Mapping the global quantum ecosystem

A comprehensive analysis based on innovation, firm, investment, skills, trade and policy data

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Forewords

The year 2025 marks a century since the initial development of quantum mechanics. Today, quantum technologies are being developed using these principles to expand the frontiers of human knowledge and solve complex problems beyond the reach of conventional digital technologies. Quantum technologies have the potential to enable powerful new forms of computing, safeguard critical communications and achieve levels of precision in sensing and measurement that enable groundbreaking advancements, ranging from medical imaging to navigation to environmental monitoring.

Governments across the world have acknowledged the potential of quantum technologies to reshape industries and drive scientific breakthroughs and are taking policy action. Over 30 countries have formulated tailored policies to support the responsible development and adoption of quantum technologies, including 18 OECD countries that have comprehensive national quantum strategies.

To support the design and implementation of these policies, this report provides a comprehensive overview of the ecosystems that sustain quantum technologies. It charts the development of quantum technologies through a dynamic network of actors: research institutions, innovative start-ups, established firms, investors, and public authorities. It also provides new analysis, including on investment patterns and skills demand, as well as initial evidence on trade flows related to equipment, goods and raw materials that are relevant for quantum technologies. Based on this analysis, the report provides key insights for governments seeking to design policies that foster innovation and presents an assessment of government efforts to promote and stimulate the development of quantum technologies.

This study was prepared in collaboration with the European Patent Office (EPO) and draws on multiple data sources to shed light on the science, firms, investments, skills, trade flows, and policies that characterise the quantum ecosystem. This collaboration provides unique insights into the evolution of quantum technologies' ecosystems, underscoring the value of international co-operation in building a robust evidence base for sound policymaking in fast-moving fields.

Building on related OECD work, including our Quantum Technologies Policy Primer (2025) and Overview of National Strategies and Policies for Quantum Technologies (2025), this report contributes to the Organisation's effort to deepen the evidence base and promote international co-operation among its membership to identify policies and best practices for the responsible development and deployment of quantum technologies.

We are committed to helping policymakers navigate the opportunities and challenges of this new frontier, and to shape a quantum technology-enabled future that delivers broad benefits for our economies and societies.

Mathias Cormann
OECD Secretary General

Quantum technologies have the potential to drive broad societal progress. They could deliver unprecedented advances in communication security, computational performance and sensing capabilities, with benefits reaching from defence to healthcare and environmental protection. Mario Draghi's landmark report identifies quantum technologies as a strategic priority, underscoring their importance for Europe's industrial competitiveness and technological sovereignty.

Despite their transformative promise, quantum technologies are still at an early stage of maturity. Policymakers, research organisations, startups and established companies dedicate considerable resources to creating a quantum ecosystem aimed at bringing quantum science to market. There is a pressing need to monitor progress across this increasingly complex landscape to better co-ordinate efforts and help turn the quantum promise into reality.

The EPO and the OECD have joined forces to produce a new study on the occasion of the United Nations' proclamation of 2025 as the International Year of Quantum Science and Technology. Bringing together their complementary expertise, the two organisations provide an unprecedented overview of the global quantum ecosystem. The study is unique in its breadth and depth, offering a comprehensive analysis of patenting activity, investment, skills, supply chains and policy trends. It is intended to serve as a valuable compass for the quantum community in the years ahead.

The study shows that the quantum ecosystem is expanding rapidly, with strong growth in innovation, new firm creation and investment, particularly in quantum computing. Europe has a solid base of quantum startups driving these advancements, but these attract less investment than their counterparts in the US. Large established firms operating primarily outside quantum contribute substantially to the ecosystem and will play a key role in bringing quantum solutions to market. Despite rapid progress, the field remains focused on technology development over commercialisation and rising dependence on a few strategic suppliers is adding to systemic vulnerabilities. Public policies have so far focused mainly on supporting research and development, but future efforts will have to expand beyond that to sustain Europe's progress in quantum.

As part of this broader effort to support European competitiveness, the EPO's Observatory on Patents and Technology has launched a new platform on quantum technologies, offering a unique lens on technological developments, and has updated the Deep Tech Finder with an extended quantum filter to help identify startups innovating in this field. These resources can be found at epo.org/trends-quantum. Together, these tools reinforce the role of patents as a cornerstone for advancing quantum technologies, helping innovators bring discoveries from the lab to the market.

In carrying out this project, the EPO's Observatory benefited from the support of 14 national patent offices: Austria, Belgium, Croatia, Cyprus, Czech Republic, Finland, France, Latvia, Luxembourg, Monaco, Netherlands, Slovenia, Spain, and the United Kingdom. We look forward to continuing this fruitful co-operation.

