financial resources capable of scaling innovation through start-up activity and entrepreneurial ventures. A particularly notable example is Cloud Computing, where South Korea shows a relatively strong investment RCA. Venture capital investment in this area reflects the country's growing digital platform ecosystem, advanced telecommunications infrastructure, and strong demand for scalable computing services. Start-ups in this sector often focus on data infrastructure, distributed computing architectures, and edge computing systems designed to support applications in artificial intelligence, connected devices, and smart services.

The presence of a strong investment RCA in cloud and edge computing is also closely linked to South Korea's broader technological ecosystem, which includes world-leading semiconductor manufacturers, advanced telecommunications networks, and a highly digitised economy. These structural advantages create favourable conditions for the development of cloud-based services and digital platforms, which in turn attract venture capital investment.

In addition to these high-potential domains, the analysis highlights opportunities for incremental investment in technologies that are closely related to South Korea's existing digital capabilities. In particular, Blockchain emerges as a domain with an investment RCA above 1. Blockchain technologies are closely connected to digital financial services, secure digital transactions, and decentralised digital infrastructures – areas where South Korea's advanced fintech sector and highly connected digital economy provide a supportive environment for innovation.

Investments in blockchain start-ups often focus on applications such as digital payments, decentralised platforms, supply chain traceability, and secure identity systems. Because these technologies are strongly related to existing software and digital platform capabilities, further investments in blockchain are likely to involve relatively low diversification risk while reinforcing South Korea's broader digital innovation ecosystem.

Figure 64 – Funding opportunities in South Korea



Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/south-korea-kr.html

3.6. THE UNITED KINGDOM

Figure 65 presents the smart investment landscape for the United Kingdom, using a colour scheme based on technological revealed comparative advantage (tech RCA). By combining technological complexity, relatedness density, and technological specialisation, the analysis highlights areas where the United Kingdom could potentially expand its technological capabilities while managing diversification risks.

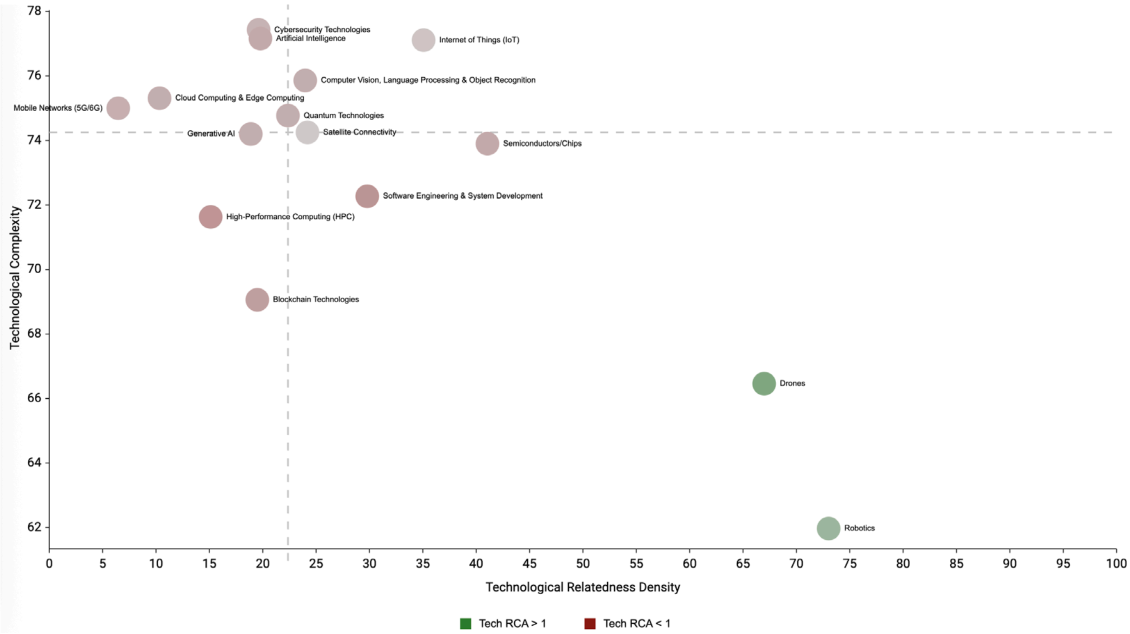
The results suggest that relatively few KSTs clearly fall within the optimal investment quadrant, where both complexity and relatedness density are high. Moreover, the technologies that do appear in this favourable zone are associated with tech RCA values below 1, indicating that the United Kingdom currently lacks a strong technological specialisation in these fields. Among the technologies located in this quadrant are the Internet of Things and artificial intelligence-related technologies such as Computer Vision, Natural Language Processing, and object recognition. These domains appear technologically close to the United Kingdom's existing innovation capabilities, suggesting that diversification into these areas could be achievable with relatively moderate risk, despite the current absence of strong patent specialisation.

Two additional technologies – quantum technology and Satellite Connectivity – appear as more borderline cases within the optimal investment area. Both technologies combine high levels of technological complexity with a degree of relatedness to the United Kingdom's existing technological base, particularly in advanced physics research, telecommunications systems, and space-related technologies. While the country's technological specialisation in these fields remains relatively limited in terms of patents, the strong scientific research base present in British universities and research institutes may support further development in these strategic domains.

Several other KSTs appear instead in the moonshot quadrant, characterised by high complexity but lower relatedness to the existing technological portfolio. These technologies include Cybersecurity, Artificial Intelligence and Generative AI, Cloud Computing, as well as Mobile Networks. These fields represent some of the most strategically important and technologically sophisticated domains of the digital economy. However, their position in the moonshot quadrant suggests that diversification into these technologies would involve higher levels of risk and would likely require substantial long-term investment, new industrial capabilities, and stronger links between research institutions and the private sector.

At the same time, the analysis highlights opportunities for incremental investment in technologies where the United Kingdom already demonstrates a degree of technological specialisation, as reflected by tech RCA values above 1. In particular, Drone Technology and Robotics emerge as domains where the United Kingdom holds existing technological strengths. Continued investment in these sectors may reinforce the country's competitive advantages in aerospace engineering, autonomous systems, and advanced manufacturing technologies.

Figure 65 – Technological opportunities for the United Kingdom



Source: https://www.paballand.com/ceps/ttd/smart/regpat/united-kingdom-uk.html

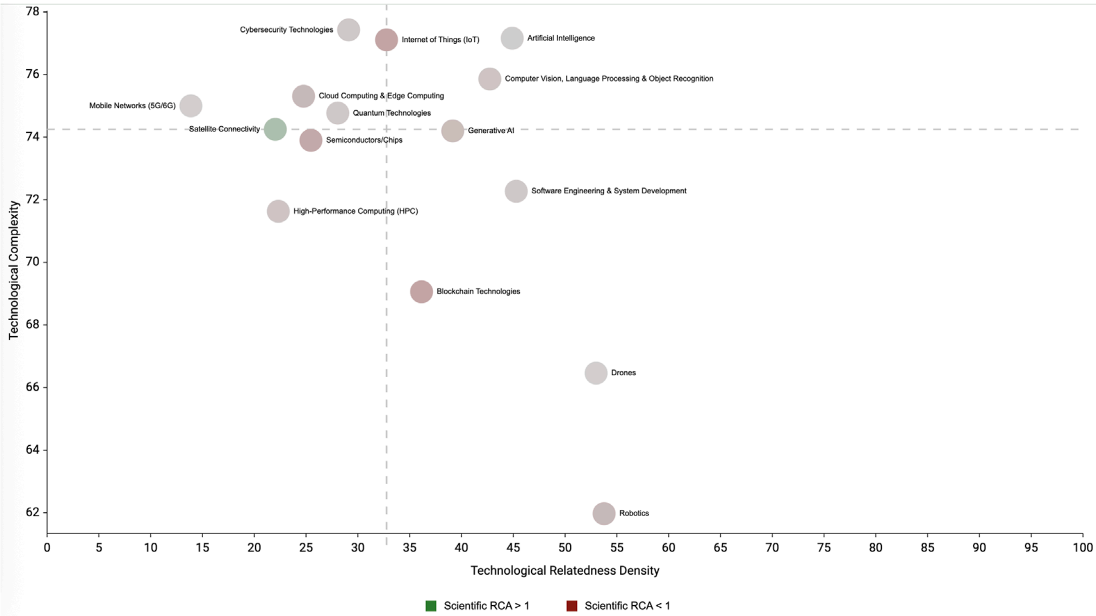
Figure 66 presents the results highlighting the scientific RCA, which appears to be above 1 only for satellite connectivity. All other areas have a scientific RCA below 1. The results suggest a relatively limited degree of scientific specialisation across the KSTs considered. In fact, the scientific RCA appears to be above 1 only for Satellite Connectivity, indicating that the United Kingdom produces a higher share of scientific publications in this field than would be expected based on global publication patterns. This finding reflects the country's long-standing research strengths in aerospace engineering, satellite communications, and space-related technologies. British universities and research centres have historically played an important role in the development of small satellite technologies, space communication systems, and orbital infrastructure. These scientific capabilities provide a strong knowledge base that could support further technological development and industrial activity in satellite connectivity.

In contrast, all other key strategic technologies examined in the analysis display scientific RCA values below 1, suggesting that the United Kingdom's research output in these fields is proportionally smaller than the global average. This pattern is somewhat notable given the strong international reputation of British universities in fields such as Artificial

Intelligence, Cloud Computing, and Cybersecurity. The results do not necessarily imply a lack of research activity in these areas, but rather indicate that the scale of scientific production relative to global output remains more limited compared with other major research systems such as the United States, China, or the European Union.

Similarly, fields such as Computer Vision, Natural Language Processing, and object recognition – which are closely related to advances in artificial intelligence – also display scientific RCA values below 1. While British research institutions remain active contributors to these domains, the country's relative share of global scientific output in these fields appears smaller than that of leading innovation systems.

Figure 66 – Scientific opportunities in the United Kingdom



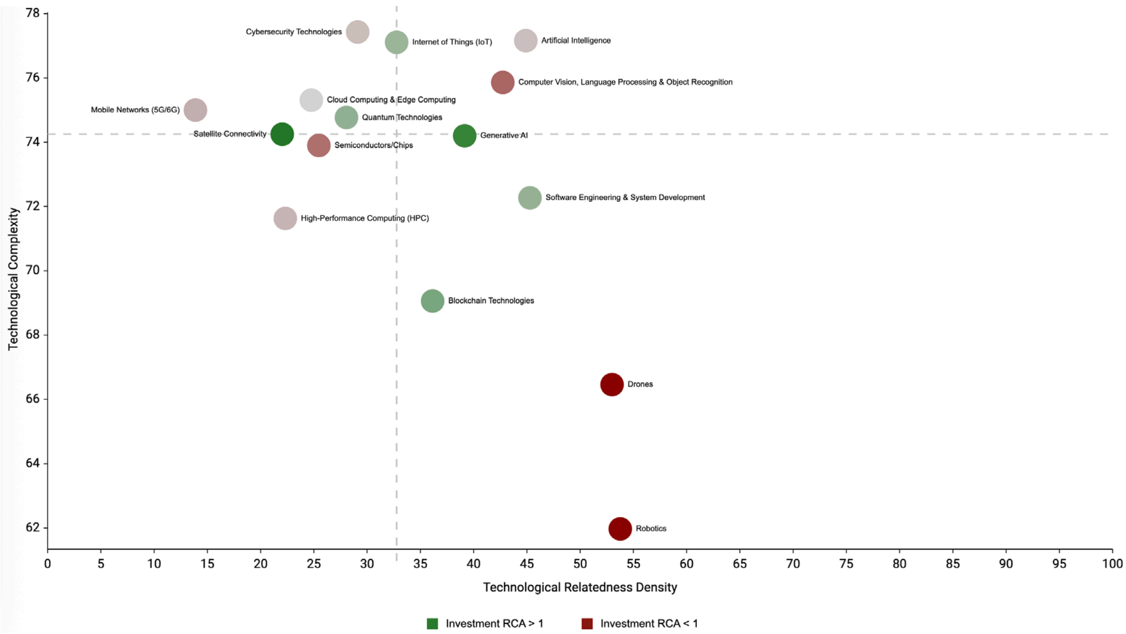
Source: https://www.paballand.com/ceps/ttd/smart/openalex/united-kingdom-uk.html

Finally, Figure 67 presents the smart investment landscape for the United Kingdom using a colour scheme based on the investment revealed comparative advantage (investment RCA). The results indicate that the investment RCA is generally below 1 for most of the selected KSTs, suggesting that the United Kingdom attracts a smaller share of venture capital investment in these advanced technological domains than the global average. This pattern highlights a structural feature of the British innovation system: while the country benefits from strong scientific research capabilities and an internationally competitive academic sector, these strengths do not always translate into a proportionally strong presence of venture-backed start-ups in deep-tech sectors. Venture capital investment in the United Kingdom often concentrates in areas such as financial technologies, digital platforms, and software services rather than in many of the highly complex technological domains considered in this analysis.

An important exception emerges in the field of Satellite Connectivity, where the United Kingdom displays an investment RCA above 1. This reflects the country's particularly dynamic ecosystem in space and satellite technologies, supported by specialised venture capital funds, strong research institutions, and a favourable regulatory environment for space start-ups. The presence of innovative companies developing satellite communication systems and space-based connectivity services has contributed to attracting significant investment in this domain. The United Kingdom's historical strengths in aerospace engineering and satellite technologies provide a solid technological base for further growth in this sector.

In contrast, other key strategic technologies – such as Artificial Intelligence, Generative AI, Cloud Computing, Cybersecurity, and Mobile Networks – display investment RCA values below 1. Although start-ups exist in all these areas, the overall scale of venture capital investment remains relatively smaller compared with leading global innovation ecosystems such as the United States or China.

Figure 67 – Funding opportunities in the United Kingdom



Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/united-kingdom-uk.html

3.7. THE UNITED STATES

In the case of the United States, as shown in Figure 68, the smart investment landscape reveals a particularly favourable technological configuration. Many KSTs appear on the right-hand side of the graph, indicating high levels of relatedness density with the country's existing technological capabilities. This pattern reflects the breadth and depth of the United States' technological portfolio, which allows the country to diversify into a wide range of advanced digital technologies with relatively limited structural barriers.

Several KSTs fall within the optimal investment quadrant, where both technological complexity and relatedness density are high. These domains combine strong growth potential with a close connection to existing technological capabilities, making them particularly attractive areas for strategic investment. Among them are Artificial Intelligence and Generative AI, which represent some of the most rapidly evolving technological domains in the digital economy. The United States benefits from a highly developed ecosystem of research institutions, technology companies, and venture-backed start-ups that actively drive innovation in these areas.

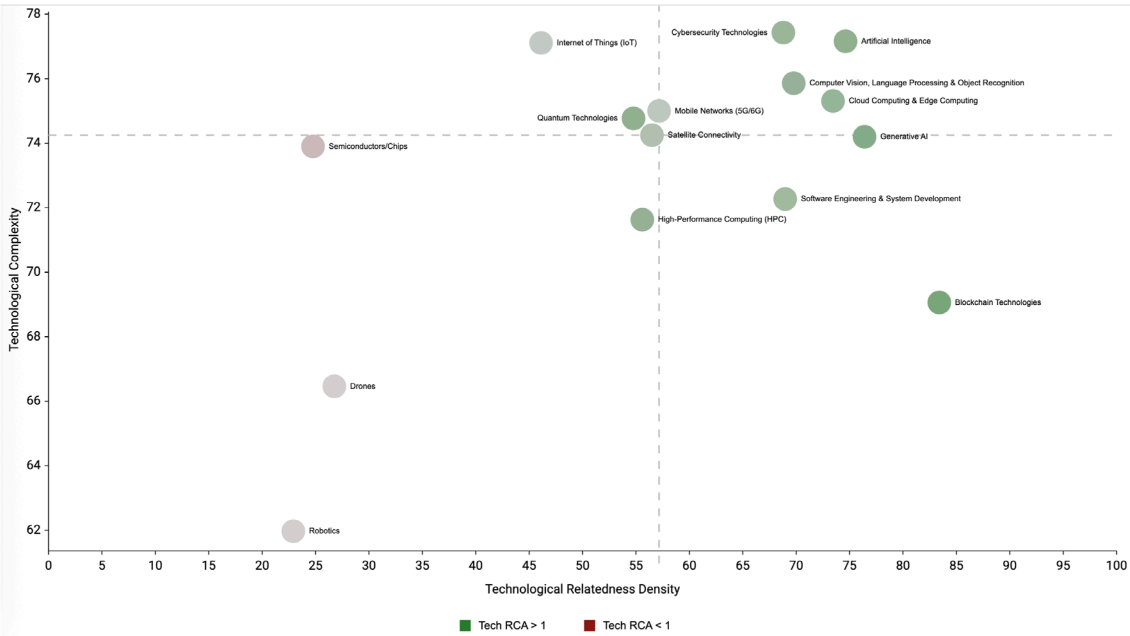
Similarly, technologies related to Computer Vision, Natural Language Processing, and object recognition also appear in this favourable quadrant. These fields are closely connected to broader developments in artificial intelligence and data-driven computing, and they benefit from the United States' strong capabilities in machine learning research, large-scale data infrastructures, and advanced computing systems.

Other technologies located in the optimal investment area include Cloud Computing, Cybersecurity, and Mobile Networks. These technologies form a core part of the digital infrastructure that supports modern information economies. The strong relatedness of these domains to the United States' existing technological capabilities reflects the country's leadership in software platforms, telecommunications technologies, and digital services.

A smaller number of technologies appear in the moonshot quadrant, characterised by high technological complexity but lower relatedness to the existing technological portfolio. In this analysis, Quantum Technology and the Internet of Things fall into this category. While the United States already possesses important research capabilities in these areas, their position in the moonshot quadrant suggests that further technological expansion may require the development of new capabilities or industrial structures. Investments in these domains therefore involve higher levels of risk but also the potential for significant long-term technological returns.

Finally, the analysis identifies several areas suitable for incremental investment, where the United States already demonstrates strong technological specialisation and where diversification risks are relatively low. In particular, Blockchain and Software Engineering and Systems Development appear in this category. These domains are closely connected to the United States' long-standing strengths in software development, digital platforms, and information technologies. Continued investment in these areas is likely to reinforce existing technological leadership while supporting incremental innovation across the broader digital ecosystem.

Figure 68 – Technological opportunities for the United States



Source: https://www.paballand.com/ceps/ttd/smart/regpat/united-states-us.html

Figure 69 presents the technological opportunity landscape for the United States from the perspective of scientific revealed comparative advantage (scientific RCA). This indicator measures whether a country produces a disproportionately large share of scientific publications in a given technological domain relative to the global average. By combining this measure with indicators of technological complexity and relatedness density, the analysis provides insight into the alignment between the country's research strengths and potential areas for technological diversification.

The results reveal a somewhat different pattern compared with the technological RCA analysis. In this case, High-Performance Computing emerges as the only KST displaying a scientific RCA above 1, indicating that the United States produces a higher share than expected of scientific publications in this field based on global publication patterns. This strong scientific specialisation reflects the country's long-standing leadership in advanced computing research, supported by major universities, national laboratories, and large technology companies. Research in high-performance computing focuses on areas such as parallel computing architectures, large-scale simulation systems, advanced processors, and the computational infrastructures required for artificial intelligence and data-intensive science.

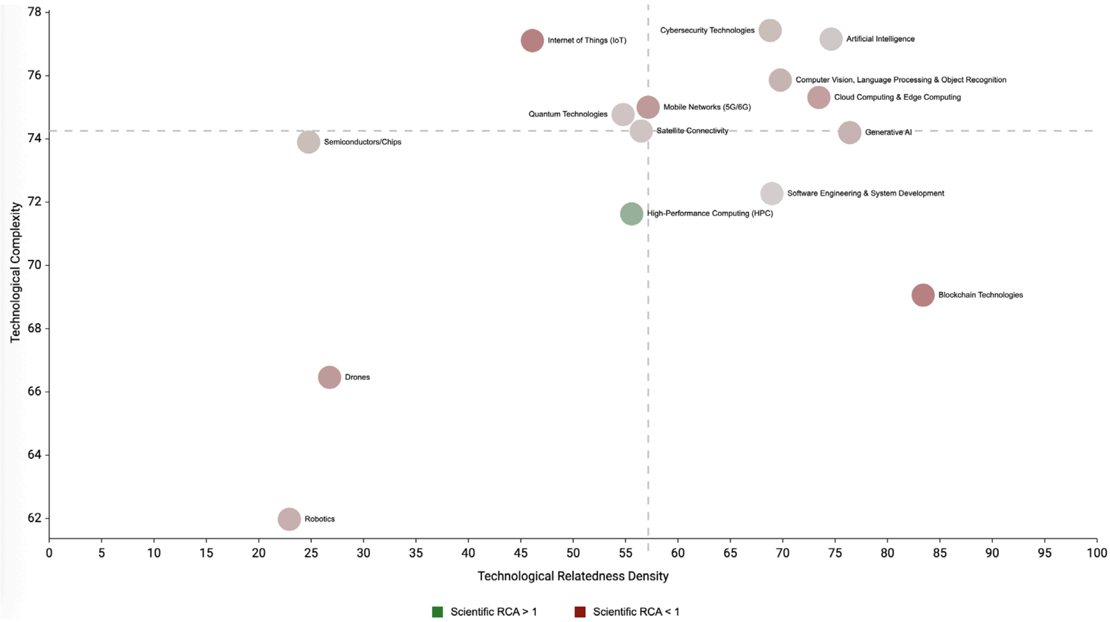
In contrast, all other KSTs examined in the analysis display scientific RCA values below 1, suggesting that the United States' share of global scientific publications in these fields is proportionally smaller than the global average. This result may appear somewhat surprising given the prominent role of American universities and research institutions in many frontier technological domains such as Artificial Intelligence, Cloud Computing, Cybersecurity, and Quantum Technology.