António Campinos
President, European Patent Office

Contents

List of tables and figures

Tables

Figures

List of abbreviations

AFRL	Air Force Research Laboratory
AIA	America Invents Act
AID	French Defence Innovation Agency
ANR	French National Research Agency
ARL	Army Research Laboratory
AWG	Arbitrary Waveform Generator
BvD	Bureau van Dijk
CAGR	Compound annual growth rate
CB	Crunchbase
CNIPA	China National Intellectual Property Administration
CVC	Corporate venture capital
DoD	Department of Defence
DR	Dealroom
DSIT	Department for Science, Innovation and Technology
EC	European Commission
EPC	European Patent Convention
EPO	European Patent Office
FWCI	Field-weighted citation impact
GBARD	Government budget allocation for R&D
GUF	General university funds
HEMT	High Electron Mobility Transistor
HHI	Herfindahl-Hirschmann index
HPC	High-performance computing
HS	Harmonized System
IP	Intellectual property
IPC	International Patent Classification
IPF	International patent family
LED	Light-emitting diodes
LOT	Lightcast Occupation Taxonomy
LSQ	Large scale quantum
M&A	Merger and acquisitions
METI	Ministery of Economy, Trade and Industry
MEXT	Ministery of Education, Culture, Sports, Science and Technology
MIT	Massachusetts Institute of Technology
MNE	Multinational enterprise
MOIP	Mission-oriented innovation policy
MSTI	Main Science and Technology Indicators
NACE	Nomenclature of Economic Activities
NER	Name entity recognition
nes	not elsewhere specified
NISQ	Noisy intermediate-scale quantum
NPL	Non-patent literature
NQIA	National Quantum Initiative Act
NVL	Naval Research Laboratory
OEC	Observatory of Economic Complexity
OECD	Organisation for Economic Co-operation and Development
PCI	Product Complexity Index
PCT	Patent Co-operation Treaty
PEPR	Priority Research Programme and Equipment
PIA	Programme d'Investissements d'Avenir
PNNL	Pacific Northwest National Laboratory
PPP	Purchasing power parity
PQC	Post-quantum cryptographic
PRO	Public research organisation including universities
QAOA	Quantum Approximate Optimization Algorithm
QGIS	Quantum geographic information system
QIST	Quantum information science and technologies
QKD	Quantum key distribution
QLDB	Amazon Quantum Ledger Database
QM/MM	Quantum Mechanics/Molecular Mechanics
QTF	Quantum Technologies Flagship
RCA	Revealed comparative advantage
RTA	Revealed technological advantage
RTI	Relative technology internationalisation
SME	Small and medium-sized enterprise
SQUID	Superconducting quantum interference device
TRL	Technological Readiness Level
UHV	Ultra-high vacuum
WIPO	World Intellectual Property Organization

List of countries, patent filing authorities and economies

AE	United Arab Emirates
AT	Austria
AU	Australia
BD	Bangladesh
BE	Belgium
BR	Brazil
CA	Canada
CH	Switzerland
CN	China
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EP	European Patent Office (EPO)
ES	Spain
EU	European Union
FI	Finland
FR	France
GB	United Kingdom
HK	Hong Kong, China
HU	Hungary
ID	Indonesia
IE	Ireland
IL	Israel
IN	India
IT	Italy
JP	Japan
KH	Cambodia
KR	Korea
KY	Cayman Islands
KZ	Kazakhstan
LA	Lao People's Democratic Republic
LT	Lithuania
LV	Latvia
MX	Mexico
MY	Malaysia
NL	Netherlands
NO	Norway
PH	Philippines
PL	Poland
PT	Portugal
RoW	Rest of World
RU	Russian Federation
SE	Sweden
SG	Singapore
TH	Thailand
TR	Türkiye
TW	Taiwan, Province of China
US	United States
VG	British Virgin Islands
VN	Vietnam
ZA	South Africa

Executive summary

Quantum technology areas, namely quantum communication, quantum computing (including simulation) and quantum sensing, hold the potential to have a profound impact on the economy, society, science and security across a broad range of industries and applications.

As a result, the quantum technology ecosystem (hereafter "quantum ecosystem") comprising a diverse array of stakeholders including large multinational enterprises (MNEs), small and medium-sized enterprises (SMEs), startups, universities, public research organisations (PROs) and investment firms – has become a strategic area of interest. Despite its early stage of technological maturity and the limited commercialisation to date of most quantum technologies, understanding the structure and dynamics of this ecosystem is critical to anticipating its future evolution and policy needs.

Taking an ecosystem perspective, this report outlines the complex web of actors and relationships underpinning modern industrial production and identifies major challenges such as barriers to technology development and diffusion, as well as the lack of skills or access to critical inputs. It draws on multiple data sources to capture the various dimensions of the quantum ecosystem, underscoring its richness and complexity.

The report describes the current state of technological development in the quantum field based on patent data and identifies the main ecosystem stakeholders involved, distinguishing between a core group of companies whose primary activity is to develop quantum and quantum enabling technologies and a broader ecosystem of organisations contributing to quantum development while pursuing other primary business objectives.

It documents current investment trends as well as the workforce skills and occupational profiles associated with these stakeholders. Despite the currently limited size of this market, the report also presents preliminary evidence on trade in quantum-relevant goods and reviews government policy measures supporting quantum development, with a focus on public R&D funding.

Key findings

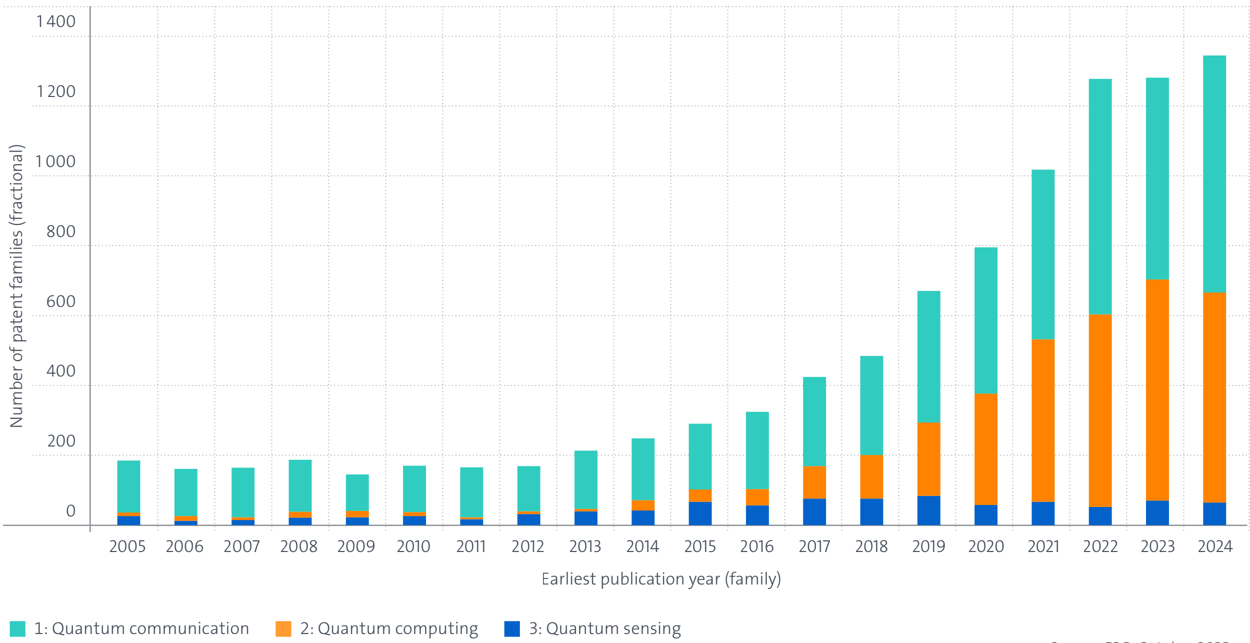
1. Rapid but uneven growth across technologies