However, the interpretation of this result requires considering the structural characteristics of the United States' innovation system. A significant share of cutting-edge technological research in the United States takes place within corporate research laboratories and private sector organisations rather than within academic institutions that primarily produce peer-reviewed publications. Companies operating at the technological frontier often prioritise proprietary research and intellectual property generation over academic publication, leading to a comparatively smaller share of scientific output despite strong technological capabilities.

This structural feature is particularly visible in fields such as Generative AI, Computer Vision, and Natural Language Processing, where many important technological breakthroughs originate from private technology companies. As a result, the country's global influence in these fields is often reflected more strongly in patents, technological platforms, and venture-backed start-ups than in scientific publication counts.

Overall, the scientific RCA analysis highlights an important characteristic of the United States' innovation ecosystem: while the country may not always dominate the global scientific publication landscape across all technological domains, it retains strong technological leadership through a combination of academic research, corporate R&D, and entrepreneurial innovation. The strong scientific specialisation in high-performance computing further reinforces the central role of advanced computing infrastructures in supporting the broader development of frontier digital technologies.

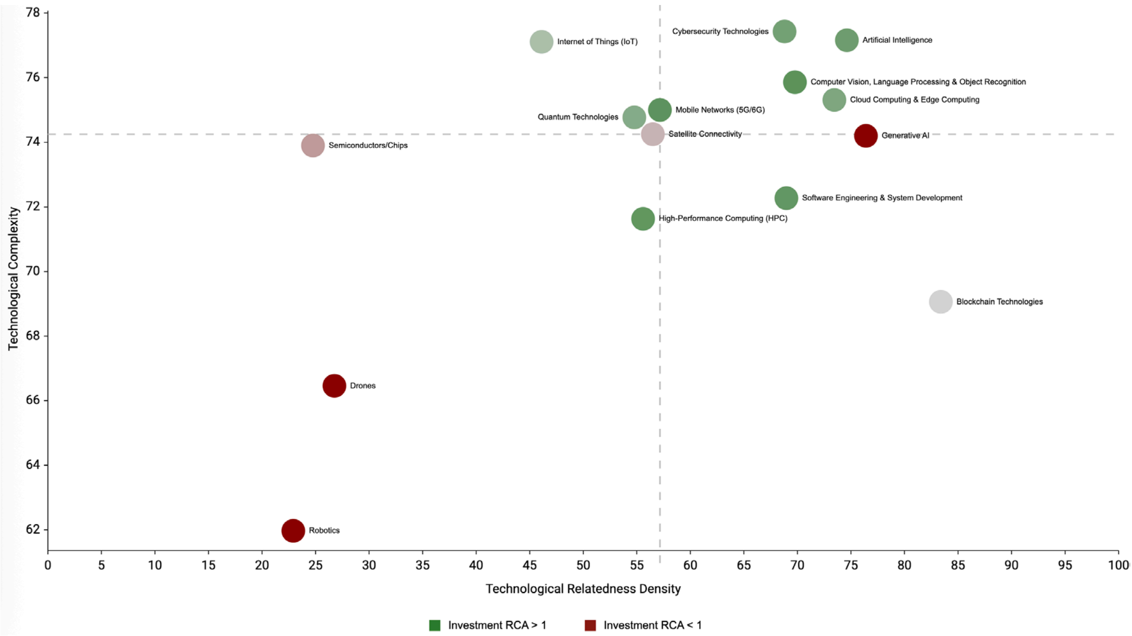
Figure 69 – Scientific opportunities in the United States



Source: https://www.paballand.com/ceps/ttd/smart/openalex/united-states-us.html

Finally, Figure 70 shows the smart investment graph based on VC investment data, highlighting an investment RCA above 1 for most of the KSTs.

Figure 70 – Funding opportunities in the United States



Source: https://www.paballand.com/ceps/ttd/smart/crunchbase/united-states-us.html

4. NETWORKS OF COLLABORATIONS IN THE 15 KSTS: THE CASE OF THE EUROPEAN UNION

Our data analysis also led us to map the current distribution of scientific, technological and investment collaboration between the selected countries. On the interactive website, users will be able to consult 210 network graphs, which show the existing level of collaboration featured by each select country in each of the 15 KSTs; and 630 organisational ecosystems graphs, which show the main players in each country, for each KST, in terms of patents, publications and VC investment in start-ups. Below, for ease of reading, we only show the technological and scientific collaborations for the European Union.

4.1. ARTIFICIAL INTELLIGENCE

Figure 71 illustrates the main international partners of the European Union in the field of Artificial Intelligence, based on patterns of co-patenting activity. Co-patenting provides an important indicator of international technological collaboration, as patents jointly filed by inventors located in different countries typically reflect shared research projects, cross-border corporate R&D activities, or collaboration between universities, research institutes, and firms. By examining the geographical distribution of these co-inventorship links, it is possible to identify the countries with which the European Union maintains the strongest technological partnerships in AI-related innovation.

The results show that the United States is by far the most important partner of the European Union in this domain, accounting for approximately 43.2 % of all co-patented AI inventions involving European inventors. This strong collaboration reflects the deep integration between European and American innovation ecosystems, particularly in advanced digital technologies. Transatlantic technological cooperation often takes place through multinational technology companies, joint research initiatives, and academic collaborations between leading universities and research laboratories. Many large technology firms operate research centres on both sides of the Atlantic, facilitating cross-border innovation activities in areas such as machine learning, data analytics, and intelligent software systems.

The United Kingdom emerges as the second most important partner, accounting for around 11.4 % of EU AI co-patents. Despite the institutional changes associated with Brexit, the United Kingdom remains closely connected to European research and innovation networks. British universities, research institutes, and technology companies continue to collaborate extensively with their counterparts in EU Member States, particularly in fields related to artificial intelligence, data science, and digital technologies.

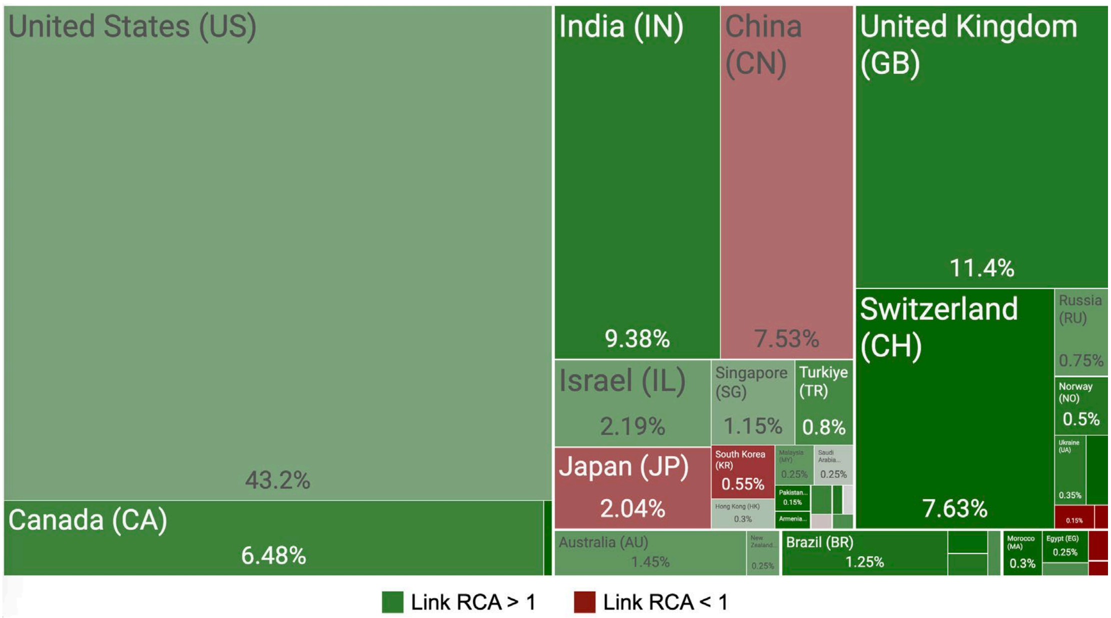
Another notable partner is India, which represents about 9.38 % of EU co-patenting activity in AI. This reflects the growing importance of India's technology sector and the increasing integration of Indian research institutions and technology companies into global innovation networks. India's large pool of engineers and computer scientists has made the country an important partner in software development, machine learning research, and AI applications across multiple industries.

Switzerland also appears as a significant partner, accounting for approximately 7.63 % of co-patents. Switzerland hosts several world-class universities and research institutions with strong expertise in artificial intelligence and data science. Collaboration between Swiss and European organisations is particularly strong in high-value research domains, including machine learning, robotics, and computational sciences.

Similarly, China accounts for about 7.53 % of EU AI co-patents, reflecting the increasing importance of technological cooperation between European and Chinese research institutions and technology companies. China has rapidly expanded its AI innovation ecosystem over the past decade, and collaborative patenting activities with European partners indicate growing technological linkages in this strategic field.

Finally, Canada accounts for approximately 6.48 % of EU co-patented AI inventions. Canada has developed a strong international reputation in artificial intelligence research, particularly in areas such as deep learning and machine learning. Research institutions and AI laboratories in Canada frequently collaborate with European partners, contributing to the development of advanced AI technologies and applications.

Figure 71 – EU network of tech collaborations in Artificial Intelligence, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/artificial-intelligence.html

Figure 72 illustrates the international network of scientific collaborations in Artificial Intelligence involving the European Union. Unlike the co-patenting landscape, which tends to concentrate collaboration among a smaller group of technological partners, the network of scientific cooperation appears significantly more distributed and globally interconnected. This reflects the open and collaborative nature of academic research, where knowledge exchange frequently takes place through co-authored publications, joint research projects, and international research consortia.

The United States remains the most important scientific partner of the European Union, accounting for approximately 20.4 % of AI-related co-publications. Transatlantic research collaboration has long been a defining feature of the global scientific system, particularly in advanced fields such as artificial intelligence, computer science, and data science. Universities, research laboratories, and technology institutes on both sides of the Atlantic regularly collaborate on cutting-edge topics including machine learning algorithms, large-scale data analysis, and intelligent systems.

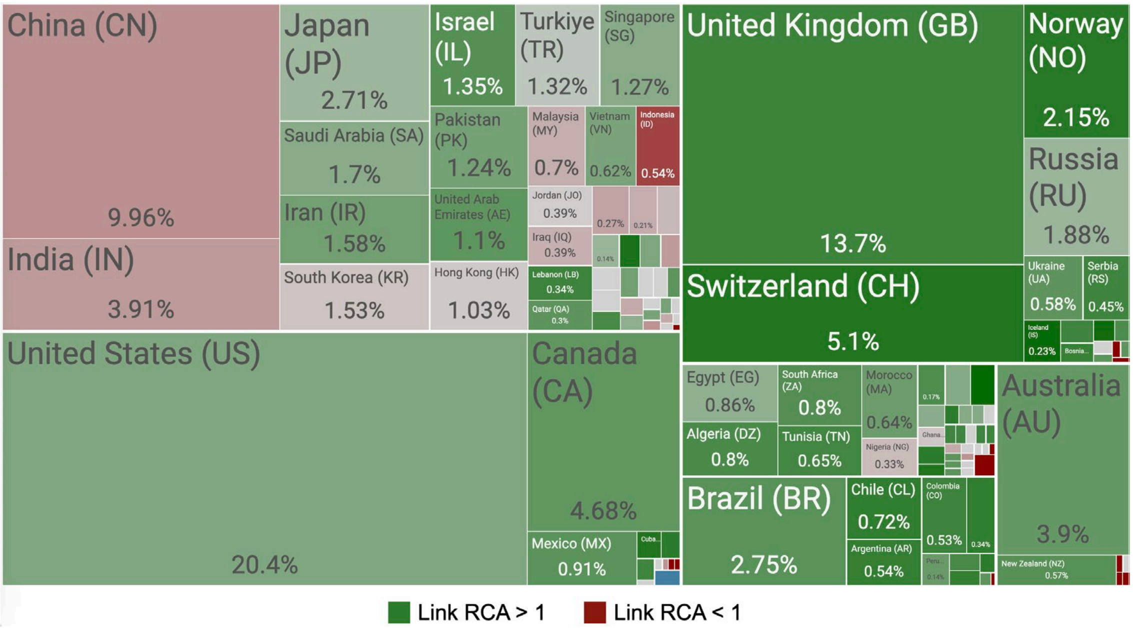
The United Kingdom represents the second most important partner, accounting for 13.7 % of collaborative publications. Despite its institutional separation from the European Union following Brexit, the United Kingdom remains deeply integrated into European research networks. British universities and research institutions maintain extensive collaboration with European counterparts in fields related to artificial intelligence, machine learning, and computational sciences.

China appears as the third most important partner, representing 10 % of AI-related co-publications with the European Union. China has become one of the world's largest producers of scientific research in artificial intelligence, and collaboration between Chinese and European research teams has expanded significantly over the past decade. These partnerships often involve joint work on machine learning models, computer vision applications, and data-driven technologies.

Other countries also play significant roles in the European Union's scientific collaboration network. Switzerland accounts for 5.1 % of collaborative publications and benefits from a highly competitive research system with strong expertise in artificial intelligence, robotics, and computational sciences. Similarly, Canada contributes 4.7 % of collaborative publications and is internationally recognised as a major hub for AI research, particularly in deep learning and machine learning.

Emerging scientific partners are also visible within the network. India and Australia each account for approximately 3.9 % of EU co-authored AI publications. Both countries have expanded their research capabilities in artificial intelligence and computer science, leading to growing collaboration with European research institutions. Meanwhile, Brazil and Japan each account for around 2.7 % of collaborative publications, further illustrating the global reach of Europe's research partnerships.

Figure 72 – EU network of scientific collaborations in Artificial Intelligence, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/artificial-intelligence.html

4.2. GENERATIVE AI

In the domain of Generative AI, the structure of co-patenting partnerships involving the European Union closely mirrors the broader collaboration patterns observed in the field of Artificial Intelligence, although several differences emerge when focusing on specific technological actors and patent portfolios.

As shown in Figure 73, the United States clearly dominates the European Union's co-patenting network in Generative AI, accounting for 43.7 % of joint patents. This strong transatlantic linkage reflects the central role of large US technology companies in the development of Generative AI architectures and applications. For example, patent families associated with transformer-based neural networks, the foundational architecture behind many modern large language models, have been widely cited across the industry and underpin much of the current Generative AI ecosystem. The transformer architecture – popularised by the 'Attention Is All You Need' model – has been patented and extensively referenced in subsequent innovations in large language models and generative systems. More recent patent filings illustrate how Generative AI is being integrated into commercial and enterprise applications[2].

The second most important partner is India, accounting for 10.5 % of EU co-patents in Generative AI. India's prominence in this network reflects the growing integration of its large software engineering workforce into global R&D activities conducted by multinational companies. Many Generative AI patents involve collaborative development of machine-learning applications for software development, enterprise automation, and data analytics.

The United Kingdom follows closely with 10.3 % of co-patents. The United Kingdom hosts several leading AI research institutions and has historically been a major contributor to machine learning and deep learning research. Many EU–UK patents in Generative AI focus on areas such as neural network architectures, natural language processing systems, and generative content platforms.

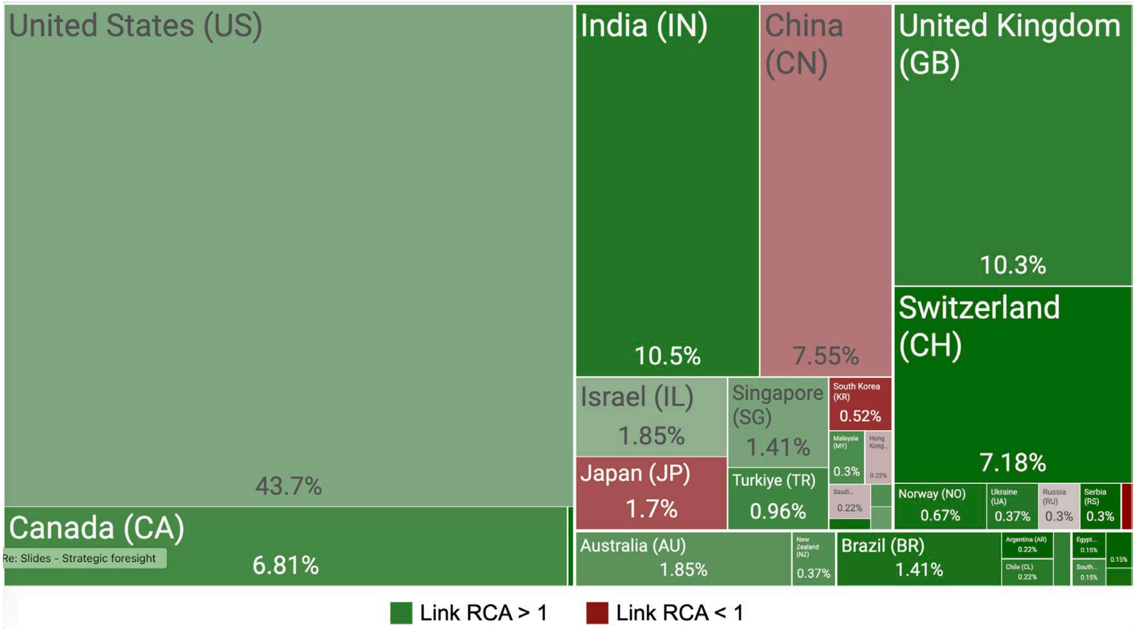
Other partners also play meaningful roles in the European Generative AI innovation network. China accounts for 7.55 % of EU co-patents, reflecting the rapid expansion of China's Generative AI innovation ecosystem. Chinese firms and research institutions have been actively filing patents related to generative models such as GANs, variational autoencoders, and large language models, which have become the dominant technological paradigms in Generative AI.

Similarly, Switzerland (7.2 %) and Canada (6.8 %) appear as important partners in the European Generative AI patent network. Both countries host world-leading research hubs in machine learning and computational sciences. Their participation in EU co-patenting activities reflects strong academic-industry collaboration and the international mobility of AI researchers.

---

[2] For instance, US12111859B2 describes architectures for enterprise generative AI systems based on large language models, which can generate, summarize, and translate text using transformer-based deep learning models. Similarly, patent US12008341B2 discloses methods for generating natural-language descriptions of computer code using machine learning models, a capability that underlies many generative AI coding assistants. These examples highlight how collaborations between European and U.S. inventors often focus on applied generative AI technologies in enterprise software, developer tools, and automated content generation.

Figure 73 – EU network of tech collaborations in generative AI, 2010-2024



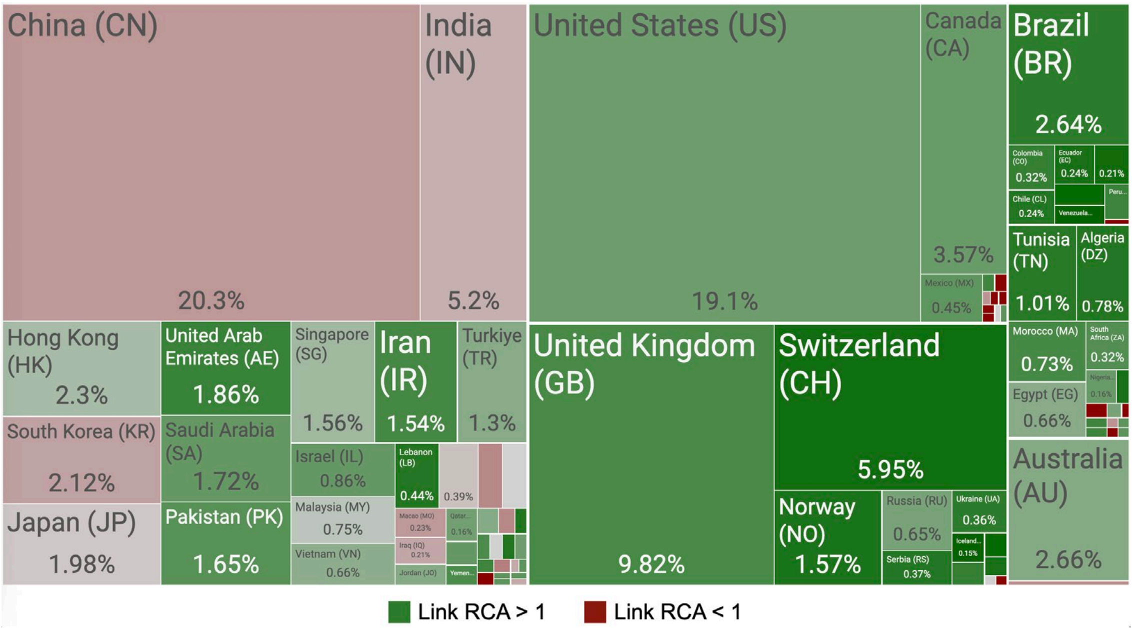
Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/generative-ai.html

In Generative AI, the structure of scientific collaboration involving the European Union differs noticeably from the co-patenting landscape. As shown in Figure 74, while the United States dominates EU partnerships in patents, China emerges as the leading partner in scientific publications, accounting for 20.3 % of EU co-authored papers in Generative AI, slightly ahead of the United States at 19.1 %. This reflects the rapid expansion of China's academic research output in machine learning and generative models over the past decade. Chinese institutions have played a central role in several influential publications in the field, including research on Generative Adversarial Networks (GANs) and large-scale multimodal models. For example, highly cited work on GAN architectures and training methods, such as papers building on the original GAN framework introduced by Ian Goodfellow and collaborators in 2014, has involved extensive collaboration with European researchers and has generated thousands of citations in the machine learning literature.