The ecosystem is expanding rapidly, reflected in rising firm entry, increasing investment – both venture and corporate – and strong growth in innovation activity across multiple competing alternative technologies within each quantum domain. While quantum communication remains central in terms of both firm creation and patenting activity, quantum computing is currently the most dynamic area, driving the sharpest increases in both firm creation and patenting.

Figure E1 shows that the number of international patent families (IPFs) in quantum increased sevenfold between 2005 and 2024, with most of this growth concentrated in the last decade. Since 2014 quantum IPFs have expanded at a compound annual growth rate (CAGR) of 20%, far outpacing the 2% growth observed across all technologies. Quantum communication generated the largest number of yearly IPFs until 2022, when it was overtaken by quantum computing. Among all fields, quantum computing has shown the most dynamic growth over the last decade, expanding nearly 20-fold since 2014, compared with a threefold increase in communication and a 50% rise in sensing. Figure E2 shows a similar acceleration in firm creation across quantum areas until 2021 (more recent data on firm entry is probably incomplete due to lags between firm creation and their inclusion in databases).

Figure E1

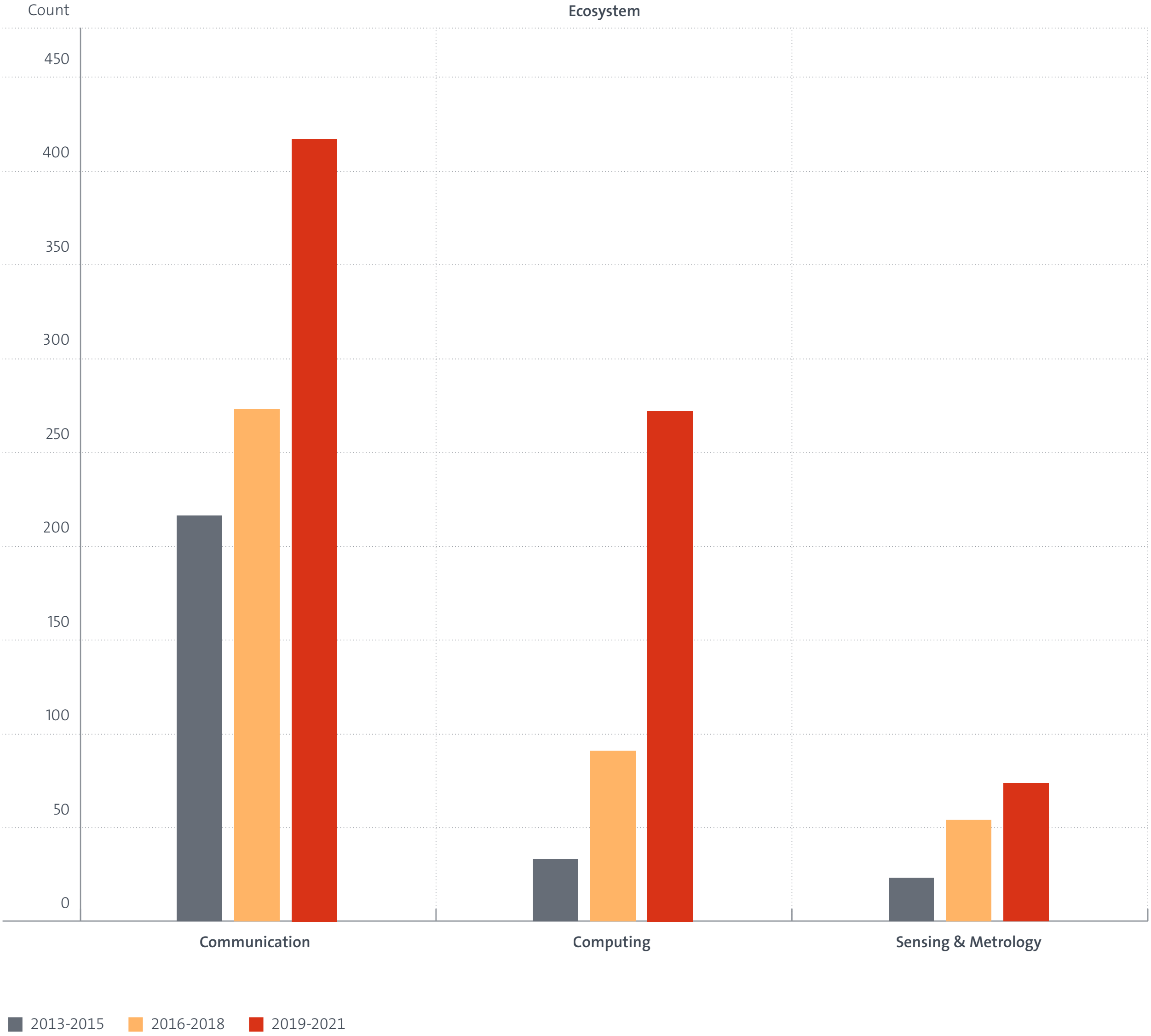
Trends in IPFs in quantum technologies by quantum area



Source: EPO, October 2025.

Figure E2

Quantum ecosystem entries by main technology: 2013-2021



Notes: The figure shows only firms with a quantum patent. Entry is defined as the year of a firm's first quantum patent. The definition of the main technology of a company is based on the technology with the strongest representation in its patent portfolio as of the latest available date (2025). If a firm has the same number of patents across multiple technologies, it is assigned proportionally across the categories.

Source: OECD calculations based on OECD, STI Micro-data Lab and Orbis, Bureau van Dijk, October 2025.

2. Young firms focused on quantum development coexist alongside diversified, established companies

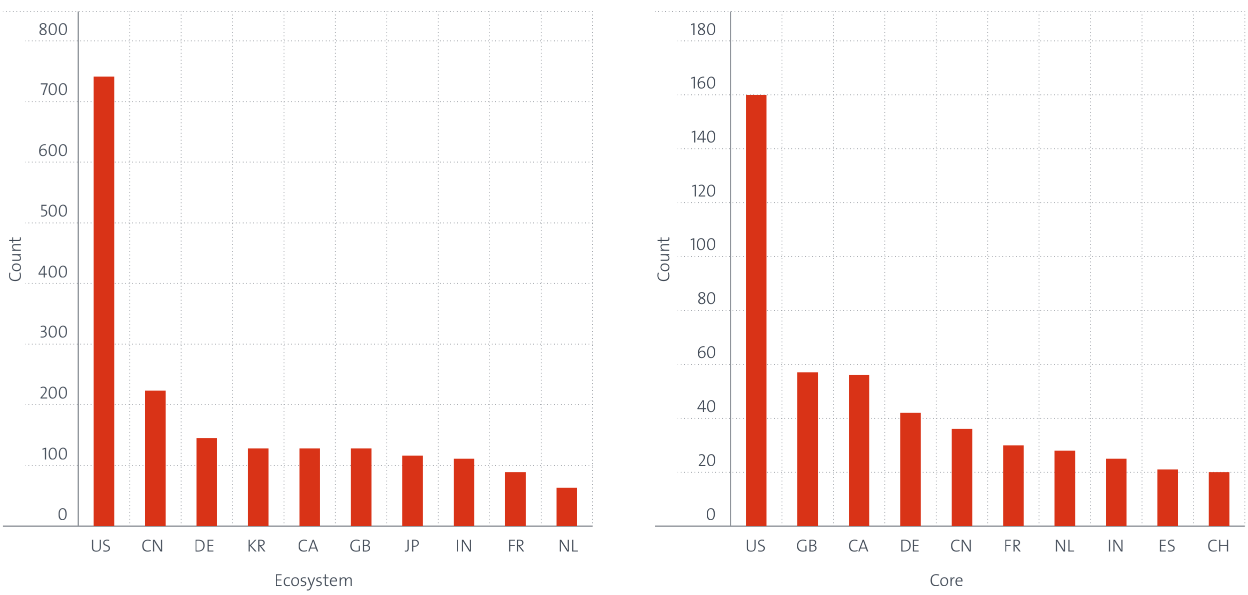
The field is characterised by the coexistence within the broad ecosystem of a relatively small number of "core" companies whose primary activity is to develop quantum and quantum-enabling technologies, and a plethora of non-core organisations composed of large established companies, universities and PROs moving into the quantum space. The broader ecosystem plays a pivotal role in both innovation and shaping labour demand, as most patents and quantum-related job postings originate from firms whose main business lies outside quantum technologies. This underscores the relevance of large, established players operating outside the core, and the potential of firms developing specific quantum applications for their own use to drive the ecosystem's growth.

The quantum industrial ecosystem comprises 4 622 organisations, including 830 core companies whose activities are primarily or entirely focused on quantum technologies. Core quantum firms are typically startups that rely heavily on early-stage investment and public funding. While these are poised to play a key role in translating deep tech research from universities into market applications, the broader ecosystem (including both public research organisations, PROs and large established companies) accounts for the majority of quantum activity. These non-core organisations whose main area of activity lies outside quantum represent more than 80% of the quantum ecosystem, accounting for most quantum-related patents and jobs created. Large established companies outside the core are likely to be well positioned for commercialisation once quantum technologies mature, as they will be able to integrate quantum advancements into their existing operations without facing the scaling challenges typical of startups.

The relative importance of core quantum players varies significantly across countries, with the United States having a lower share of core companies in its ecosystem than most European countries and Canada. These differences may signal how strongly national ecosystems will eventually rely on scaling up their startups to bring quantum technologies to market. However, this interpretation should be made with caution, as the broader ecosystem in each country includes not only large firms that are well positioned for commercialisation but also public research organisations with different roles and incentives.

Figure E3

Number of firms in the quantum ecosystem entering the quantum field by country: 2015-2024



Notes: The figure shows the top ten countries by total entries in the ecosystem and founding in the core portion within the period 2015-2024. This includes 1 872 of the 4 622 firms included in the quantum ecosystem, and 475 of the 830 quantum-focused firms (other firms were founded before 2015).