The United States remains the second most important partner with 19.1 % of EU co-publications, reflecting deep transatlantic research links in machine learning and natural language technologies. Collaborative research often builds on influential work such as the transformer architecture introduced in 'Attention Is All You Need' (2017) by researchers at Google, which laid the foundation for modern Generative AI systems including large language models. This publication has become one of the most cited papers in artificial intelligence and has shaped a large body of joint research between European and American institutions.

Among other key partners, the United Kingdom accounts for 9.8 % of EU co-authored publications, reflecting the strength of British research centres such as University of Cambridge and University of Oxford in machine learning and computational linguistics. Switzerland contributes 6 % of collaborative publications, largely driven by research from institutions such as ETH Zurich, which has produced highly cited work on deep learning architectures and generative models. Meanwhile, India accounts for 5.2 % of EU collaborations, reflecting the growing participation of Indian researchers in international AI research networks and their contributions to areas such as large language models, generative data synthesis, and multilingual AI systems.

Figure 74 – EU network of scientific collaborations in generative AI, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/generative-ai.html

4.3. BLOCKCHAIN TECHNOLOGIES

In the domain of Blockchain, the pattern of technological collaboration involving the European Union is highly concentrated around a limited number of international partners. As shown in Figure 75, the United States clearly emerges as the European Union's principal co-patenting partner, accounting for 47.8 % of all blockchain patents jointly filed with EU inventors. This strong transatlantic linkage reflects the leading role played by US technology firms and research institutions in the development of blockchain platforms, cryptographic protocols, and distributed computing infrastructures. Many of the technological breakthroughs in blockchain – ranging from scalable consensus mechanisms to smart contract architectures – have been developed through collaborations involving multinational technology companies and research teams spanning both sides of the Atlantic.

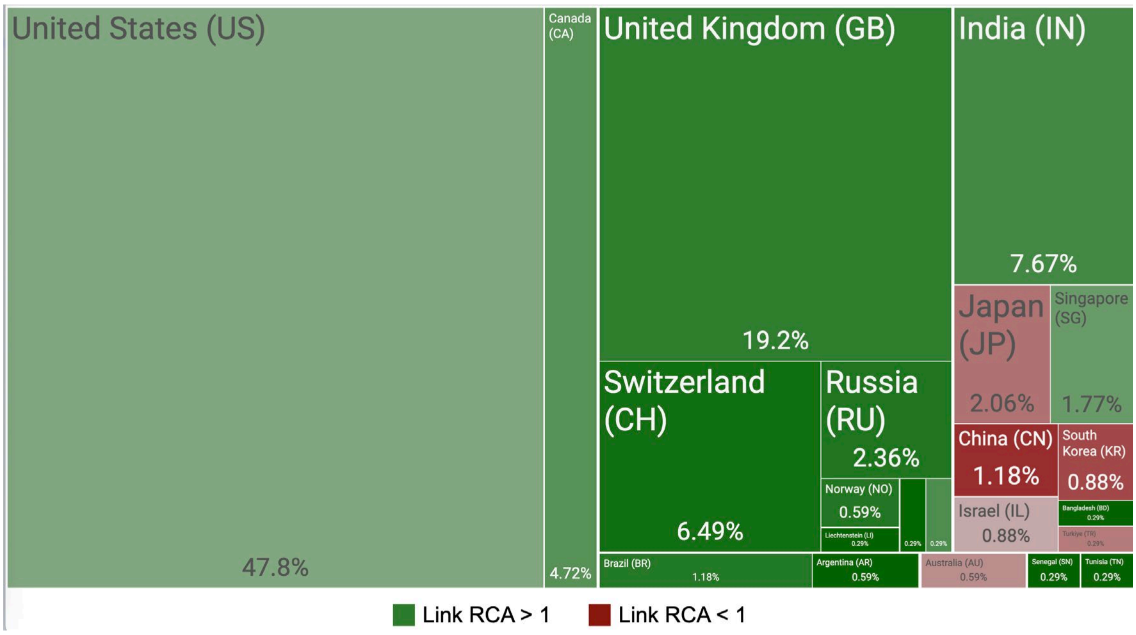
The United Kingdom represents the second most important partner, accounting for 19.2 % of EU co-patented blockchain inventions. The United Kingdom hosts one of the most dynamic fintech ecosystems globally, particularly in London, where blockchain technologies have been widely explored in applications related to digital payments, decentralised finance, and secure digital identity systems. The strong links between British and European research institutions and financial technology companies explain the high level of collaboration in this domain.

Other partners play more modest but still notable roles in the European blockchain innovation network. India accounts for 7.7 % of EU blockchain co-patents, reflecting the country's growing participation in global digital technology development and its strong software engineering capabilities. Similarly, Switzerland represents 6.5 % of EU collaborations, supported by the presence of a highly developed blockchain ecosystem centred around the 'Crypto Valley' in the Zug region, where numerous blockchain start-ups and research initiatives are located.

Canada follows with 4.7 % of co-patenting activity, benefiting from strong research capabilities in cryptography, distributed systems, and financial technologies. Canadian universities and technology companies have contributed significantly to the development of blockchain protocols and decentralised digital infrastructures.

An interesting feature of the collaboration network is that the European Union maintains slightly stronger technological cooperation with Russia (2.36 %) than with either Japan (2.06 %) or China (2 %). Although these shares remain relatively small, they highlight the diversity of Europe's international technological partnerships in blockchain technologies. In particular, Russian research institutions have historically been active in fields such as cryptography and distributed computing, which form key components of blockchain architectures.

Figure 75 – EU network of tech collaborations in blockchain, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/blockchain-technologies.html

When examining the network of scientific collaborations in Blockchain, a markedly different picture emerges compared with the co-patenting landscape. Scientific collaboration networks tend to be more geographically diversified, reflecting the open and international nature of academic research. In this context, the European Union maintains a broad set of research partnerships spanning both advanced innovation systems and emerging research actors.

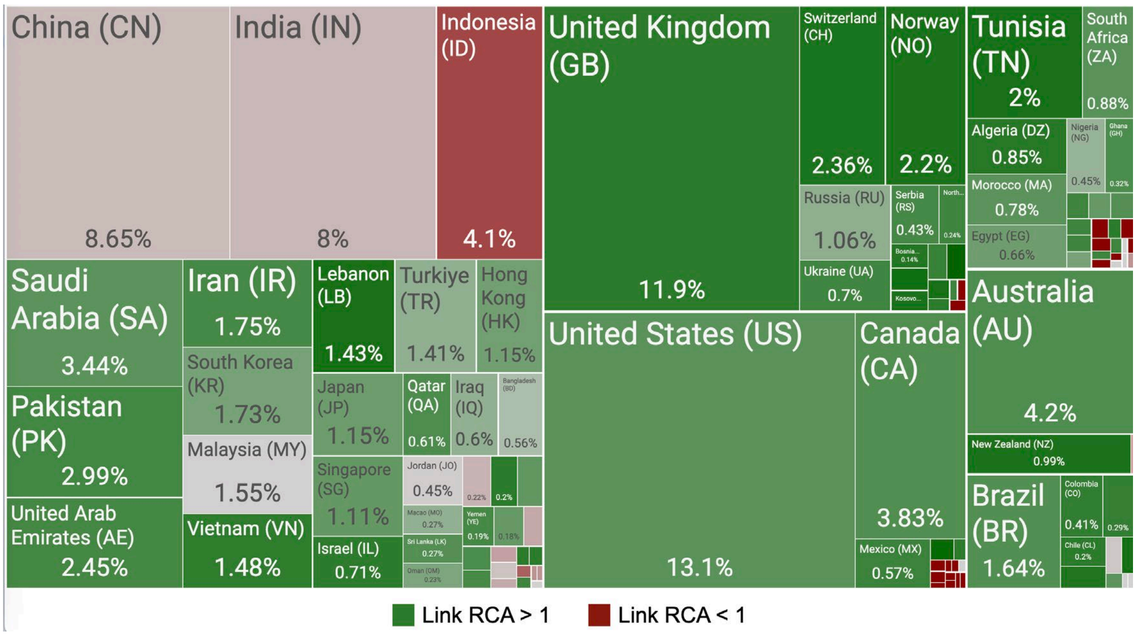
The United States remains the most important partner for European researchers, accounting for 13.1 % of EU co-authored publications in blockchain research. Transatlantic collaboration is particularly strong in areas such as cryptography, distributed consensus mechanisms, and decentralised digital infrastructures. Many highly cited academic papers on blockchain architectures and applications have emerged from collaborative networks linking European and American universities and research laboratories.

The United Kingdom follows closely with 11.9 % of collaborative publications, reflecting the country's strong academic presence in financial technologies, distributed systems, and digital security. British universities and research institutes have played an important role in developing theoretical and applied research related to blockchain protocols, decentralised applications, and smart contract systems.

In contrast with the patent collaboration network, China and India appear as much more prominent partners in the scientific landscape, accounting for 8.6 % and 8 % of EU co-publications respectively. Both countries have rapidly expanded their research output in computer science and digital technologies, including blockchain systems. Academic collaborations between European, Chinese, and Indian researchers frequently focus on topics such as distributed ledger scalability, blockchain security, and decentralised digital platforms.

Beyond these leading partners, the scientific collaboration network is remarkably diverse, encompassing a wide range of countries across multiple regions. As illustrated in Figure 78, European researchers maintain important collaborative links with countries such as Australia, Saudi Arabia, Switzerland, Pakistan, Tunisia, Norway, Canada, Brazil, and Vietnam, among others. These collaborations often emerge through international research projects, joint doctoral programmes, and global academic networks focusing on emerging digital technologies

Figure 76 – EU network of scientific collaborations in blockchain technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/blockchain-technologies.html

4.4. Cloud computing and edge computing

In the domain of Cloud and Edge Computing, the pattern of technological collaboration involving the European Union once again highlights the strong role of a small group of key international partners. As shown in Figure 79, the United States clearly dominates the European Union's co-patenting network in this field, accounting for approximately 41.9 % of all patents jointly filed with EU inventors. This strong transatlantic partnership reflects the leading position of American technology companies in cloud infrastructure, data centre architectures, and distributed computing platforms. Many of the foundational innovations in cloud computing – including virtualisation technologies, large-scale data management systems, and distributed computing frameworks – have emerged from US-based firms and research institutions, often through collaborative projects involving European partners.

China represents the second most important technological partner, accounting for 17.1 % of EU co-patents in cloud and edge computing technologies. China has rapidly expanded its capabilities in digital infrastructure, large-scale data processing systems, and cloud platforms over the past decade. The presence of significant EU–China collaboration in this domain reflects the global diffusion of cloud technologies and the growing integration of Chinese technology firms into international innovation networks.

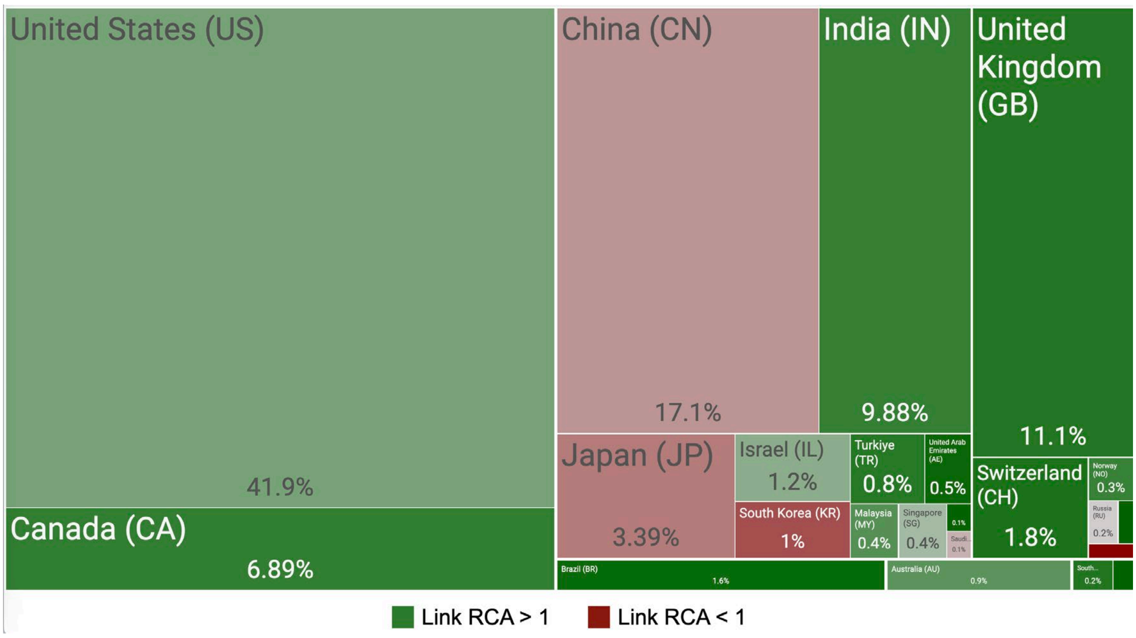
The United Kingdom ranks third, accounting for 11.1 % of EU co-patented inventions. The United Kingdom maintains strong research and industrial capabilities in software systems, distributed computing, and data-driven technologies. British universities and technology companies frequently collaborate with European partners on innovations related to cloud architectures, edge computing systems, and scalable digital infrastructures.

Other important partners include India, which accounts for 9.9 % of co-patenting activity. India's strong presence reflects its large and globally integrated software engineering sector, where cloud platforms and distributed computing systems play a central role. Collaborative patents often involve developments in cloud-based services, enterprise software platforms, and large-scale data processing systems.

Similarly, Canada represents 6.9 % of EU co-patents, benefiting from strong research capabilities in computer science, distributed computing, and artificial intelligence. Canadian universities and technology firms frequently collaborate with European partners on innovations related to cloud infrastructure and edge computing technologies.

Finally, Japan accounts for 3.4 % of EU technological collaborations in this domain. Although the share remains relatively modest, Japan's strong expertise in advanced computing systems, telecommunications technologies, and enterprise software contributes to ongoing collaborative research and development activities with European partners.

Figure 77 – EU network of tech collaborations in cloud and edge computing, 2010-2024



Source: https://www.paballand.com/ceps/ttd/position/regpat/cloud-computing--edge-computing.html

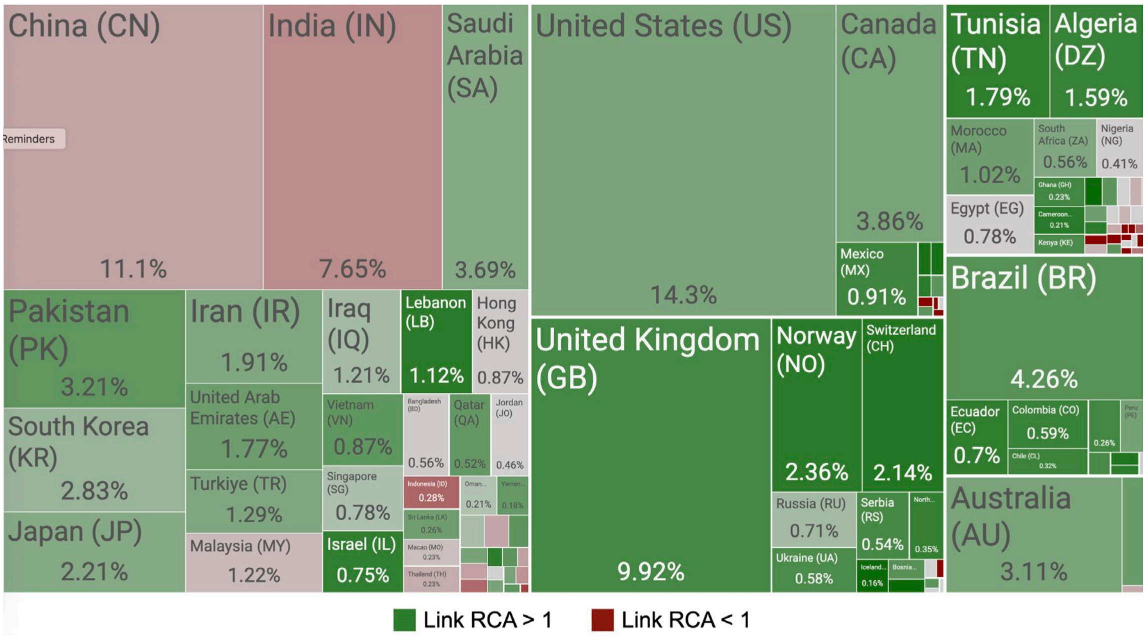
In the field of Cloud Computing, the pattern of scientific collaboration involving the European Union differs somewhat from the technological collaboration network observed in patents. While the United States remains the leading research partner of the EU, accounting for 14.3 % of co-authored scientific publications, the distribution of collaborations is more balanced across several major research systems. The United States maintains a central role in EU scientific collaborations due to its long-standing leadership in distributed computing research, large-scale data systems, and digital infrastructure technologies. Transatlantic research networks frequently contribute to advances in cloud architectures, resource management in data centres, and distributed computing frameworks, often involving collaborations between European universities and major American research institutions.

China emerges as the second most important partner, accounting for over 11 % of EU co-authored publications in this domain. China has rapidly expanded its research capacity in computer science and digital infrastructure technologies over the past decade, leading to a significant increase in collaborative scientific output with European research institutions. Research collaborations between European and Chinese teams often focus on topics such as edge computing architectures, distributed storage systems, and scalable cloud platforms.

The United Kingdom follows with 9.9 % of collaborative publications, reflecting the country's strong research capabilities in computer science, distributed systems, and software engineering. British universities remain deeply integrated into European research networks and continue to play an important role in advancing scientific work on cloud infrastructure, virtualisation technologies, and large-scale computing systems.

Another major partner is India, which accounts for 7.65 % of EU co-authored publications. India’s growing presence in global research networks reflects the rapid expansion of its computer science research community and its strong expertise in software engineering, distributed computing, and digital infrastructure technologies.

Figure 78 – EU network of scientific collaborations in cloud and edge computing, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/cloud-computing-&-edge-computing.html

4.5. COMPUTER VISION, NATURAL LANGUAGE PROCESSING AND OBJECT RECOGNITION

In the domain of Computer Vision, Natural Language Processing, and object recognition technologies, the pattern of technological collaboration involving the European Union is once again strongly concentrated around a limited number of international partners. As illustrated in Figure 81, the United States clearly dominates the EU’s co-patenting network in these technologies, accounting for 44.5 % of all patents jointly filed with European inventors. This strong transatlantic linkage reflects the leading position of US technology companies and research institutions in artificial intelligence and machine learning. Many key innovations in image recognition systems, deep learning architectures, and language models have been developed through collaborative projects between European and American organisations.

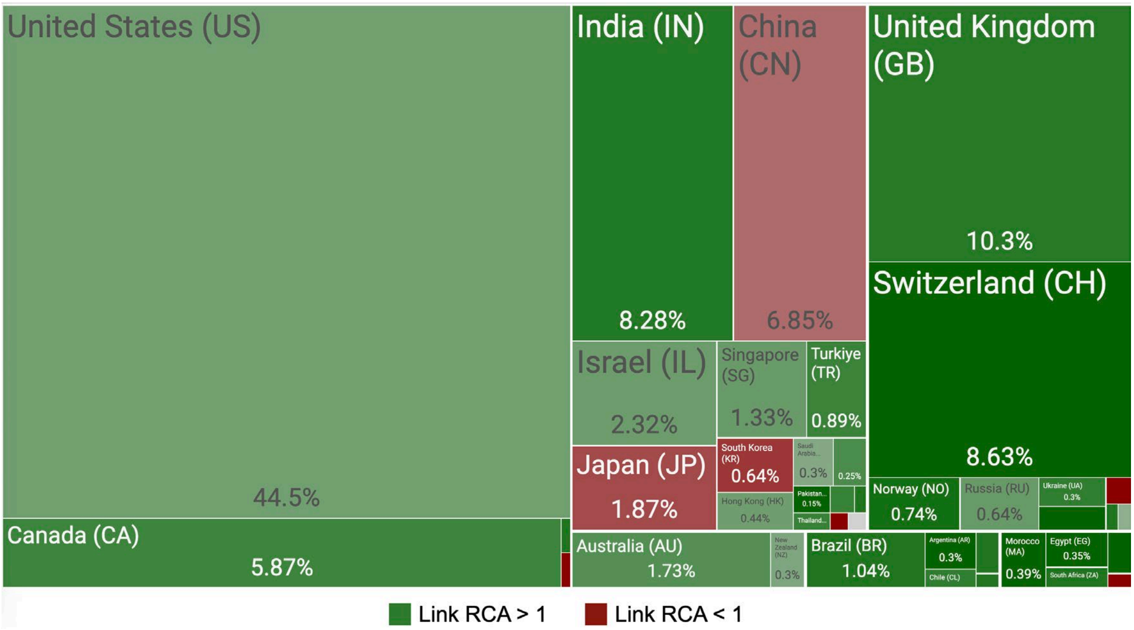
The United Kingdom emerges as the second most important partner, representing 10.3 % of EU co-patented inventions in this domain. The United Kingdom hosts several leading research centres in machine learning, computer vision, and computational linguistics, and maintains strong collaborative ties with European research institutions and technology companies. These collaborations frequently focus on applications such as automated image recognition, intelligent video analytics, and natural language understanding systems.