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

3. Geographical concentration but strong international competition

The United States stands out as the leading player across all quantum domains in terms of firm entries, innovation output and total investment mobilised. Other countries, including Canada and the United Kingdom with their strong revealed technological advantage (RTA) and dense cluster of core firms, but also China, Germany, Japan and Korea (which stands out particularly for quantum communication) with their broad industrial base and rich patent portfolios, also play major and complementary roles in the emerging global quantum landscape.

Figure E4 shows that the United States accounts for the largest share of patenting activity in quantum, although its share has declined from 41% in 2015-2019 to 31% in 2020-2024. Europe follows with an increasing share of IPFs, driven mainly by Germany, the United Kingdom, and France. Japan ranks as the second-largest national IPF filer, followed by China and Korea. In terms of technological specialisation, Canada has the highest RTA, followed by the United Kingdom, Finland, the United States, France and the Netherlands.

Figure E4

Contribution of quantum IPFs by region with RTA by region

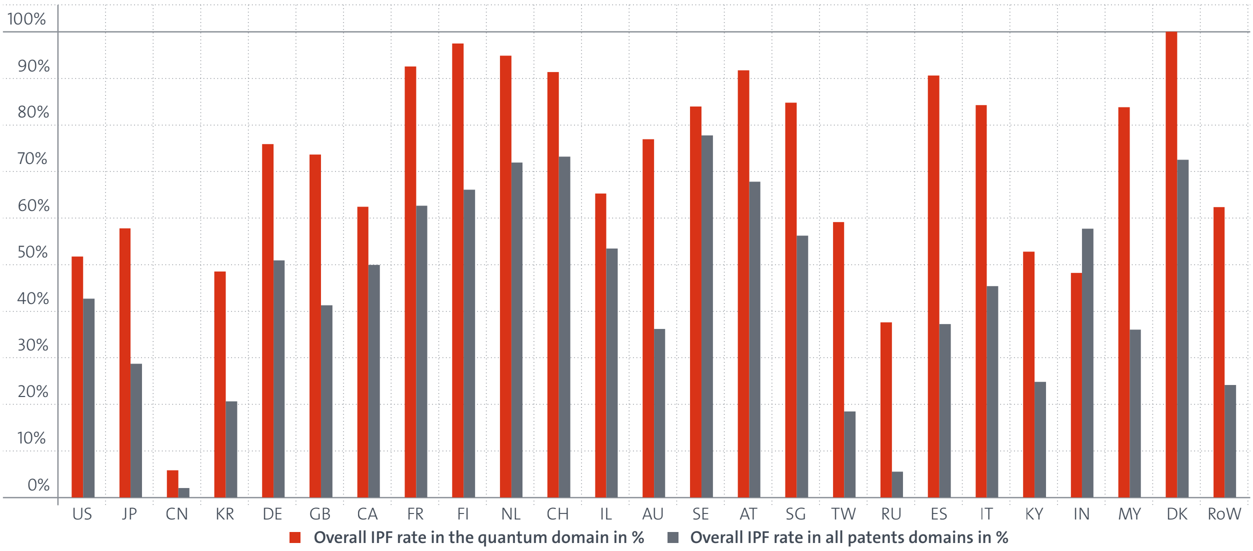
Notes: The graph shows the percentage of global IPFs on the left and the revealed technological advantage (RTA) on the right by applicant country for two time periods. The RTA indicates each country's degree of specialisation in quantum by comparing its patent share in quantum to its global patent share. An RTA above one indicates that the country is more specialised in quantum than the global average.

Source: EPO, October 2025.

The internationalisation rate, which is the percentage of IPFs compared to all patent families, is particularly high in the quantum domain (31.2%) compared to all patent domains (12.0%). Figure E5 compares the internationalisation rate of the quantum domain with that of all domains, by applicant location, ordered by each location's share of IPFs. The high internationalisation rate highlights the strategic importance that applicants across locations attribute to the quantum domain and the strong international competition between inventors.

Figure E5

Internationalisation rate per applicant location in the quantum domain compared to all domains

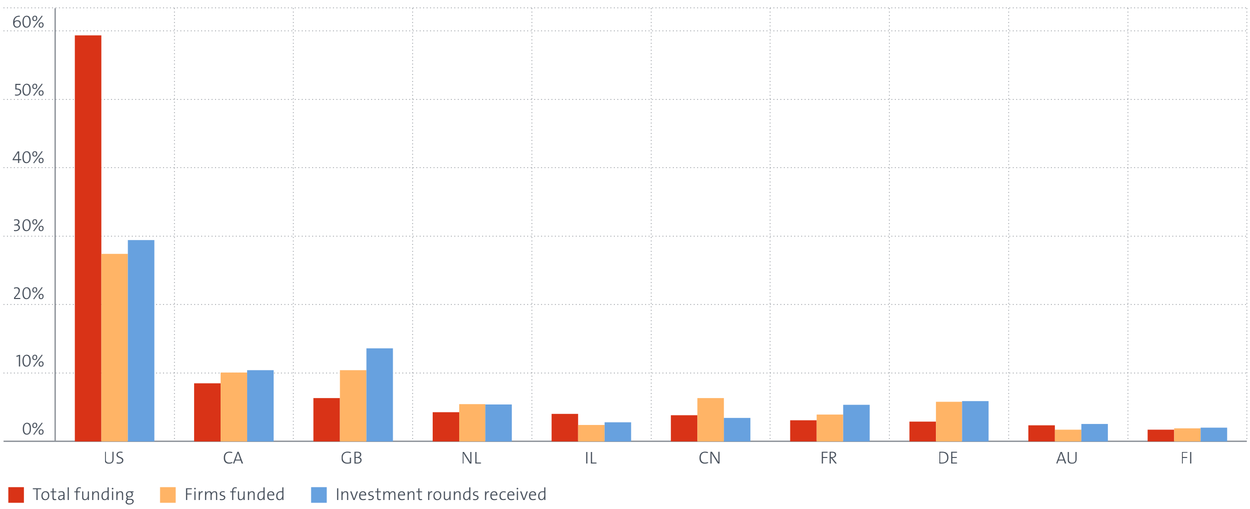


Source: EPO, October 2025.

Figure E6 shows that the distribution of funding only partially mirrors the distribution of patents and startups, with the US playing a disproportionately prominent role. Around 60% of total quantum funding ever recorded went to US-based companies, even though the US is home to only approximately 30% of all quantum IPFs and startups. This discrepancy comes from larger average deals, as the US represents also around 30% of the global number of deals recorded in quantum. Similarly, other countries, like Israel, appear to be particularly attractive in terms of funding compared to the number of startups they hold.

Figure E6

Country shares in global quantum funding, firms funded and investments rounds



Notes: The figure shows funding to core quantum companies. "Total funding" denotes the proportion of overall international funding to quantum firms that was received by firms in a given country. "Firms funded" refers to the proportion of a country's core quantum firms, relative to the global total of funded firms, that obtained some form of funding. Finally, "Investment rounds received" represents the proportion of all international investments in quantum firms that was directed to those located in a given country.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

4. High technological complexity and skill requirements

The industry remains strongly science-driven, with highly educated founders and a workforce concentrated in technical and research roles. The composition of job vacancies and the scientific character of quantum patenting both point to a continued focus on technology development rather than commercialisation.

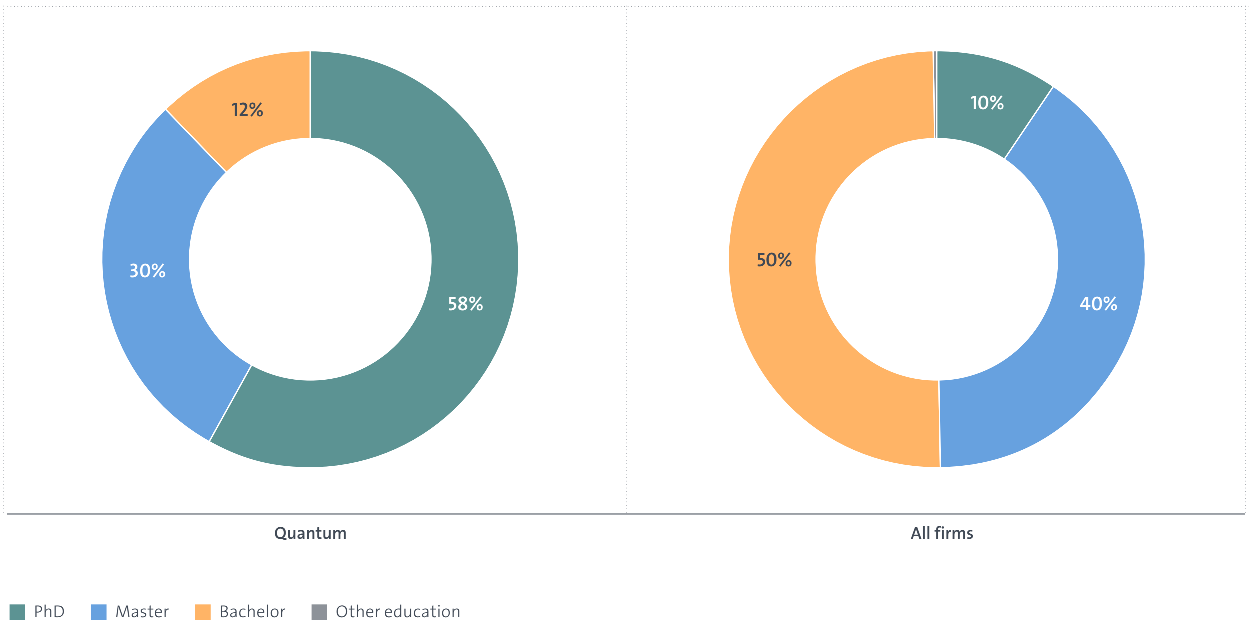
Founders of core quantum firms are more highly educated than the general population of non-quantum companies, as shown in Figure E7, with over half holding a PhD degree, versus just 10% for the general population. Employees of quantum firms also typically possess advanced scientific and engineering qualifications. Job postings reveal that demand for quantum-related skills is heavily concentrated in a small number of technical and research-oriented occupations such as computer science (26%), science and research (25%) and education and training (10%). By contrast, commercialisation-oriented occupations such as business management, marketing and sales account for less than 10% of vacancies altogether.

The high educational level and strong research orientation of quantum founders and employees are reflected in the scientific character of quantum patenting. As shown in Figure E8, a significantly larger share of quantum patents cite non-patent literature (NPL) compared with patents in other technology fields. This indicates a close proximity between quantum innovation and scientific research, as most NPL citations refer to academic journals and other outputs from basic research.

Both the composition of quantum-related vacancies and the strong scientific focus of quantum patents suggests that the industry remains primarily oriented toward advancing the development of quantum technologies, although some firms outside core companies have started applying quantum technologies to specific activities, including optimisation, cryptography and financial modelling.