Another significant partner is Switzerland, which accounts for 8.6 % of EU co-patenting activity. Switzerland's strong presence reflects the influence of its highly competitive research institutions and technology ecosystem, particularly in fields related to machine learning, robotics, and computer vision.

Interestingly, India appears as a more prominent partner than China in this specific technological domain, accounting for 8.3 % of EU co-patents, compared with 6.9 % for China. India's strong participation reflects the integration of its large software engineering workforce into global research and development networks, particularly in areas related to machine learning, data analytics, and AI-enabled software systems.

Finally, Canada accounts for 5.9 % of EU technological collaborations in this field. Canada has developed a strong international reputation in artificial intelligence research, particularly in deep learning and machine learning, which has contributed to its active role in collaborative innovation networks.

Figure 79 – EU network of tech collaborations in computer vision, NLP and object recognition, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/computer-vision,-language-processing-&-object-recognition.html

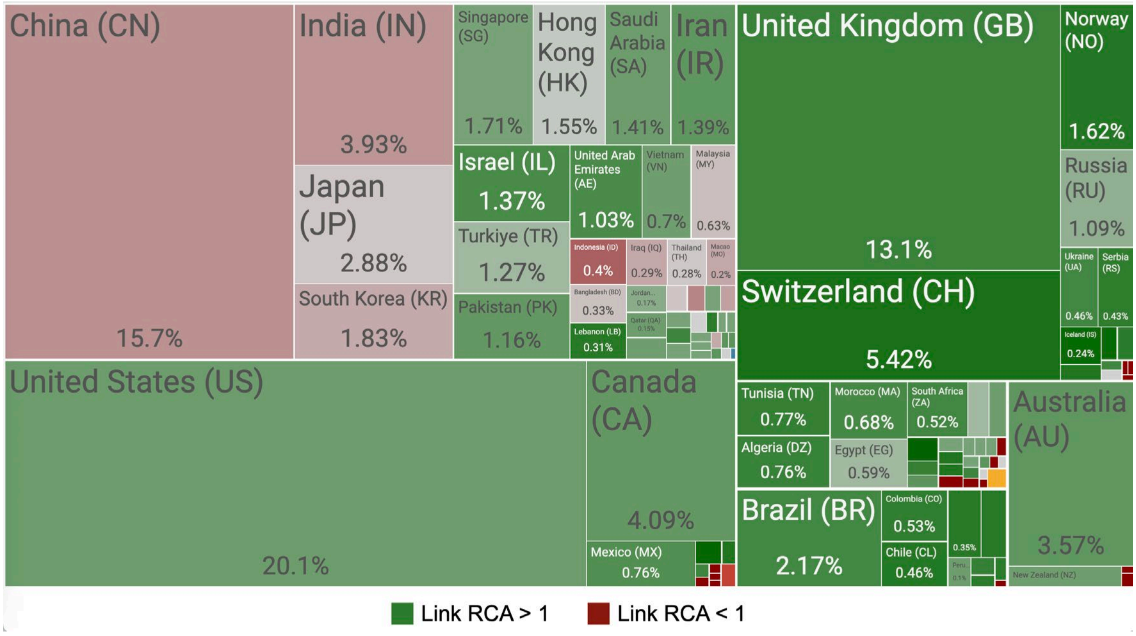
When examining scientific collaborations in the fields of Computer Vision, Natural Language Processing, and object recognition, the collaboration network involving the European Union appears broader and more diversified than the corresponding co-patenting landscape. As shown in Figure 84, the United States remains the EU's most important scientific partner, accounting for 20.1 % of co-authored publications in these domains. Transatlantic collaboration has historically played a central role in advancing machine learning, computer vision systems, and language technologies, with research teams spanning universities and research laboratories across both regions.

China emerges as the second most important partner, representing 15.7 % of EU co-publications in this technological area. China's strong presence reflects the rapid expansion of its research output in artificial intelligence and machine learning over the past decade. Chinese universities and research institutes contribute extensively to global scientific work on image recognition systems, visual perception models, and large-scale language processing technologies.

The United Kingdom follows with 13.1 % of collaborative publications, maintaining a strong position in European research networks despite its institutional separation from the EU. British universities and research centres remain highly active in machine learning, computer vision, and computational linguistics, contributing significantly to joint research projects and scientific publications with European partners.

Beyond these three leading collaborators, the scientific collaboration network extends to a wider group of research-intensive countries. Switzerland and Canada are notable partners due to their internationally recognised expertise in artificial intelligence and deep learning research. Similarly, India and Australia contribute to a growing share of collaborative publications, reflecting the expansion of their research communities in computer science and AI-related fields. Additional collaborations involve Japan and Brazil, illustrating the increasingly global nature of scientific research in these technologies.

Figure 80 – EU network of scientific collaborations in computer vision, NLP and object recognition, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/computer-vision,-language-processing-&-object-recognition.html

4.6. CYBERSECURITY TECHNOLOGIES

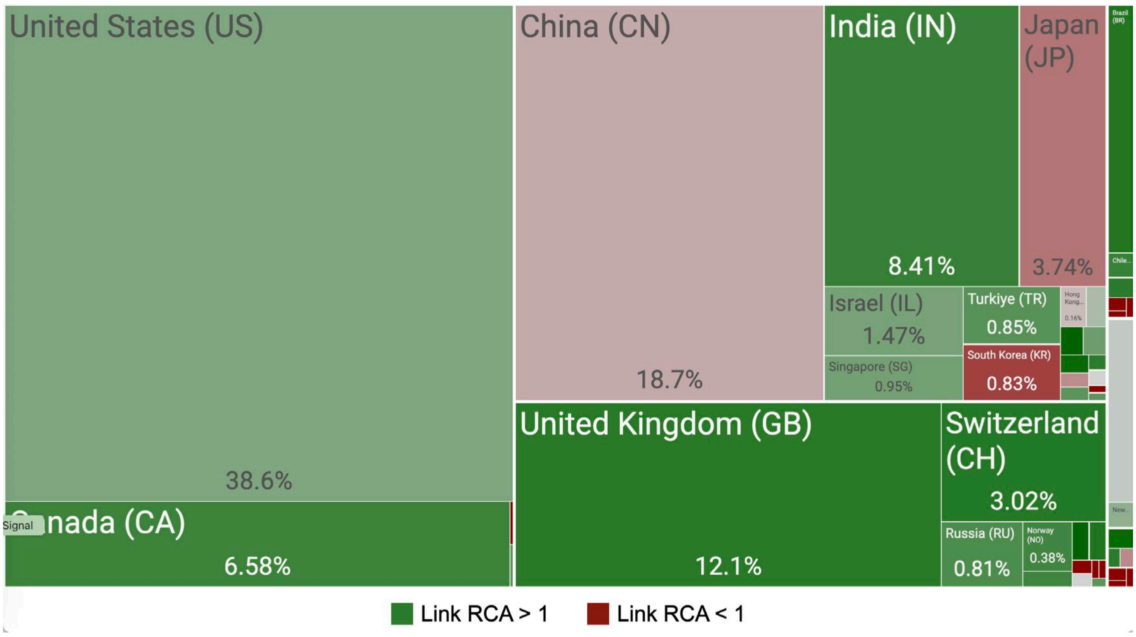
In the domain of Cybersecurity, the technological collaboration network involving the European Union is again strongly structured around a limited number of major innovation partners. As shown in Figure 86, the United States stands out as the EU's principal co-patenting partner, accounting for 38.6 % of all jointly filed cybersecurity patents involving European inventors. This strong transatlantic collaboration reflects the deep integration of European and American innovation ecosystems in digital security technologies. Many of the most advanced cybersecurity solutions – ranging from secure network architectures to cryptographic protocols and threat detection systems – are developed through joint research and development efforts between European organisations and large US technology companies.

China appears as the second most important partner, representing 18.7 % of EU co-patenting activity in cybersecurity technologies. China has rapidly expanded its capabilities in information security, cryptography, and secure digital infrastructures, supported by strong public investment and the growing importance of cybersecurity in national digital strategies. Collaborative patents between Chinese and European inventors reflect the global nature of innovation in secure computing systems and digital infrastructure protection.

The United Kingdom follows with 12.1 % of EU co-patents in this field. The United Kingdom maintains a strong cybersecurity ecosystem centred around universities, research institutes, and specialised technology firms. Close collaboration between British and European organisations has historically supported innovation in areas such as network security, digital authentication systems, and secure communications.

Other significant partners include India, accounting for 8.4 % of EU co-patenting activity, reflecting the growing role of India's software and digital technology sector in global cybersecurity research and development. Finally, Canada represents 6.6 % of EU technological collaborations in cybersecurity technologies. Canada's strong research capabilities in cryptography, secure distributed systems, and digital infrastructure protection contribute to its active role in international cybersecurity innovation networks.

Figure 81 – EU network of tech collaborations in cybersecurity technologies, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/cybersecurity-technologies.html

In the field of Cybersecurity, the pattern of scientific collaboration involving the European Union is considerably more distributed than the co-patenting network. This reflects the open and international nature of academic research in digital security, where knowledge exchange often occurs through multi-country research teams and large collaborative projects.

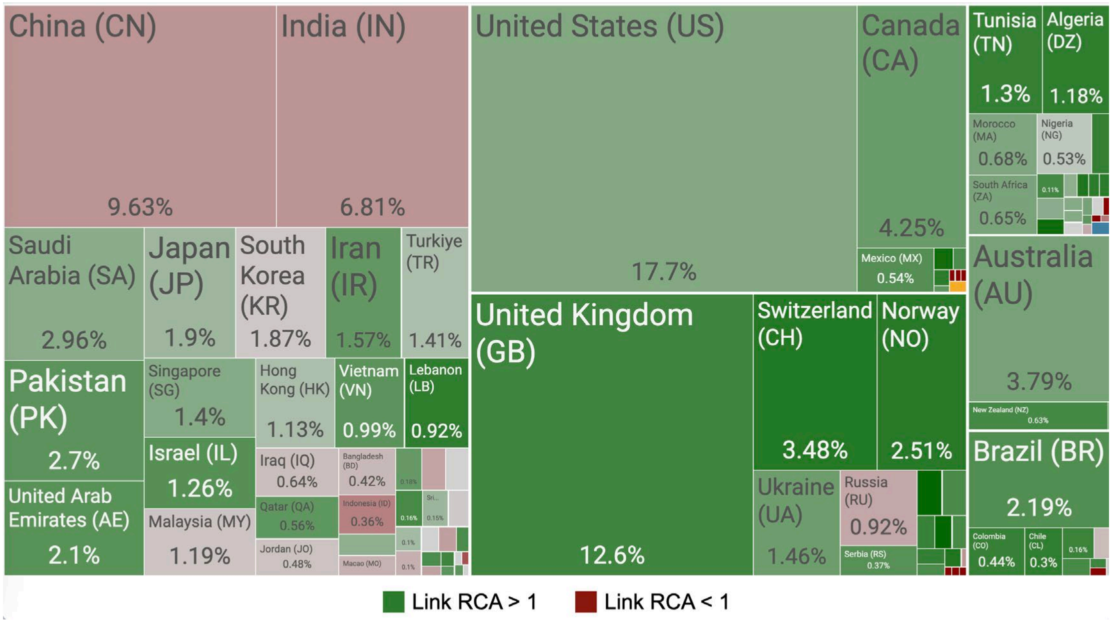
The United States remains the most important research partner of the EU, accounting for 17.7 % of co-authored scientific publications in cybersecurity. Transatlantic collaboration is particularly strong in areas such as cryptography, secure network architectures, privacy-preserving data systems, and cyber-threat detection. Joint research projects between European and American universities and research laboratories frequently address emerging challenges related to the security of cloud infrastructures, critical digital systems, and large-scale distributed networks.

The United Kingdom follows with 12.6 % of collaborative publications, maintaining a strong position within European research networks despite its institutional separation from the EU. British universities and research institutes have long been active in cybersecurity research, particularly in fields such as cryptographic systems, digital identity technologies, and cyber resilience. Close collaboration between British and European research teams continues to generate a substantial share of joint scientific output.

China represents the third most important partner, accounting for 9.6 % of EU co-publications in cybersecurity technologies. China's growing presence reflects the rapid expansion of its research community in computer science and information security. Collaborative research between European and Chinese institutions often focuses on topics such as network security protocols, data protection techniques, and secure communication infrastructures.

Beyond these leading partners, the scientific collaboration network extends to a broader group of countries across multiple regions. Researchers in the EU frequently collaborate with partners in countries such as Switzerland, Canada, India, Australia, and Japan, among others. These collaborations contribute to a dense global research network addressing increasingly complex challenges related to digital security and cyber resilience.

Figure 82 – EU network of scientific collaborations in cybersecurity technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/cybersecurity-technologies.html

4.7. Drones

Figure 83 illustrates the international technological collaboration network of the European Union in the field of Drone Technology, based on patterns of co-patenting activity. As in several other advanced technology domains, the United States emerges as the EU's primary technological partner, accounting for 38.5 % of all drone-related patents jointly filed with European inventors. This strong transatlantic collaboration reflects the close integration of European and American aerospace and defence innovation ecosystems. Many developments in autonomous flight systems, navigation technologies, and drone-based sensing platforms involve research and development efforts linking European aerospace firms, research institutes, and US technology companies.

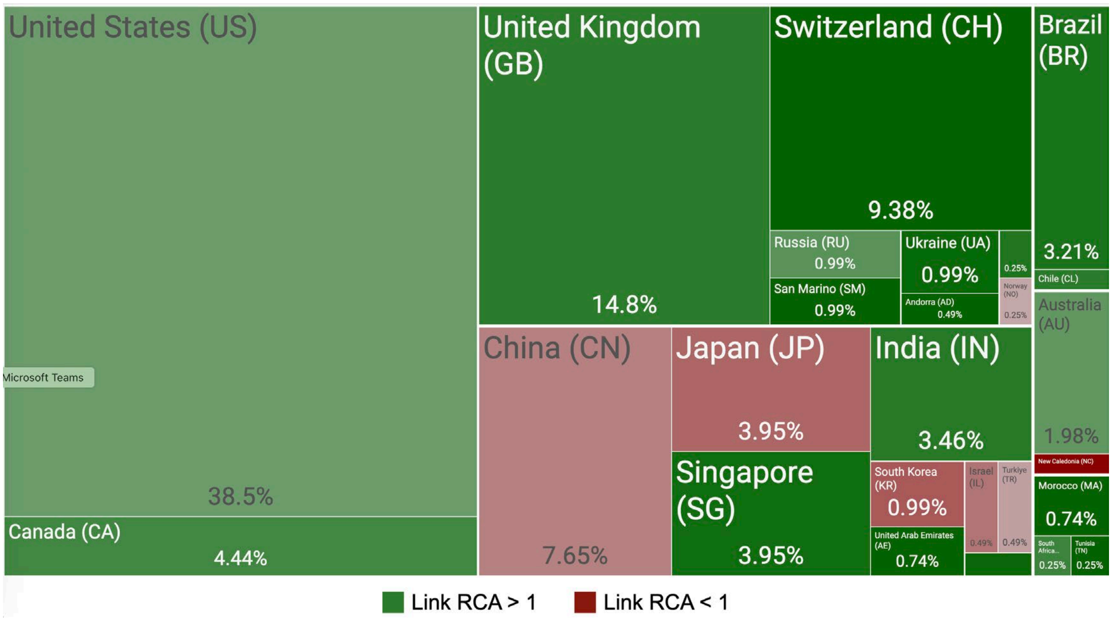
The United Kingdom represents the second most important partner, accounting for 14.8 % of EU co-patented drone technologies. The United Kingdom maintains a strong research and industrial base in aerospace engineering, autonomous systems, and robotics, which contributes to its active participation in collaborative drone innovation. Despite institutional changes following Brexit, British research institutions and technology firms remain deeply connected to European technological networks in aerospace and autonomous systems.

Another notable partner is Switzerland, representing 9.38 % of EU co-patenting activity in this domain. Switzerland's strong presence reflects the role of its universities and research centres in fields such as robotics, autonomous navigation systems, and aerial robotics. These capabilities support collaborations with European partners on advanced drone technologies used in applications such as environmental monitoring, infrastructure inspection, and autonomous logistics.

In contrast with some other digital technology domains, collaboration between the EU and China appears relatively more limited in the field of drone technologies, accounting for 7.7 % of co-patented inventions. While China has developed a powerful drone manufacturing industry, particularly in commercial UAV production, technological collaboration with European inventors remains comparatively smaller in patenting activities.

Other partners contribute more modest shares to the EU's drone co-patenting network. Countries such as Canada, Singapore, India, Japan, and Brazil each account for between 3 % and 5 % of total EU co-patenting cases in this technological area. These collaborations often involve specialised applications of drone technologies, including aerial imaging systems, autonomous navigation platforms, and drone-enabled data collection solutions.

Figure 83 – EU network of tech collaborations in drone technologies, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/drones.html

When examining scientific collaborations in Drone Technology, the structure of the research network involving the European Union differs markedly from the technological collaboration patterns observed in patents. In this case, China emerges as the EU's leading scientific partner, accounting for 17.7 % of co-authored publications in drone-related research. This reflects China's strong and rapidly expanding research activity in areas such as autonomous aerial systems, robotics, and intelligent sensing technologies, which has led to a growing number of collaborative research projects with European universities and research institutes.

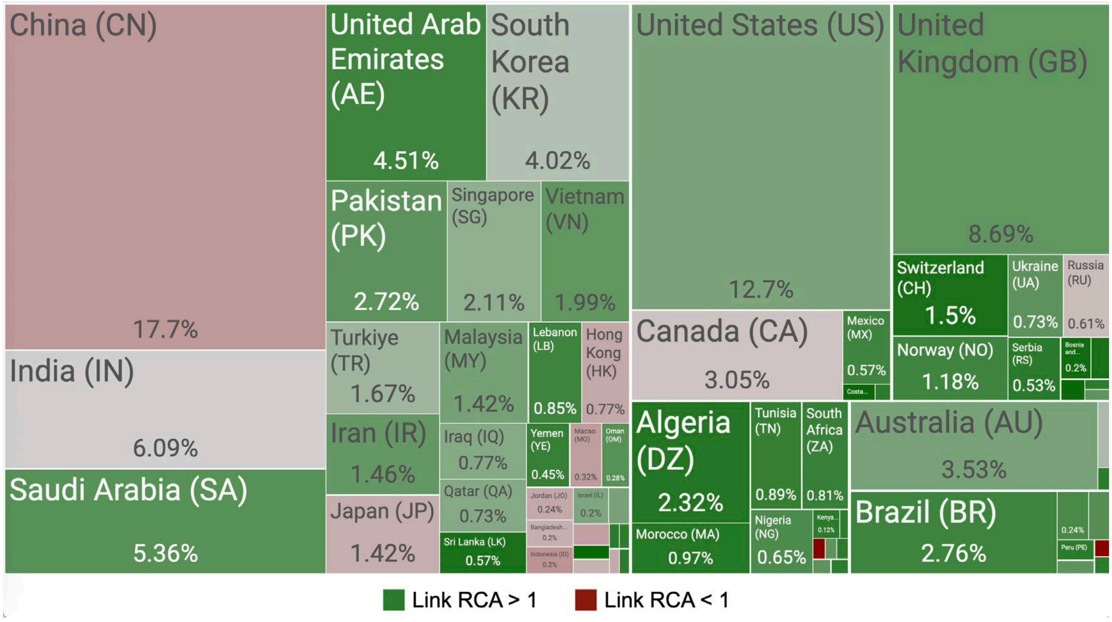
The United States, which dominates the co-patenting network in drone technologies, appears less prominent in the scientific collaboration landscape, accounting for 12.7 % of EU co-authored publications. Although transatlantic research cooperation remains important – particularly in areas such as autonomous navigation, aerial robotics, and unmanned vehicle systems – the relative share of EU–US collaborations is smaller than that observed in several other technological domains.

The United Kingdom follows with 8.7 % of collaborative publications, reflecting the strong presence of British universities in aerospace engineering, robotics, and intelligent control systems. Despite institutional changes following Brexit, research collaboration between British and European institutions remains dense in emerging fields related to autonomous and unmanned systems.

Interestingly, the scientific collaboration network also highlights the growing importance of several partners from the Middle East. Saudi Arabia and the United Arab Emirates account for 5.4 % and 4.5 % of EU co-publications, respectively. These shares are slightly higher than those of more established scientific partners such as South Korea (4 %) and Canada (3 %). The growing presence of these countries reflects significant public investment in research and innovation infrastructures, particularly in areas related to robotics, aerospace technologies, and intelligent systems.

Beyond these leading collaborators, the scientific network appears highly diversified, extending to a wide range of emerging research partners. European researchers maintain notable collaborative links with countries such as Brazil, Algeria, Pakistan, Vietnam, Türkiye, and Iran, among others. In fact, EU researchers collaborate scientifically with Türkiye and Iran at roughly similar levels to those observed with Switzerland, traditionally one of Europe's closest research partners.

Figure 84 – EU network of scientific collaborations drone technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/drones.html

4.8. HIGH-PERFORMANCE COMPUTING

In the field of High-Performance Computing, the technological collaboration network involving the European Union is strongly concentrated around a single dominant partner. As shown in Figure 85, the United States accounts for more than half of all EU co-patenting activity in high-performance computing, with a share of 51.6 %. This overwhelming predominance reflects the deep integration between European and American research and industrial ecosystems in advanced computing technologies. High-performance computing systems require extremely sophisticated hardware and software architectures, and innovation in this field often emerges from collaborations involving major technology companies, national laboratories, and leading research universities on both sides of the Atlantic.