Figure E7

Highest educational achievement of quantum firms' founders

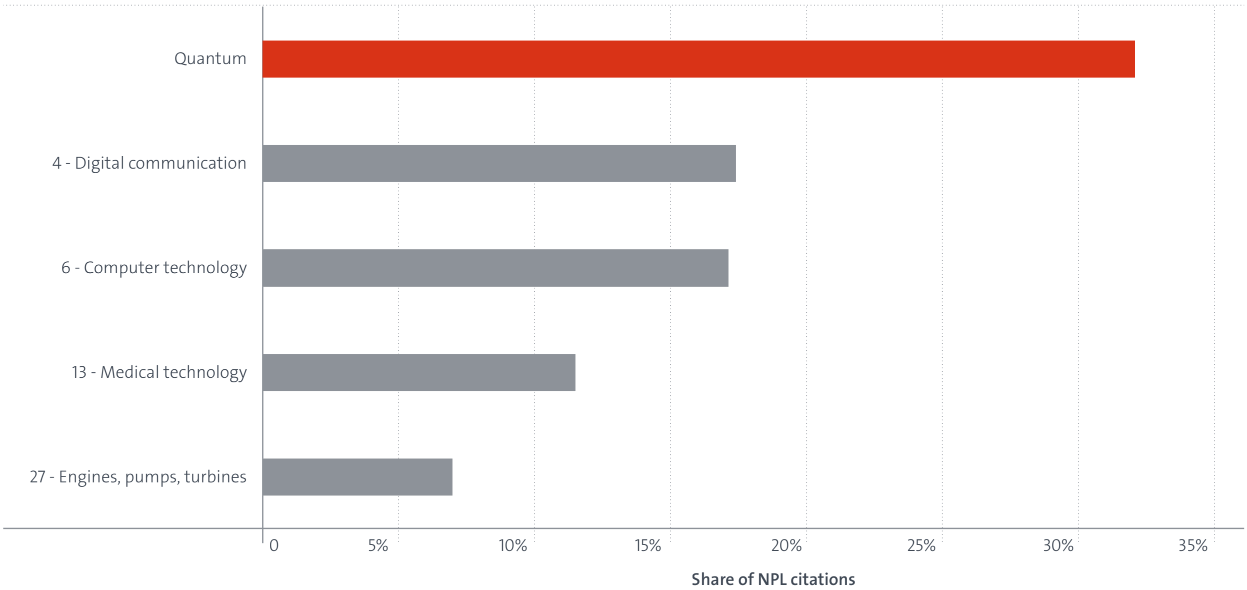


Notes: The figure includes information on 657 out of 1 208 identified founders of core quantum firms. For the remaining ones, information on maximum education achievement is unavailable. Other education includes high school; Bachelor includes bachelor's, graduate, JD and DUT degrees; Master includes master, MBA, MSc, postgraduate and LLM degrees; PhD includes PhDs. All firms refer to all companies with founder information available in Crunchbase.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure E8

NPL backward citation rate in quantum vs other technology fields: 2005-2024



Notes: This figure shows the percentage of citations in the patent application to non-patent literature (NPL) out of the total number of backward citations by both quantum patents (in red) and a selection of other major technological areas (in grey) according to the WIPO technology fields.

Source: EPO, October 2025.

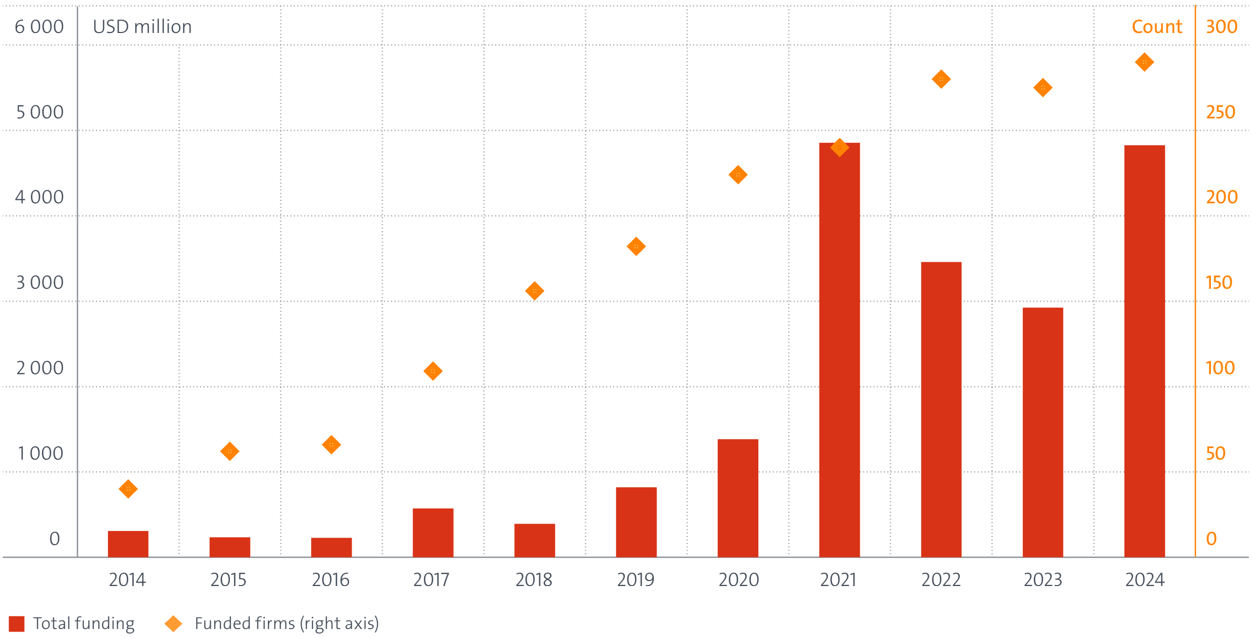
5. Challenges to scaling-up and commercialisation

Recent data on firm entry, investment and job postings require cautious interpretation, but suggest that the pace of growth may have plateaued in recent years. Trade data, albeit of limited in precision, indicate increasing concentration and dependencies in global supply chains for critical quantum components, for example, industrial diamonds, aluminium oxide and oxometallic salts. Advancing toward commercialisation (an increasing but still small focus in firms' job postings) and establishing dominant technological paradigms are important steps for the ecosystem's continued growth.