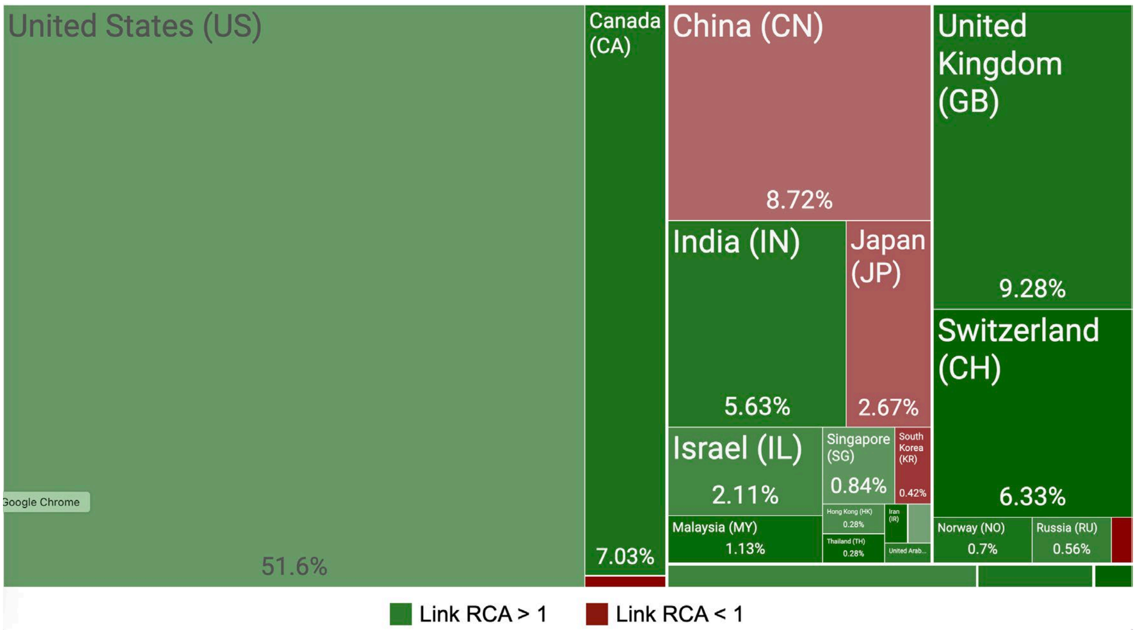
The strong EU–US partnership is also linked to the central role played by American technology firms and research infrastructures in the development of advanced processors, parallel computing architectures, and large-scale computing platforms. Collaborative patents frequently concern innovations in areas such as distributed computing systems, processor design, high-speed interconnect technologies, and advanced computing infrastructures used for scientific simulations and artificial intelligence applications.

Other international partners play a significantly smaller role in the EU's technological collaboration network in this domain. The United Kingdom accounts for 9.3 % of EU co-patenting activity, reflecting its strong capabilities in computer science, advanced computing systems, and scientific computing. Despite institutional changes following Brexit, the United Kingdom remains closely connected to European technological networks in advanced digital technologies.

China follows with 8.7 % of co-patents, illustrating the country's growing technological capabilities in supercomputing systems and advanced computing infrastructures. China has significantly expanded its investments in high-performance computing over the past decade, leading to increasing collaboration with international partners in certain areas of computing research and development.

Other notable partners include Canada, which accounts for 7 % of EU co-patenting activity, supported by strong research expertise in computer science and distributed computing systems. Switzerland represents 6.3 % of EU collaborations, reflecting the role of its highly competitive research institutions in advanced computing research. Finally, India accounts for 5.6 % of co-patenting activity, benefiting from its strong software engineering sector and growing participation in global digital technology development.

Figure 85 – EU network tech collaborations in HPC, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/high-performance-computing-hpc.html

A similar pattern emerges when examining scientific collaborations in High-Performance Computing involving the European Union. As shown in Figure 86, the United States remains the EU's most important research partner, accounting for 26.7 % of co-authored scientific publications in this domain. This strong transatlantic partnership reflects the long-standing integration between European and American research infrastructures in supercomputing and advanced computational science. Collaborative research often takes place through large international projects addressing challenges such as parallel computing architectures, large-scale simulations, and high-performance data processing systems.

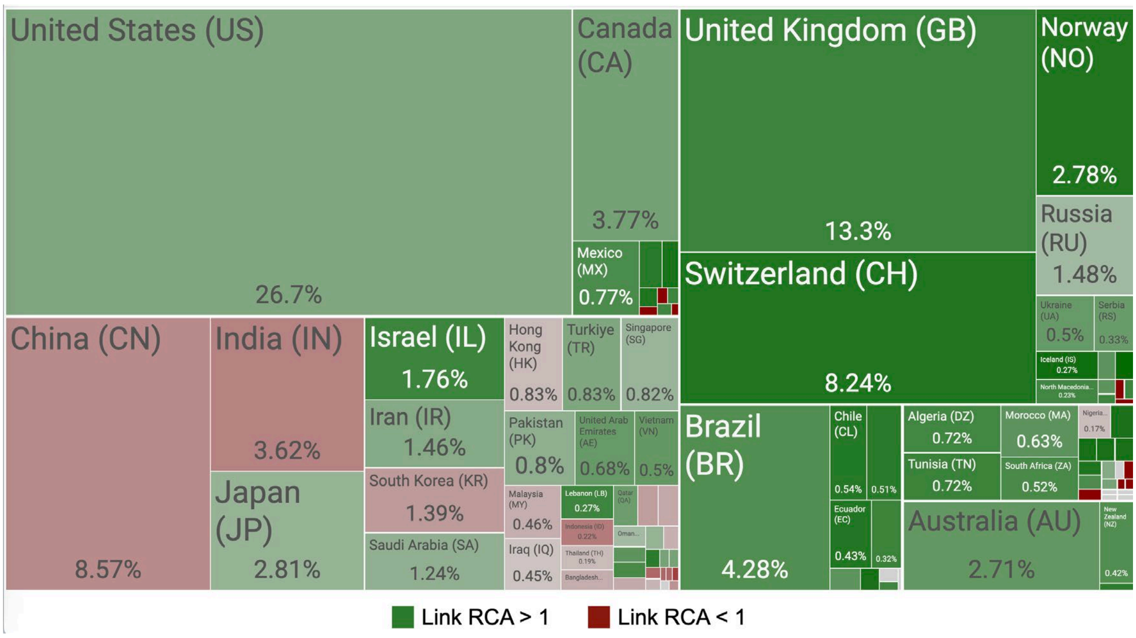
The United Kingdom emerges as the second most important partner, representing 13.3 % of collaborative publications. British universities and research centres maintain strong expertise in computational science, distributed computing, and advanced numerical modelling, and continue to collaborate extensively with European research institutions despite institutional changes following Brexit.

China follows with 8.6 % of EU co-authored publications, reflecting the rapid expansion of China's research capabilities in supercomputing and advanced computing systems. Chinese universities and research institutes increasingly participate in international research collaborations focusing on high-performance computing architectures, scalable algorithms, and large-scale scientific computing applications.

Another important partner is Switzerland, which accounts for 8.2 % of collaborative publications. Switzerland hosts several leading research institutions with strong capabilities in computational science, numerical modelling, and large-scale computing infrastructures, which contributes to its active participation in international scientific collaborations in this field.

Beyond these leading partners, the collaboration network extends to a broader group of countries that contribute smaller but still significant shares of joint research output. These include Brazil, India, Australia, Norway, and Japan, each of which participates in collaborative research projects related to high-performance computing technologies.

Figure 86 – EU network of scientific collaborations in HPC, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/high-performance-computing-hpc.html

4.9. INTERNET OF THINGS

In the domain of the Internet of Things, the technological collaboration network involving the European Union is again strongly centred on a limited number of major innovation partners. As shown in Figure 87, the United States clearly dominates the EU's co-patenting network, accounting for 43 % of all IoT patents jointly filed with European inventors. This strong transatlantic partnership reflects the central role of American technology companies and research institutions in the development of connected-device platforms, cloud infrastructures supporting IoT systems, and advanced sensor technologies. Many innovations in IoT architectures – such as edge computing frameworks, device connectivity protocols, and large-scale data management systems – emerge from collaborative research and development efforts linking European organisations with US technology firms and research laboratories.

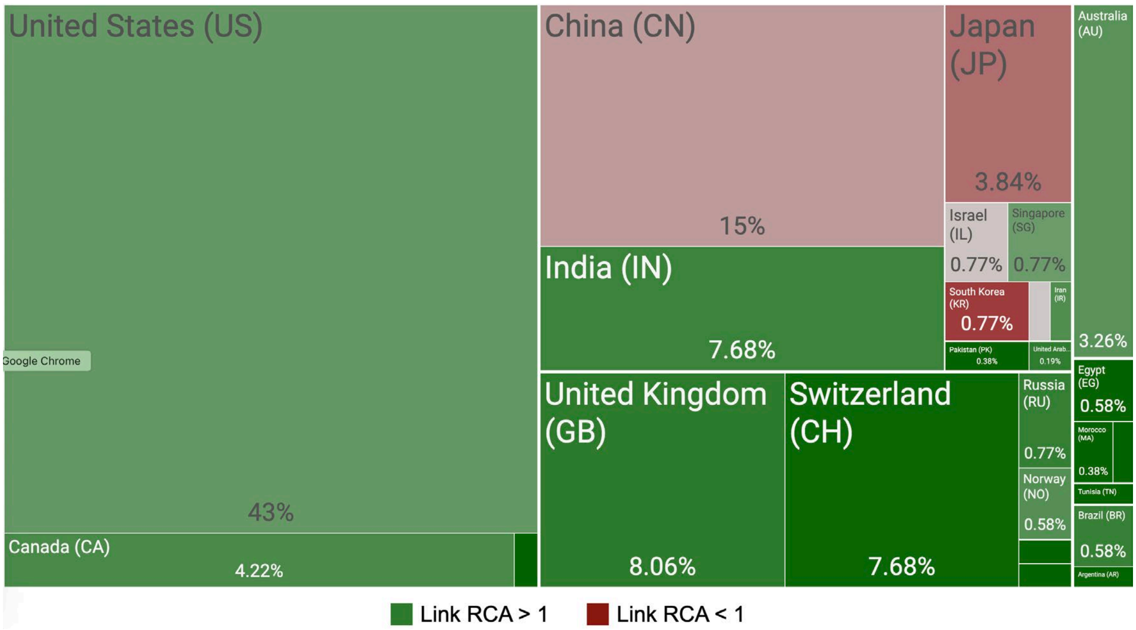
China appears as the second most important partner, accounting for 15 % of EU co-patenting activity in IoT technologies. China has rapidly expanded its capabilities in smart devices, industrial IoT systems, and connected infrastructures, supported by large-scale investments in digital technologies and smart city initiatives. Collaboration between Chinese and European inventors often focuses on applications such as connected manufacturing systems, smart infrastructure platforms, and sensor-based monitoring technologies.

The United Kingdom follows with 8 % of EU co-patents, reflecting its strong research and industrial capabilities in telecommunications, embedded systems, and software platforms supporting connected devices. Despite institutional changes following Brexit, the United Kingdom remains closely integrated into European technological networks in digital infrastructure technologies.

Two other partners hold similar shares of the EU's IoT co-patenting network: Switzerland and India, each accounting for 7.7 % of co-patented inventions. Switzerland's presence reflects the role of its highly competitive research institutions and advanced electronics ecosystem, while India's participation is closely linked to its strong software engineering sector and growing involvement in global digital technology development.

Additional partners contribute smaller but still notable shares to the EU's IoT technological collaboration network. Canada accounts for 4.2 % of co-patenting activity, benefiting from strong research capabilities in computer science, telecommunications, and distributed systems. Japan represents 3.8 % of EU collaborations, reflecting its expertise in electronics, sensor technologies, and industrial automation systems. Finally, Australia accounts for 3.2 % of EU co-patenting activity, illustrating the participation of its research institutions and technology companies in global IoT innovation networks.

Figure 87 – EU network of tech collaborations in IoT, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/internet-of-things-iot.html

In the domain of the Internet of Things, the scientific collaboration network involving the European Union appears significantly more distributed across countries than the corresponding co-patenting network. While the United States dominates technological collaboration, the research landscape reflects a broader and more globally interconnected set of partnerships.

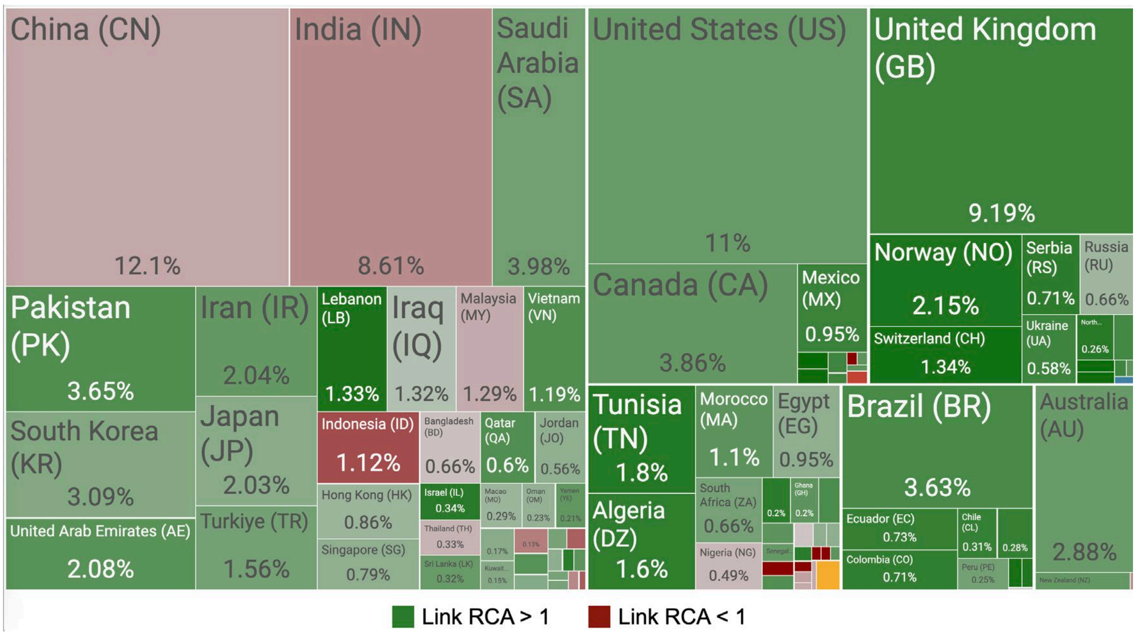
In this context, China emerges as the EU's leading partner in scientific publications, accounting for 12.1 % of co-authored research articles in IoT-related fields. China's prominent role reflects its rapid expansion in IoT research output and strong academic activity in connected systems, sensor networks, and smart infrastructure technologies. Bibliometric studies of IoT research consistently show China among the most productive countries worldwide in this domain.

The United States follows closely with 11 % of EU co-authored publications, highlighting the continued importance of transatlantic scientific cooperation in distributed systems, wireless communication technologies, and large-scale digital infrastructures. The United Kingdom ranks third with 9.2 % of collaborative publications, reflecting the strength of British universities in telecommunications, embedded systems, and smart city technologies.

Another key partner is India, which accounts for 8.6 % of EU co-publications in IoT research. India has developed a growing research community in computer science, wireless networks, and digital infrastructure, which has fostered numerous joint publications with European institutions.

Beyond these leading collaborators, the IoT scientific network is notably diverse and geographically widespread. Significant collaborations involve countries such as Pakistan, South Korea, Australia, Saudi Arabia, Brazil, Iran, Japan, the United Arab Emirates, and Norway. These collaborations often arise through large international research projects addressing applications such as smart cities, environmental monitoring, and industrial IoT systems.

Figure 88 – EU network of scientific collaborations in IoT, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/internet-of-things-iot.html

4.10. MOBILE NETWORKS (5G AND 6G)

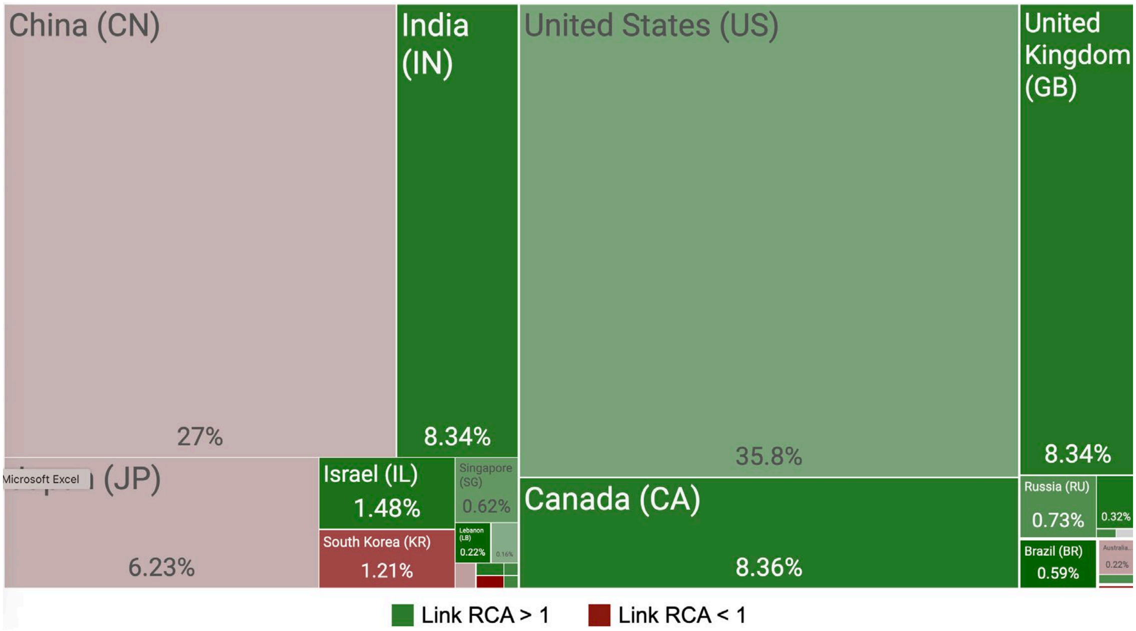
In the domain of Mobile Networks (5G and 6G), the technological collaboration network involving the European Union reflects the strategic importance of global partnerships in the development of next-generation digital infrastructure. As illustrated in Figure 88, the United States remains the EU's most important partner in co-patenting activities, accounting for 35.8 % of all jointly filed patents in this technological domain. This strong transatlantic collaboration reflects the deep integration between European and American telecommunications ecosystems, where research institutions, equipment manufacturers, and technology companies cooperate on innovations related to wireless communication architectures, network virtualisation, and advanced spectrum management technologies.

Closely following the United States is China, which accounts for 27 % of EU co-patented inventions in mobile network technologies. China's prominent role reflects the rapid expansion of its telecommunications sector and the strong technological capabilities of its equipment manufacturers and research institutions. Collaboration between European and Chinese inventors often involves the development of advanced wireless communication protocols, radio access network technologies, and infrastructure components for next-generation 5G and emerging 6G systems.

The United Kingdom, India, and Canada appear as the next most significant partners, each accounting for 8.3 % of EU co-patenting activity in this field. These collaborations reflect strong research capabilities in telecommunications engineering, distributed network architectures, and software-defined networking technologies. Universities and technology firms in these countries frequently collaborate with European organisations on innovations related to network optimisation, edge computing integration, and advanced wireless communication systems.

Finally, Japan accounts for 6.2 % of EU technological collaborations in mobile networks. Japan has long maintained a strong presence in telecommunications technologies, particularly in areas related to mobile communication standards, radio frequency technologies, and network infrastructure systems. Collaborative patents between Japanese and European inventors often focus on improvements in wireless communication performance, spectrum efficiency, and network reliability.

Figure 89 – EU network of tech collaborations in mobile networks (5G/6G), 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/mobile-networks-5g-6g.html

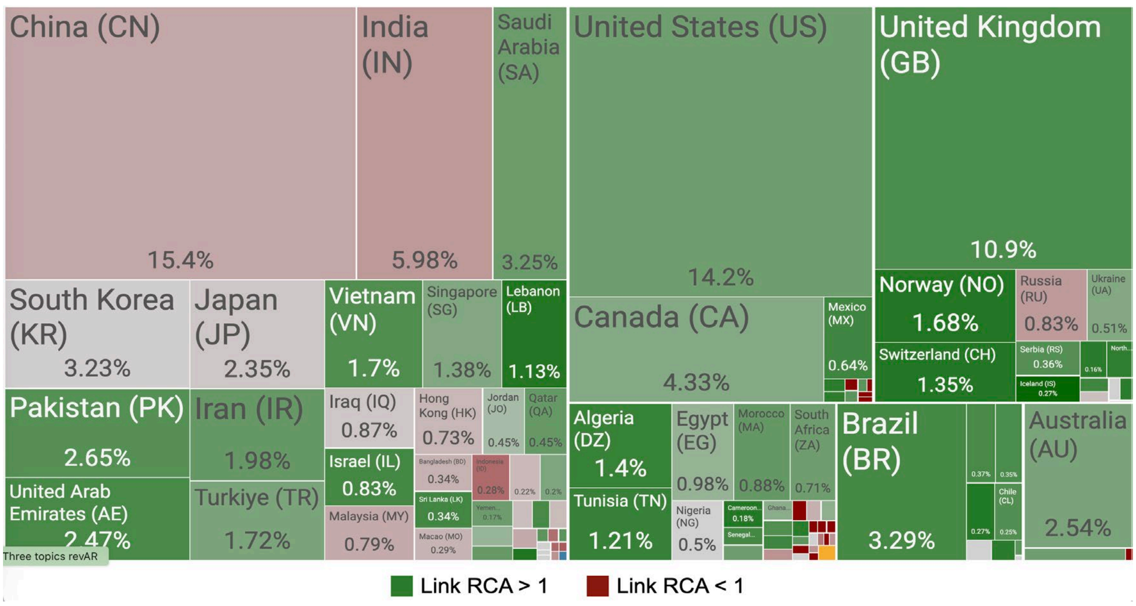
When looking at scientific collaborations, the structure of the research network involving the European Union differs from the technological collaboration pattern observed in patents. In this case, China slightly overtakes the United States as the EU's leading partner in scientific publishing, accounting for 15.4 % of co-authored publications, compared with 14.2 % for the United States. This reflects the rapid expansion of China's research output in telecommunications engineering, wireless networks, and next-generation communication systems over the past decade.

Despite this shift, the United States remains a central partner in the European research network, particularly in areas such as advanced wireless communication protocols, network virtualisation, and the integration of artificial intelligence into network management systems. Transatlantic research collaborations frequently involve universities, telecommunications research centres, and major technology companies working on the development of next-generation communication infrastructures.

The United Kingdom also plays an important role in the EU's scientific collaboration network, reflecting its strong academic presence in telecommunications engineering and digital network research. Similarly, India and Canada appear among the EU's major partners in scientific publications related to mobile network technologies. Both countries have developed significant research communities in wireless communications, distributed networks, and digital infrastructure technologies.

Beyond these leading partners, the scientific collaboration landscape is notably diverse. Countries such as Brazil, South Korea, Pakistan, Japan, and the United Arab Emirates also contribute to the EU's research network in this field. These collaborations often arise through international research initiatives focusing on topics such as ultra-reliable wireless communication, spectrum management, and the development of future 6G communication architectures.

Figure 90 – EU network of scientific collaborations in mobile networks (5G/6G), 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/mobile-networks-5g-6g.html

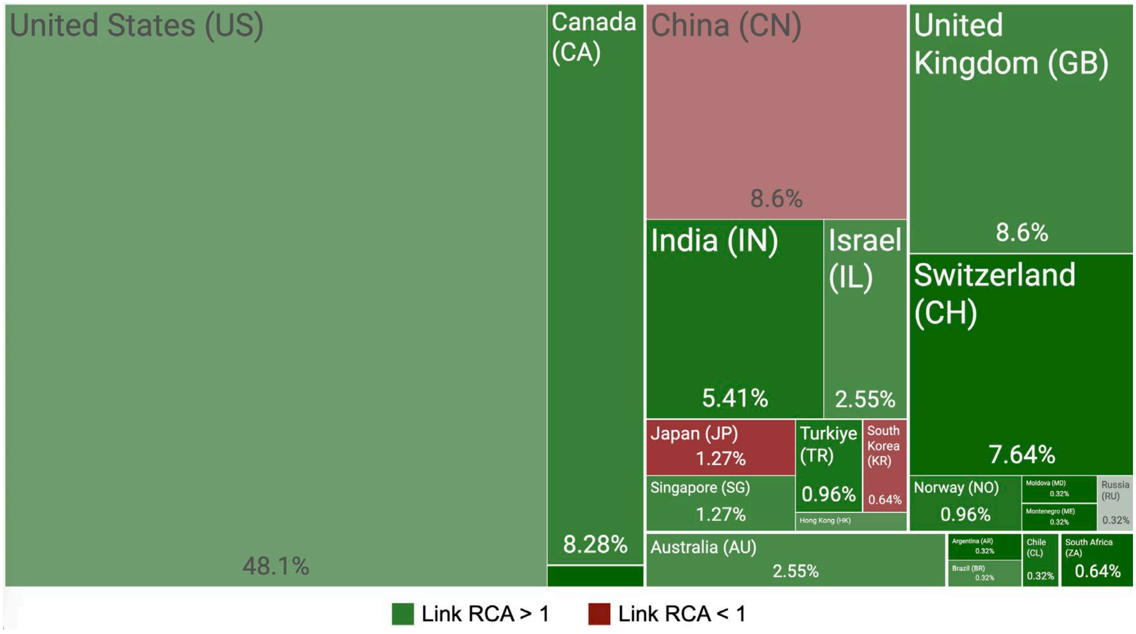
4.11. QUANTUM TECHNOLOGIES

In the domain of Quantum Technology, the technological collaboration network involving the European Union is highly concentrated around a small group of key innovation partners. As shown in Figure 90, the United States clearly dominates the EU's co-patenting landscape, accounting for 48.1 % of all quantum technology patents jointly filed with European inventors. This strong transatlantic partnership reflects the central role played by US research institutions, technology companies, and national laboratories in the development of quantum computing architectures, quantum communication systems, and quantum sensing technologies. Collaborative patents often emerge from joint research projects linking European universities, research centres, and firms with American institutions active in quantum information science.

Beyond the United States, a second group of partners contributes relatively similar shares of around 8 % each to the EU's co-patenting network in quantum technologies. This group includes Canada, China, the United Kingdom, and Switzerland. These countries host internationally recognised research centres in quantum physics and quantum engineering, and they play an important role in advancing innovations related to quantum algorithms, photonic quantum systems, and secure quantum communication infrastructures. Collaboration between European researchers and institutions in these countries often takes place through large international research projects and cross-border research teams working at the frontier of quantum science.

Additional partners contribute smaller but still meaningful shares to the EU's quantum technology co-patenting network. India accounts for 5.4 % of collaborative patents, reflecting the growing participation of Indian researchers and technology organisations in global quantum research initiatives. Meanwhile, Israel represents 2.6 % of EU co-patenting activity in this domain. Israel's presence reflects its strong research ecosystem in quantum information science, photonics, and advanced computing technologies, supported by close collaboration between universities, research institutes, and technology start-ups.

Figure 91 – EU network of technology collaborations in quantum technologies, 2010-2024



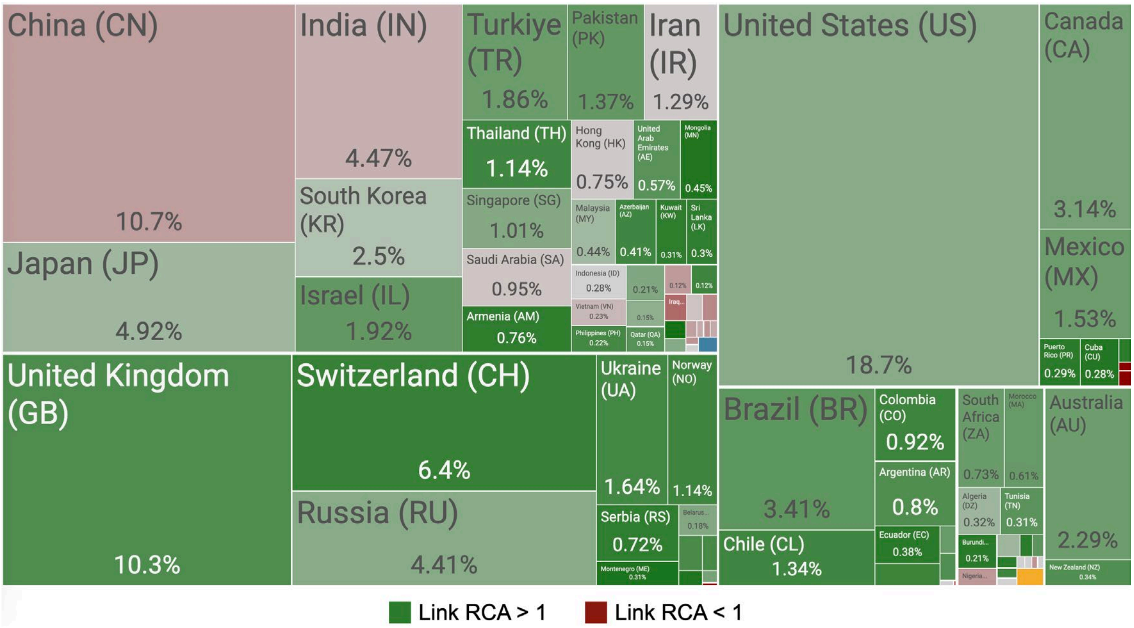
Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/quantum-technologies.html

Once again, the situation changes when looking at scientific publications, with a richer network of collaborations. As shown in Figure 92, the United States remains the EU's most important research partner, accounting for 18.7 % of co-authored scientific publications in quantum technologies. This strong transatlantic collaboration reflects the deep integration of European and American research infrastructures in quantum physics, quantum computing, and quantum communication systems.

China and the United Kingdom follow as the next most important partners, each accounting for slightly above 10 % of collaborative publications. China's growing role reflects the rapid expansion of its scientific research output in quantum information science, photonics, and quantum communication systems. Meanwhile, the United Kingdom maintains strong research capabilities in quantum computing and quantum technologies, supported by leading universities and research institutes that remain deeply integrated into European research networks.

Beyond these leading collaborators, the EU's scientific network in quantum technologies extends to a broader group of recurring research partners. Countries such as Switzerland, India, Canada, and Brazil continue to play a visible role in collaborative publications, reflecting their strong research communities in physics, photonics, and advanced computing. At the same time, the network also includes collaborations with countries such as Russia, Mexico, and Thailand, illustrating the global reach of scientific research in quantum technologies.

Figure 92 – EU network of scientific collaborations in quantum technologies, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/quantum-technologies.html

4.12. ROBOTICS

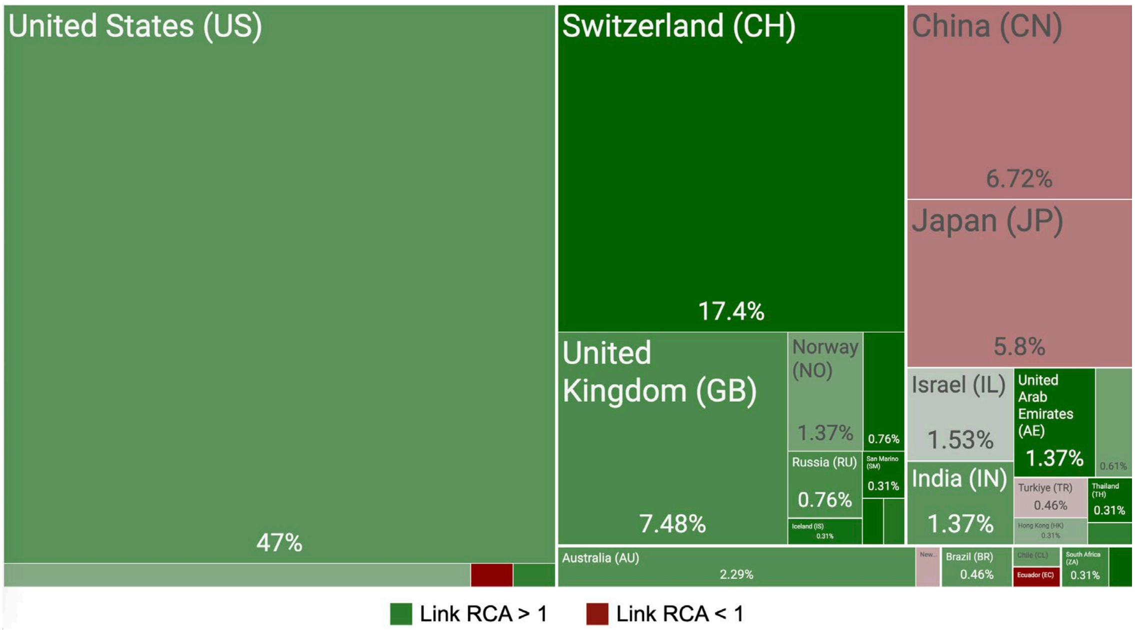
In the domain of Robotics, the technological collaboration network involving the European Union is again characterised by the strong presence of a few major partners. As shown in Figure 93, the United States clearly dominates the EU's co-patenting landscape, accounting for 47 % of all jointly filed robotics patents involving European inventors. This strong transatlantic partnership reflects the close integration of European and American research and industrial ecosystems in fields such as autonomous systems, intelligent machines, and advanced manufacturing technologies. Many collaborative patents relate to innovations in robotic control systems, machine perception technologies, and autonomous navigation platforms.

A particularly notable feature of the collaboration network is the prominent role of Switzerland, which accounts for 17.4 % of EU co-patenting activity in robotics. Switzerland's strong position reflects the presence of highly competitive research institutions and innovation ecosystems specialising in robotics, automation, and artificial intelligence. Universities and research laboratories in Switzerland are internationally recognised for their work on robotic manipulation, aerial robotics, and autonomous systems, and they frequently collaborate with European partners on advanced robotics technologies.

The United Kingdom represents the next most important partner, accounting for 7.5 % of EU co-patents in robotics technologies. British universities and technology firms have long been active in research on intelligent robotics, autonomous systems, and human–robot interaction, which contributes to ongoing collaboration with European research institutions and industrial partners.

Other important partners include China, accounting for 6.7 % of co-patenting activity, and Japan, which accounts for 5.8 % of EU collaborations in robotics technologies. Both countries have strong industrial and research capabilities in robotics, particularly in industrial automation systems, service robots, and advanced robotic components.

Figure 93 – EU network of technology collaborations in robotics, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/robotics.html

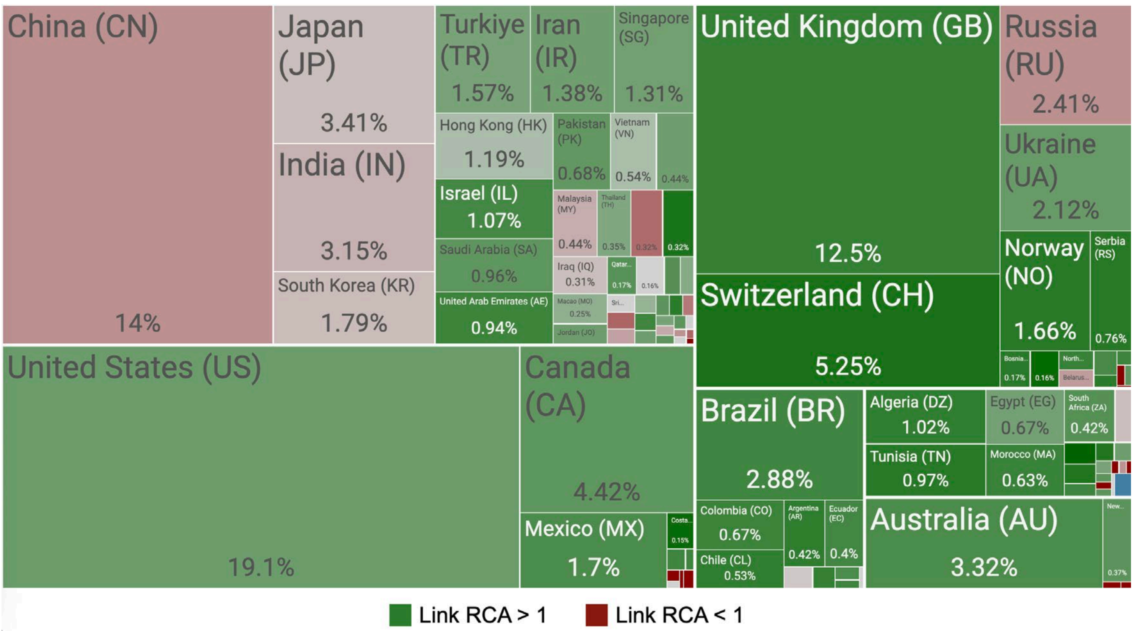
When examining scientific collaborations in Robotics, the structure of the research network involving the European Union appears broader and more balanced than the co-patenting landscape. The United States remains the EU's most important research partner, accounting for 19.1 % of co-authored scientific publications in robotics. This strong transatlantic collaboration reflects the close ties between European and American research institutions in fields such as autonomous systems, robotic perception, and human–robot interaction.

China follows with 14 % of EU co-publications, illustrating the rapid growth of China's scientific output in robotics, intelligent systems, and AI-enabled automation. Chinese universities and research institutes have significantly expanded their research activity in areas such as robotic vision, autonomous navigation, and collaborative robots, leading to increasing collaboration with European research teams.

The United Kingdom ranks third with 12.5 % of collaborative publications, reflecting the strong presence of British universities and research centres in robotics research. British institutions remain deeply integrated into European research networks and contribute extensively to joint scientific work on robotic control systems, machine learning for robotics, and intelligent manufacturing technologies.

Interestingly, scientific collaboration with some of the world's major industrial leaders in robotics appears comparatively more limited. Japan, traditionally one of the most advanced robotics innovation systems, accounts for 3.4 % of EU co-authored publications, while South Korea represents only 1.8 % of collaborations. This relatively modest presence may partly reflect the stronger role played by industrial research and proprietary innovation within these countries' robotics ecosystems, where technological development often takes place within corporate R&D environments rather than through academic publication.

Figure 94 – EU network of scientific collaborations in robotics, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/robotics.html

4.13. Satellite Connectivity

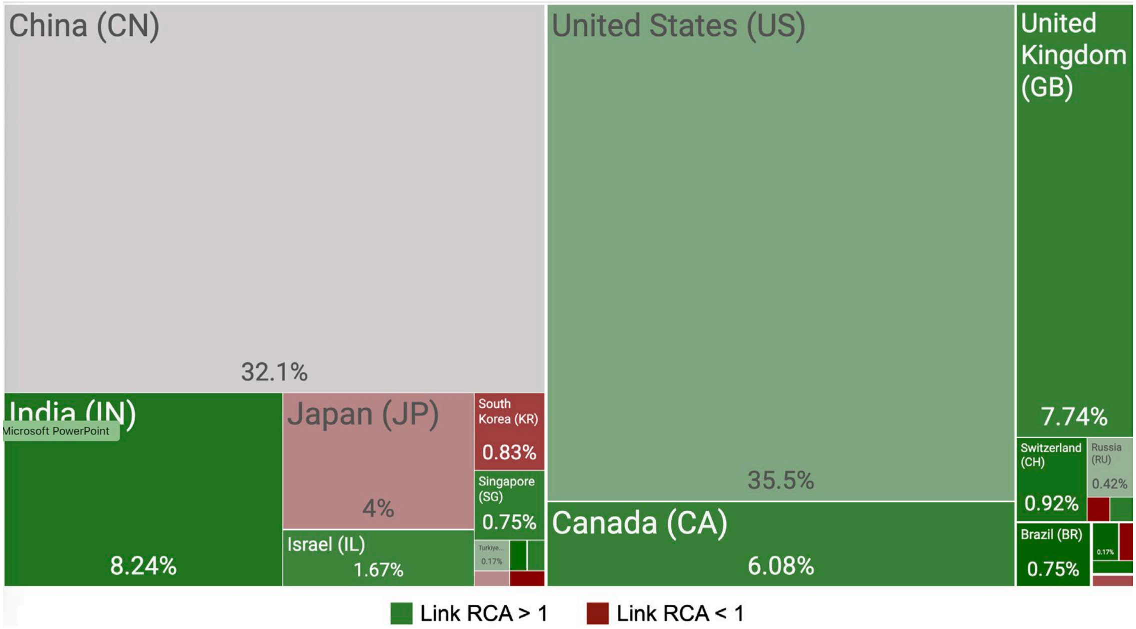
In the domain of Satellite Connectivity, the technological collaboration network involving the European Union shows a more balanced distribution among major global innovation partners than in several other technological fields. As illustrated in Figure 95, the United States and China are almost on a par as the EU's principal co-patenting partners, accounting for 35.5 % and 32.1 % of jointly filed patents, respectively. This reflects the strategic importance of satellite communication systems and space-based digital infrastructure, where innovation increasingly relies on international collaboration across major aerospace and telecommunications ecosystems.

The strong presence of the United States in the EU's co-patenting network reflects long-standing cooperation in aerospace technologies, satellite communication platforms, and space-based data systems. Transatlantic collaboration often involves research institutions, space agencies, and private aerospace companies working on technologies such as satellite communication payloads, ground infrastructure systems, and integrated space–terrestrial communication networks.

The similarly high share of collaboration with China reflects the rapid expansion of China's capabilities in space technologies and satellite communication infrastructures. Over the past decade, China has significantly strengthened its space technology ecosystem, including the development of satellite constellations, advanced communication systems, and space-based navigation technologies. These developments have increasingly led to collaborative innovation activities involving European research institutions and technology companies.

Beyond these two dominant partners, India and the United Kingdom also emerge as significant collaborators, each accounting for approximately 8 % of EU co-patenting activity in satellite connectivity technologies. India's presence reflects the growing capabilities of its space technology ecosystem and the role of its research institutions and aerospace industry in developing satellite communication systems. Meanwhile, the United Kingdom maintains strong expertise in satellite technologies, telecommunications infrastructure, and space engineering, which contributes to ongoing technological collaboration with European partners.

Figure 95 – EU network of technology collaborations in satellite connectivity, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/satellite-connectivity.html

When examining scientific collaborations in Satellite Connectivity, the structure of the research network involving the European Union differs from the technological collaboration landscape observed in patents. In this case, the United States emerges as the EU’s most important partner by a wider margin, accounting for 21.2 % of co-authored scientific publications in this domain. This strong transatlantic collaboration reflects the long-standing integration between European and American research communities in aerospace engineering, satellite communication systems, and space-based digital infrastructure technologies.

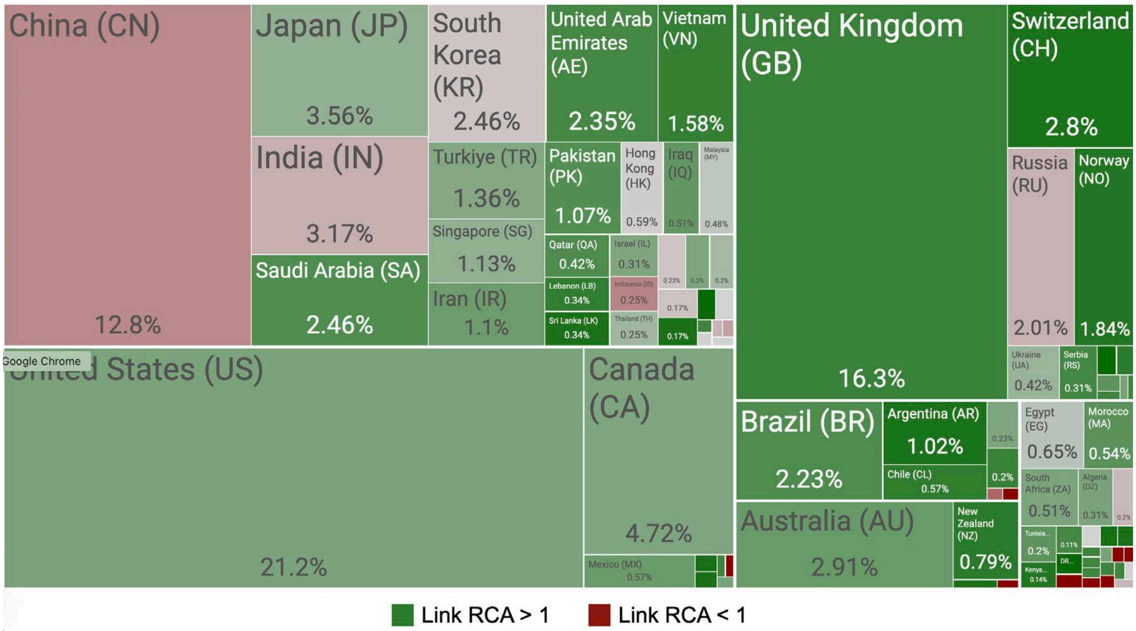
The United Kingdom appears as the second most important partner, accounting for 16.3 % of collaborative publications. British universities and research institutions have strong expertise in satellite engineering, space communications, and telecommunications technologies, and they remain deeply connected to European research networks in these areas.

China, which was almost on a par with the United States in the co-patenting landscape, holds a smaller share of scientific collaborations at 12.8 %. This reflects the rapid expansion of China’s research output in space technologies and telecommunications engineering, while also highlighting the stronger historical research ties between European and western scientific institutions.

Another notable partner is Canada, accounting for 4.7 % of EU co-authored publications. Canada has developed significant research capabilities in satellite communications, space technologies, and aerospace engineering, which contributes to its active participation in international scientific collaborations.

Beyond these leading partners, the scientific collaboration network extends to a broader group of countries, including Japan, India, Switzerland, Saudi Arabia, Australia, and Brazil. These collaborations often arise through international research projects focused on satellite communication architectures, space-based data transmission systems, and integrated terrestrial–satellite communication networks.

Figure 96 – EU network of scientific collaborations in satellite connectivity, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/satellite-connectivity.html

4.14. SEMICONDUCTORS AND CHIPS

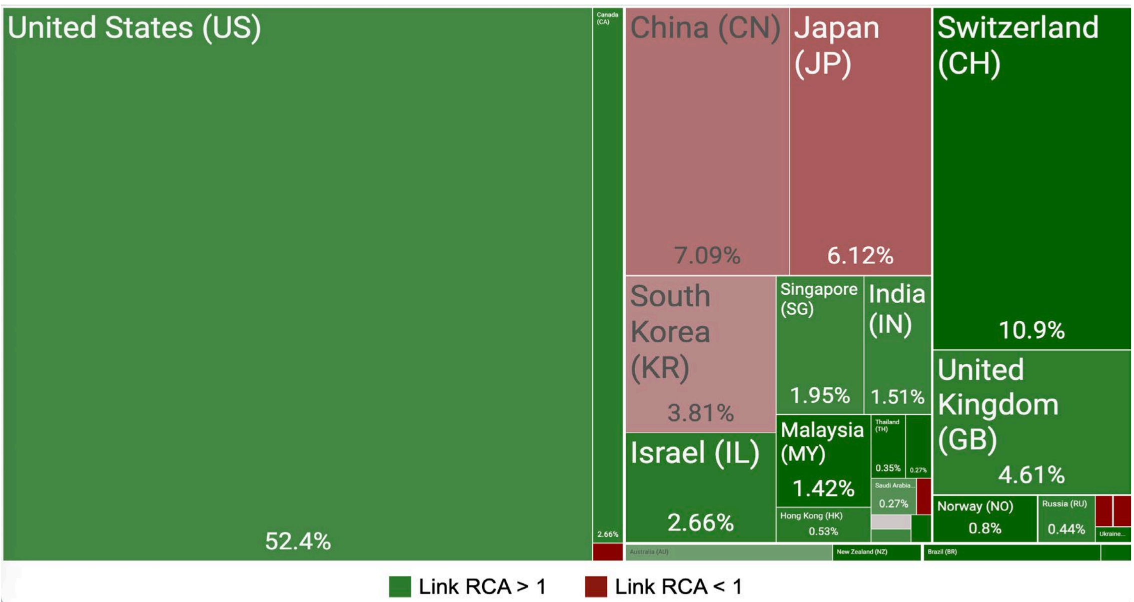
In the domain of Semiconductors, the technological collaboration network involving the European Union is strongly dominated by the United States, which accounts for 52.4 % of all co-patenting cases involving European inventors. This overwhelming share highlights the central role of transatlantic technological cooperation in the semiconductor industry, where innovation often emerges from complex global value chains linking chip designers, equipment manufacturers, and advanced research laboratories. Collaborative patents between European and American organisations frequently concern processor architectures, semiconductor manufacturing processes, and advanced materials used in next-generation microchips.

A notable feature of the collaboration network is the strong presence of Switzerland, which accounts for 10.9 % of EU co-patenting activity in this technological domain. Switzerland's prominent role reflects the presence of highly specialised firms and research institutions involved in semiconductor design, electronic components, and microelectronics engineering. These actors often collaborate closely with European partners on innovations related to chip design, embedded systems, and advanced electronic devices.

By contrast, collaboration with major semiconductor manufacturing countries appears somewhat more limited. China accounts for 7.1 % of EU co-patenting activity, while Japan represents 6.1 % of collaborative patents in this field. Both countries maintain strong capabilities in semiconductor technologies, particularly in manufacturing equipment, materials, and advanced chip design, but the level of direct technological collaboration with European inventors appears lower than that observed with the United States or Switzerland.

The United Kingdom appears as a comparatively smaller partner in this domain, accounting for 4.6 % of EU co-patenting cases in semiconductors and chips. While the United Kingdom hosts significant expertise in microelectronics research and chip design – particularly through universities and specialised technology firms – its level of technological collaboration with EU partners in semiconductor patenting appears more limited compared with several other key strategic technologies.

Figure 97 – EU network of technology collaborations in semiconductors and chips, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/semiconductors-chips.html

When examining scientific collaborations in Semiconductors, the structure of the research network involving the European Union appears significantly more diversified than the technological collaboration landscape observed in patents. Although the United States remains the EU's most important scientific partner, accounting for 19.2 % of co-authored publications, the distribution of collaborations is more balanced across several major research systems.

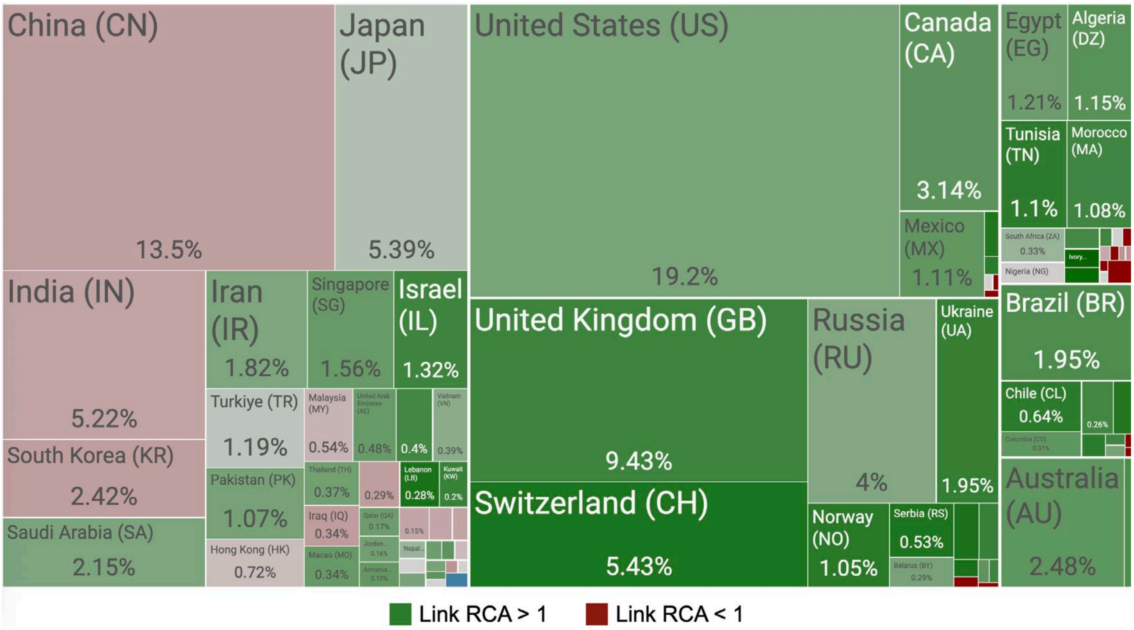
China emerges as the second most important partner, with 13.5 % of EU co-publications in semiconductor-related research. This strong presence reflects the rapid expansion of China's scientific output in microelectronics, semiconductor materials, and integrated circuit design. Chinese universities and research institutes have significantly increased their participation in international collaborations addressing challenges related to advanced chip architectures, nanotechnology-based components, and semiconductor fabrication technologies.

The United Kingdom follows with 9.4 % of collaborative publications, reflecting its strong academic capabilities in microelectronics engineering, semiconductor physics, and electronic system design. British universities remain closely connected to European research networks and contribute substantially to joint research projects in semiconductor technologies.

Beyond these leading partners, the EU's scientific collaboration network in semiconductors includes a wider group of recurring partners. Countries such as Switzerland, India, Russia, Australia, and South Korea regularly co-author publications with European researchers. These collaborations often focus on areas such as semiconductor materials science, nanoscale electronics, and next-generation chip architectures.

Interestingly, the network also includes collaborations with countries such as Ukraine and Brazil, each accounting for shares close to 2 % of EU co-authored publications. Although smaller in scale, these collaborations illustrate the broad international reach of semiconductor research and the participation of a diverse range of research communities in advancing microelectronics technologies.

Figure 98 – EU network of scientific collaborations in semiconductors and chips, 2010-2025



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/semiconductors-chips.html

4.15. SOFTWARE ENGINEERING AND SYSTEM DEVELOPMENT

In the domain of Software Engineering and Systems Development, the technological collaboration network involving the European Union once again highlights the strong prominence of the United States as a key innovation partner. As shown in Figure 97, the United States accounts for 46.5 % of all co-patenting cases involving European inventors in this technological domain. This strong transatlantic collaboration reflects the central role of American technology firms and research institutions in the global software ecosystem. Many innovations in areas such as software architectures, distributed systems, cloud platforms, and enterprise software solutions emerge from collaborative research and development activities linking European organisations with US-based technology companies.

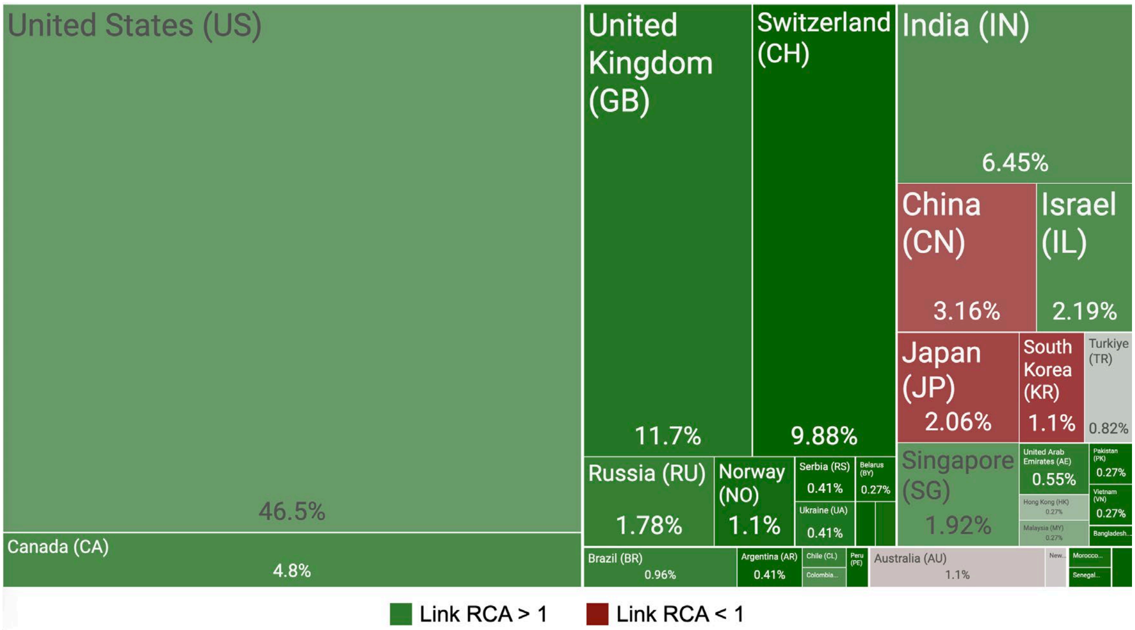
In contrast with several other key strategic technologies, China appears as a relatively minor partner in the EU's co-patenting network in software engineering and system development, accounting for only 3.2 % of collaborative patents. While China has developed strong capabilities in digital technologies and software applications, technological collaboration with European inventors in the form of joint patents appears comparatively limited in this specific domain.

Instead, several countries with strong software engineering traditions emerge as more prominent partners for the European Union. The United Kingdom represents the second most important partner, accounting for 11.7 % of EU co-patented inventions in software engineering and system development. British universities and technology firms have long been active in research on software architectures, distributed computing systems, and digital platforms, which contributes to ongoing collaboration with European partners.

Similarly, Switzerland accounts for 9.9 % of EU co-patenting activity in this field. Switzerland hosts several highly competitive research institutions and technology companies specialising in software systems, computer science, and digital infrastructure technologies, which explains its strong presence in collaborative innovation activities.

Another important partner is India, accounting for 6.5 % of EU co-patented inventions. India's strong participation reflects the global integration of its software engineering sector, which plays a major role in the development of enterprise software systems, digital platforms, and large-scale information technologies. Collaborative patents between Indian and European inventors often emerge from multinational technology companies operating across multiple global research and development centres.

Figure 99 – EU network of technology collaborations in software engineering and systems development, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/regpat/european-union-eu/software-engineering-&-system-development.html

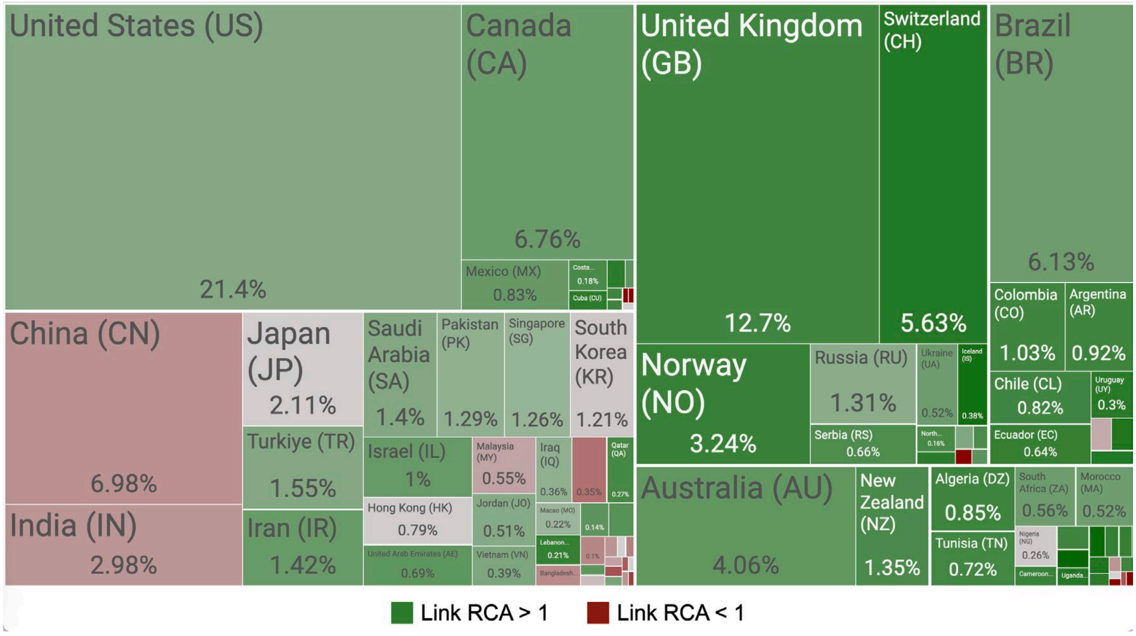
When examining scientific collaborations, the United States is by far the most important research partner of the EU, accounting for 21.4 % of co-authored publications. This strong transatlantic collaboration reflects the deep integration of European and American research communities in computer science and software systems research. Universities and research institutes on both sides of the Atlantic frequently collaborate on topics such as distributed systems, software architectures, programming languages, and large-scale computing infrastructures.

The United Kingdom emerges as the second most important partner, accounting for 12.7 % of collaborative publications. British universities maintain strong research capabilities in software engineering, systems design, and computer science more broadly, and they remain deeply embedded in European academic networks despite institutional changes following Brexit.

By contrast, China holds a significantly smaller share of EU scientific collaborations in this domain, accounting for less than 7 % of co-publications. China's share is comparable to that of Canada and Brazil, both of which contribute similar proportions of joint publications with European researchers. These collaborations often arise in areas such as distributed computing systems, cloud platforms, and software reliability engineering.

Somewhat surprisingly, India – despite its globally recognised strength in software development – accounts for only around 3 % of EU co-authored publications in software engineering and system development. This share is lower than that of Australia, which accounts for around 4 % of collaborations with European researchers. One possible explanation is that India's comparative advantage in software technologies is more strongly expressed in industrial and service activities than in academic research output.

Figure 100 – EU network of scientific collaborations in software engineering and systems development, 2010-2024



Source: https://www.paballand.com/ceps/ttd/networks/openalex/european-union-eu/software-engineering-&-system-development.html

4.16. SYNOPSIS

A clear structural pattern emerges across the 15 key strategic technologies examined. Technological collaboration networks (measured through co-patenting) are strongly concentrated, whereas scientific collaboration networks are significantly more diversified.

Across almost all domains, the United States is the dominant technological partner of the European Union. The US leads EU co-patenting collaborations in areas such as artificial intelligence, robotics, high-performance computing, semiconductors, cybersecurity, software engineering, and IoT. In several domains the US share exceeds 40 % or even 50 % of co-patenting cases, illustrating the depth of transatlantic technological integration. This reflects the central role played by US technology companies, research laboratories, and digital platforms in global innovation systems.

A second important pattern concerns the growing presence of China. China appears as a major co-patenting partner in several technological infrastructures, including cloud computing, cybersecurity, mobile networks, IoT, and satellite connectivity. In some cases, such as mobile networks and satellite technologies, China approaches parity with the

United States in technological collaboration with European inventors. However, China remains less present in certain domains, particularly software engineering and robotics.

A third group of partners emerges across several technologies. The United Kingdom remains a key partner of the EU in technological collaboration across many sectors, particularly AI, cloud computing, cybersecurity, robotics, and telecommunications technologies. Switzerland stands out in specialised high-technology domains such as robotics, semiconductors, and software systems, reflecting the strong technological capabilities of its research institutions and innovation ecosystem. Meanwhile, India appears frequently in collaborations in software engineering, telecommunications technologies, and AI-related domains, reflecting its large pool of software engineers and integration into global technology value chains.

In contrast to the patent landscape, scientific collaboration networks are far more geographically distributed. Although the United States remains a central partner in most research collaborations, its dominance is considerably weaker. In several technological areas – including Generative AI, IoT, mobile networks, and drone technologies – China becomes the leading partner of the EU in scientific publishing. This reflects China's rapidly expanding research output in engineering and computer science.

The United Kingdom consistently ranks among the top scientific collaborators of the EU across most domains, illustrating the continued integration of British universities within European research networks. Switzerland, Canada, and India also appear frequently as strong research partners.

Another notable feature of the scientific collaboration networks is their global diversity. EU researchers collaborate with a wide range of countries beyond the traditional advanced innovation systems. Recurring partners include Australia, Brazil, South Korea, Saudi Arabia, Norway, Pakistan, Türkiye, Iran, Mexico, Thailand, and the United Arab Emirates. This broader geographic distribution reflects the open nature of academic research and the increasing global diffusion of scientific capabilities in emerging technological fields.

Overall, the comparison between technological and scientific collaboration networks highlights a structural difference in how innovation systems operate. Technological cooperation tends to concentrate around a small number of highly industrialised innovation systems, particularly the United States and China. Scientific collaboration networks, by contrast, are far more globally distributed, reflecting the collaborative nature of academic research and the internationalisation of scientific knowledge production.

For the European Union, this dual structure demonstrates a strong integration within global research and innovation networks. Transatlantic cooperation remains a cornerstone of Europe's technological innovation ecosystem, while scientific collaborations extend across a much broader global research community.

Table 2 – Summary of findings – EU technology and scientific networks of collaboration

KST	Main technological partner(s) (co-patenting)	Secondary technological partners	Main scientific partner(s) (co-publications)	Secondary scientific partners
Artificial Intelligence	United States	UK, India, Switzerland, China, Canada	United States / China	UK, Switzerland, Canada, India
Generative AI	United States	India, UK, China, Switzerland	China	United States, UK, Switzerland, India
Blockchain	United States	UK, India, Switzerland, Canada	United States	UK, China, India
Cloud & Edge Computing	United States	China, UK, India, Canada	United States	China, UK, India
Computer Vision, NLP & Object Recognition	United States	UK, Switzerland, India	United States	China, UK
Cybersecurity	United States	China, UK, India, Canada	United States	UK, China
Drone Technologies	United States	UK, Switzerland, China	China	United States, UK, Saudi Arabia, UAE

High-Performance Computing	United States	UK, China, Canada, Switzerland	United States	UK, China, Switzerland
Internet of Things	United States	China, UK, Switzerland, India	China	United States, UK, India
Mobile Networks (5G/6G)	United States, China	UK, India, Canada	China	United States, UK
Quantum Technologies	United States	Canada, China, UK, Switzerland	United States	China, UK
Robotics	United States	Switzerland, UK, China, Japan	United States	China, UK
Satellite Connectivity	United States, China	India, UK	United States	UK, China
Semiconductors & Chips	United States	Switzerland, China, Japan	United States	China, UK
Software Engineering & Systems Development	United States	UK, Switzerland, India	United States	UK, Canada, Brazil

5. COMPLEMENTARITIES BETWEEN SELECTED COUNTRIES

Potential technological complementarity between countries is measured following the framework developed by Pierre-Alexandre Balland and Ron Boschma (2021), which builds on the concept of technological relatedness and diversification in innovation systems. The approach is designed to identify whether the technological capabilities of one country may support another country's ability to develop or expand into a given technological domain.

For a given country and a specific target technology, the indicator evaluates whether another country possesses capabilities in technologies that are related to the target technology but currently absent in the technological portfolio of the country of interest. The idea underlying the method is that technological diversification tends to occur in activities that are cognitively or technologically related to existing capabilities. Therefore, if a partner country is specialised in technologies that are strongly related to a target technology, it may provide useful complementary knowledge that could facilitate the focal country's development in that field.

Technological relatedness is typically estimated using co-occurrence patterns in large datasets of patents or scientific publications. Technologies that frequently appear together in the same patents or publications are interpreted as being technologically related, as they likely rely on similar knowledge bases, scientific principles, or production capabilities. By analysing these co-occurrence patterns across a large number of technological classifications, it is possible to construct a network of related technologies that captures the structure of the technological space.

National technological capabilities are identified through measures of technological specialisation, commonly using a revealed technological advantage (RTA) index. This indicator compares the share of a given technology in a country's patenting or publication portfolio with the corresponding share at the global level. If the index exceeds a certain threshold – typically greater than 1 – the country is considered to possess a specialisation or capability in that technology. This step therefore maps the technological strengths of each country across the different technological domains.

Potential complementarity is then computed by combining these two elements. For each country and target technology, the indicator evaluates how strongly the target technology is related to the set of technologies in which another country is specialised. This is done by weighting the technological relatedness between the target technology and all technologies in which the partner country has a revealed technological advantage. The higher the resulting score, the greater the potential complementarity between the two countries.

Importantly, the resulting measure captures latent complementarity between national technological portfolios rather than actual collaboration. In other words, it identifies whether another country possesses technological capabilities that could theoretically support the focal country's diversification into the target technology, regardless of whether formal partnerships, research collaborations, or industrial linkages currently exist. The indicator therefore provides insight into possible future pathways for technological cooperation and knowledge exchange between countries.

By highlighting complementarities in technological capabilities, this approach offers a useful tool for understanding how international innovation systems may evolve and where opportunities for mutually beneficial technological collaboration may emerge.

Below, we show the complementarity results for three selected KSTs: Artificial Intelligence, Quantum computing, and Semiconductors and Microchips. Graphs for patents and publications for all 15 KSTs are of course available for consultation in interactive format at this link.

Figure 101 illustrates the potential technological complementarities between the European Union and other countries in the domain of Artificial Intelligence. The analysis identifies those countries whose technological capabilities are most closely related to the EU's technological portfolio but remain partially absent from it, thereby indicating promising opportunities for collaboration and knowledge exchange.

From the perspective of patent-based technological capabilities, the United States emerges as the most complementary partner of the EU. This strong complementarity reflects the leading role of the United States in several AI-related technological domains where European specialisation remains comparatively weaker, such as large-scale machine learning architectures, advanced data processing systems, and AI-enabled digital platforms. Collaboration with US partners therefore offers significant opportunities for European actors to access technological capabilities that are closely related to their own innovation activities but not yet fully developed within the European technological ecosystem.

Beyond the United States, the EU also displays significant technological complementarities with Canada, India, and South Korea. Canada has developed internationally recognised expertise in areas such as deep learning, reinforcement learning, and advanced machine learning algorithms. India contributes complementary strengths related to software engineering, AI-enabled services, and large-scale data applications. Meanwhile, South Korea's strong capabilities in electronics, semiconductors, and digital infrastructures complement European technological capacities in AI-enabled industrial systems and smart manufacturing.

When examining scientific complementarities based on research publications, a slightly different pattern emerges. In this case, India appears as one of the most complementary research partners for the EU. The growing presence of Indian researchers in machine learning, data science, and AI applications has created strong opportunities for knowledge exchange and collaborative research with European institutions. Similarly, South Korea stands out as another highly complementary partner in the scientific landscape, reflecting its strong research output in artificial intelligence, robotics, and intelligent systems.

Figure 101 – Complementarities between select countries in AI – based on patent and publications data

(a) Patents (RegPat) (b) publications (OpenAlex)

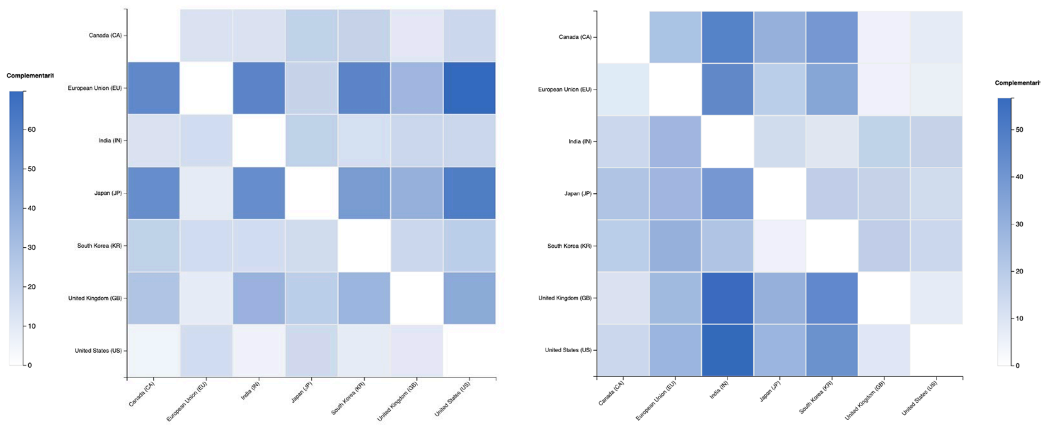


Figure 102 illustrates the pattern of technological complementarities between the European Union and other countries in the field of quantum technology. From the perspective of patent-based technological capabilities, the analysis indicates that Canada and the United States are the countries most complementary with the European Union. Both countries host highly advanced innovation ecosystems in quantum computing, quantum communication, and quantum sensing technologies. Canada has developed internationally recognised expertise in quantum information science and photonics-based quantum systems, while the United States plays a leading role in the development of quantum computing architectures, quantum algorithms, and large-scale quantum hardware platforms. These strengths complement European capabilities in areas such as quantum physics research, photonics, and quantum materials.

Other countries also display moderate but still significant levels of technological complementarity with the EU. In particular, Japan, South Korea, and India appear as relevant partners in the technological landscape. Japan contributes strong capabilities in quantum materials, superconducting devices, and advanced electronics, while South Korea's expertise in semiconductors and advanced electronic systems provides complementary strengths for the development of scalable quantum hardware. India, for its part, has been expanding its research and innovation activities in quantum communication systems and quantum algorithms, which complement existing European research capacities.

When examining scientific complementarities based on research publications, the pattern differs slightly. In this case, India, Japan, and South Korea emerge as the most complementary research partners for the European Union. These countries possess strong scientific capabilities in fields closely related to quantum technologies, including condensed matter physics, photonics, and advanced computing systems. Their research portfolios contain knowledge areas that are closely related to, but not entirely overlapping with, the EU's existing scientific strengths.

Figure 102 – Complementarities between select countries in quantum technologies – based on patent and publications data

(a) Patents (RegPat) (b) publications (OpenAlex)

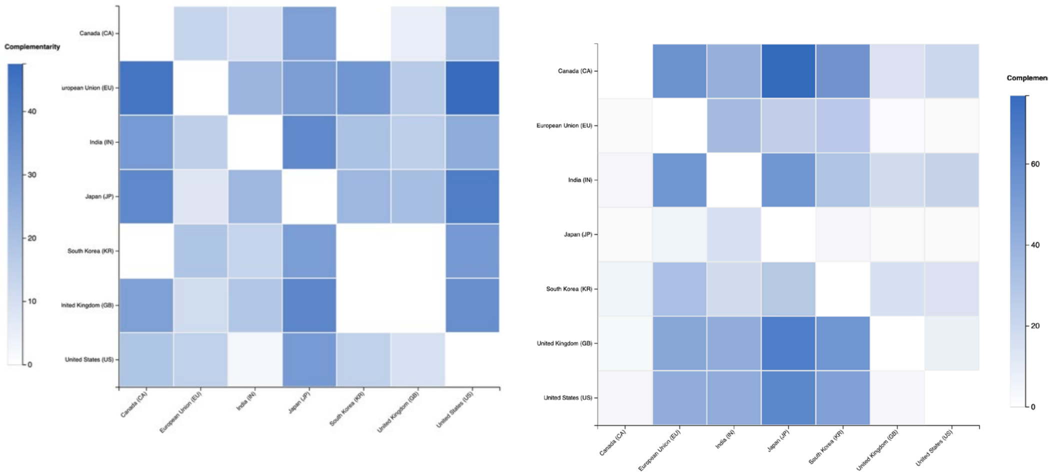


Figure 103 examines international complementarities between the European Union and other countries in the domain of Semiconductors and Chips. Compared with other key strategic technologies analysed previously, the complementarity pattern in this sector appears somewhat less pronounced, indicating that the EU already shares a relatively similar technological specialisation profile with several global semiconductor producers. As a result, fewer countries exhibit strong complementarities with the EU's existing patent portfolio.

From a technological perspective based on patents, Japan stands out as the country most complementary with the EU. Japan possesses strong capabilities in semiconductor manufacturing equipment, advanced materials, and precision electronics – areas that are closely related to, but not fully overlapping with, Europe's technological strengths. These complementary capabilities suggest that deeper technological collaboration between European and Japanese actors could support the development of advanced semiconductor supply chains, particularly in areas such as chip manufacturing processes, specialised components, and high-performance electronic systems.

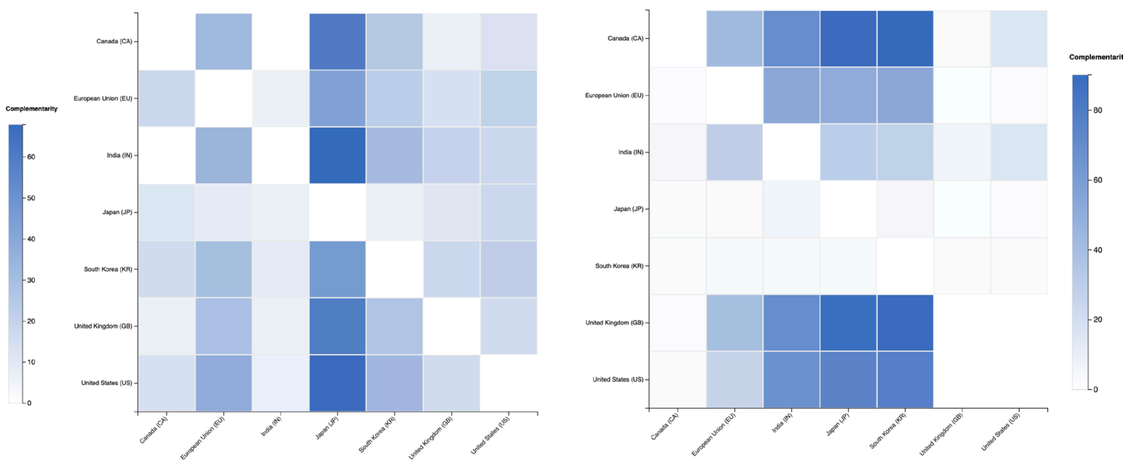
Other countries show comparatively lower levels of technological complementarity with the EU in the semiconductor domain. This reflects the highly integrated and mature nature of the global semiconductor innovation ecosystem, where technological capabilities tend to be concentrated in a limited number of advanced industrial systems.

When examining scientific complementarities, however, the picture becomes somewhat broader. The analysis indicates that India, Japan, and South Korea display the highest levels of complementarity with the EU. These countries possess strong research capabilities in areas related to semiconductor technologies, including microelectronics engineering, materials science, and nanoscale device architectures.

India's research ecosystem contributes complementary expertise in microelectronics design and computational engineering, while South Korea's strong capabilities in semiconductor manufacturing and electronic systems provide additional scientific strengths relevant to next-generation chip technologies. Japan again appears prominently due to its long-standing scientific expertise in semiconductor materials, electronic devices, and photonics.

Figure 103 – Complementarities between countries in semiconductors & chips – based on patent and publications data

(a) Patents (RegPat) (b) publications (OpenAlex)



6. KEY HIGHLIGHTS AND FUTURE RESEARCH

The global innovation landscape across 15 KSTs is characterised by increasing technological complexity, the globalisation of knowledge production, and strong geographic concentration of industrial innovation capabilities. An integrated analysis of technological specialisation, scientific output, venture capital investment, and international collaboration networks reveals the multifaceted position of the European Union within this evolving system. Across technologies such as AI, quantum technologies, semiconductors, robotics, telecommunications infrastructures, and digital systems, the evidence points to a global innovation ecosystem structured around multiple interconnected layers. These layers include industrial technological leadership, global research networks, and geographically concentrated entrepreneurial ecosystems (Balland & Boschma, 2021; OECD, 2023).

From the perspective of technological specialisation, measured through patent activity, global technological leadership remains concentrated among a relatively small group of advanced industrial economies. The United States and China consistently emerge as the dominant actors across several of the selected KSTs. The United States maintains a leading position in AI, robotics, cybersecurity, HPC, and software systems. This technological leadership reflects the strength of its research universities, large technology firms, and integrated venture capital ecosystem supporting high-risk innovation (Cockburn, Henderson, & Stern, 2019). In contrast, China has developed particularly strong technological capabilities in telecommunications infrastructure, IoT, and mobile network systems, while rapidly expanding its patent activity in AI and digital platforms (WIPO, 2023).

Other advanced economies exhibit strong specialisation in particular technological sectors. Japan remains a major technological power in semiconductors, robotics, and advanced electronics, reflecting its long-standing strengths in precision manufacturing and component technologies. Similarly, South Korea holds a prominent position in semiconductor manufacturing and digital infrastructure technologies, supported by globally competitive electronics companies. The European Union demonstrates strong technological capabilities in several industrial and infrastructure technologies – including robotics, satellite connectivity, and certain advanced manufacturing systems – although its technological specialisation often appears more fragmented across Member States (European Commission, 2023).

The global landscape of scientific specialisation, measured through research publications, presents a different picture. Scientific knowledge production is significantly more geographically distributed than technological patenting activity. China has emerged as the world's largest producer of scientific publications in several technology domains, including AI and robotics. This growth reflects large-scale national investments in research infrastructure and the rapid expansion of the country's higher education system (Zhang et al., 2022). The European Union also performs strongly in terms of research output and is among the world's largest producer of scientific publications across many technological domains, including quantum technologies, robotics, and software engineering (European Commission, 2023). In contrast, the United States often produces fewer scientific publications relative to its technological output in certain domains, reflecting the strong role of private sector research and proprietary technological development within its innovation system. Another notable feature of the global scientific landscape is the growing role of India, which appears as a major contributor to scientific research in fields such as distributed computing, cloud systems, and AI applications. This development reflects the scale of India's engineering and computer science research communities as well as the global integration of its information technology sector (OECD, 2023).

A third dimension of the innovation ecosystem concerns venture capital investment, which plays a critical role in translating scientific and technological breakthroughs into commercial innovation. In contrast with the relatively distributed nature of scientific research, venture capital investment remains highly geographically concentrated. The United States dominates global venture capital activity across most emerging digital technologies, including AI, software systems, and computer vision. This dominance reflects the maturity of the American venture capital ecosystem and its strong integration with research universities and technology clusters such as Silicon Valley (Gompers, Gornall, Kaplan, & Strebulaev, 2021). Other countries host important but smaller venture capital ecosystems. China maintains significant investment activity in digital infrastructure technologies and semiconductor start-ups, supported by strong domestic technology companies. Innovation hubs such as the United Kingdom, Israel, Singapore, and Canada also play a visible role in the global venture capital landscape, particularly in sectors such as cybersecurity and AI.

The analysis of international collaboration networks highlights the strong interdependence of global innovation systems. In technological collaboration networks measured through co-patenting activity, the United States consistently emerges as the most important partner of the European Union across nearly all technological domains. In sectors such as semiconductors, high-performance computing, robotics, and software engineering, a substantial share of EU patents involves American co-inventors. This pattern reflects the deep integration of transatlantic innovation ecosystems and the global value chains that connect research institutions, multinational companies, and advanced manufacturing systems. China also appears as an important technological partner for the EU in several infrastructure-related technologies, particularly mobile networks, Internet of Things systems, and satellite connectivity. Other recurring technological partners include the United Kingdom, Switzerland, Canada, India, and Japan. These countries contribute complementary technological capabilities across multiple domains and play an important role in collaborative innovation activities.

In contrast, scientific collaboration networks are far more geographically distributed. While the United States remains a central partner in many research collaborations, countries such as China, the United Kingdom, Switzerland, Canada, and India also appear prominently in co-authored scientific publications with European researchers. Moreover, the EU collaborates with a wide range of additional countries – including Australia, Brazil, Saudi Arabia, Norway, Pakistan, Türkiye, and the United Arab Emirates – illustrating the global reach of academic research networks.

Finally, the analysis of technological complementarities provides insights into potential strategic partnerships that could strengthen the EU's innovation ecosystem. Complementarity analysis identifies countries whose technological capabilities are closely related to – but not fully overlapping with – the EU's existing technological portfolio. In AI, the EU appears strongly complementary with the United States, Canada, India, and South Korea. In quantum technologies, Canada and the United States emerge as the most complementary technological partners, while scientific complementarities appear stronger with India, Japan, and South Korea. In the semiconductor domain, Japan stands out as the most complementary technological partner, while India and South Korea display strong complementarities in scientific research.

Table 3 summarises our findings.

Table 3 – Summary of findings per selected country and specialisation

Country	Technological specialisation	Scientific specialisation	Venture capital ecosystem
United States	AI, software systems, cybersecurity, semiconductors, HPC	AI, computing systems	global leader
China	telecommunications, IoT, cloud infrastructure	AI and telecom research	strong domestic VC
Japan	semiconductors, robotics, electronics	materials science, quantum physics	moderate

South Korea	semiconductors, telecom hardware	electronics engineering	growing
United Kingdom	AI, cybersecurity, fintech	computer science	strong European VC hub
Switzerland	robotics, advanced electronics	AI research	specialised innovation ecosystem
India	software engineering, digital services	AI, distributed systems	rapidly growing
Canada	AI, advanced computing	machine learning research	strong AI start-up hub
Israel	cybersecurity, AI applications	computer science	highly dynamic
Singapore	digital infrastructure, fintech	computing research	strong regional VC hub

REFERENCES

Balland, P.-A., & Boschma, R. (2021). Complementary Interregional Linkages and Smart Specialization: An Empirical Study on European Regions. *Regional Studies,* 55(6), 1059-1070.

Cockburn, I. M., Henderson, R., & Stern, S. (2019). The Impact of Artificial Intelligence on Innovation. NBER Working Paper No. 24449.

European Commission. (2023). Science, Research and Innovation Performance of the EU 2023. European Commission.

Gompers, P., Gornall, W., Kaplan, S., & Strebulaev, I. (2021). Venture Capitalists and the Governance of Start-ups. *Journal of Financial Economics*, 142(1), 1-27.

OECD. (2023). OECD Science, Technology and Innovation Outlook 2023. OECD Publishing.

WIPO. (2023). World Intellectual Property Report 2023: Innovation and Global Value Chains. World Intellectual Property Organization.

Zhang, D., Mishra, S., Brynjolfsson, E., et al. (2022). The AI Index Report 2022. Stanford Institute for Human-Centered Artificial Intelligence.

CEPS
PLACE DU CONGRES 1
B-1000 BRUSSELS