Figure E9 shows the evolution of total funding received by core quantum firms and the number of firms financed between 2014 and 2024. Overall, funding activity has expanded significantly over the past decade, reflecting growing investor interest in quantum technologies. However, after a sharp rise peaking in 2021, total investment volumes have plateaued, with 2022 and 2023 recording declines before a partial recovery in 2024. This slowdown reflects a reduction in the average deal size rather than a fall in the number of firms funded, which has remained relatively stable.

Figure E9

Total funding to and number of core quantum firms financed: 2014-2024



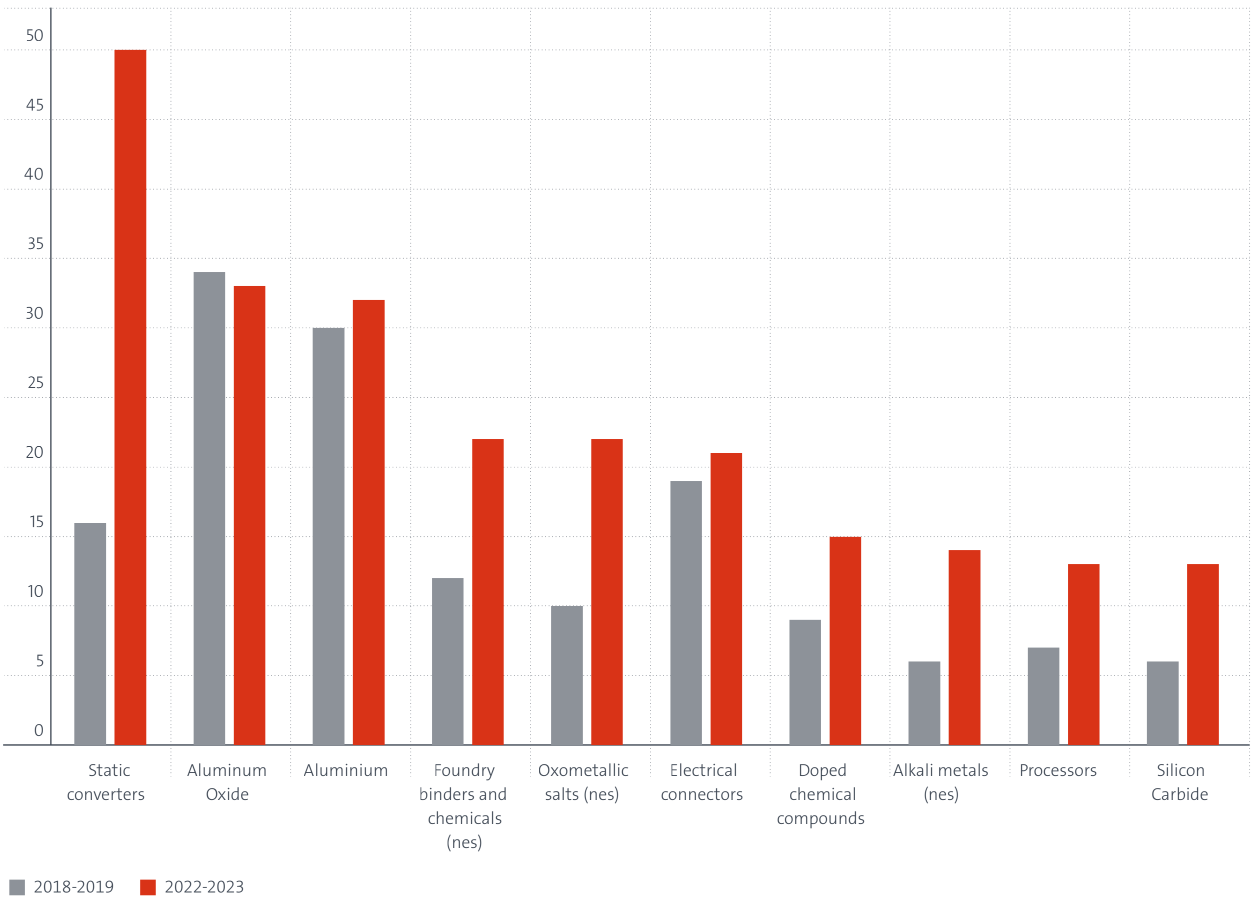
Notes: The figure portrays USD 20.01 billion, equivalent to 85% of total investment recorded.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure E10 presents the number of countries dependent on specific strategic inputs, focusing on those with the highest number of dependencies in 2022-2023. The data reveal that such dependencies have in most cases increased compared to 2018-2019. This trend is most pronounced for static converters, the input with the largest number of dependencies in the latest period, with 50 economies reliant on a strategically important supplier – China in almost 40 of those cases. The next two most critical inputs, aluminium oxide and aluminium (each with around 30 dependencies), have Australia and Russia as key strategic suppliers respectively. Korea emerges as the most critical supplier of oxometallic salts, a product with growing dependency levels. China also plays a central role as a strategic supplier of foundry binders and chemicals and electrical connectors.

Figure E10

Total trade dependencies for quantum-relevant goods by type: 2018-2019 and 2022-2023



Notes: The figure shows the top ten quantum-relevant products by total number of dependencies in 2022-2023.

Source: OECD calculations based on UN BACI database, August 2025.

6. R&D-focused public policies.

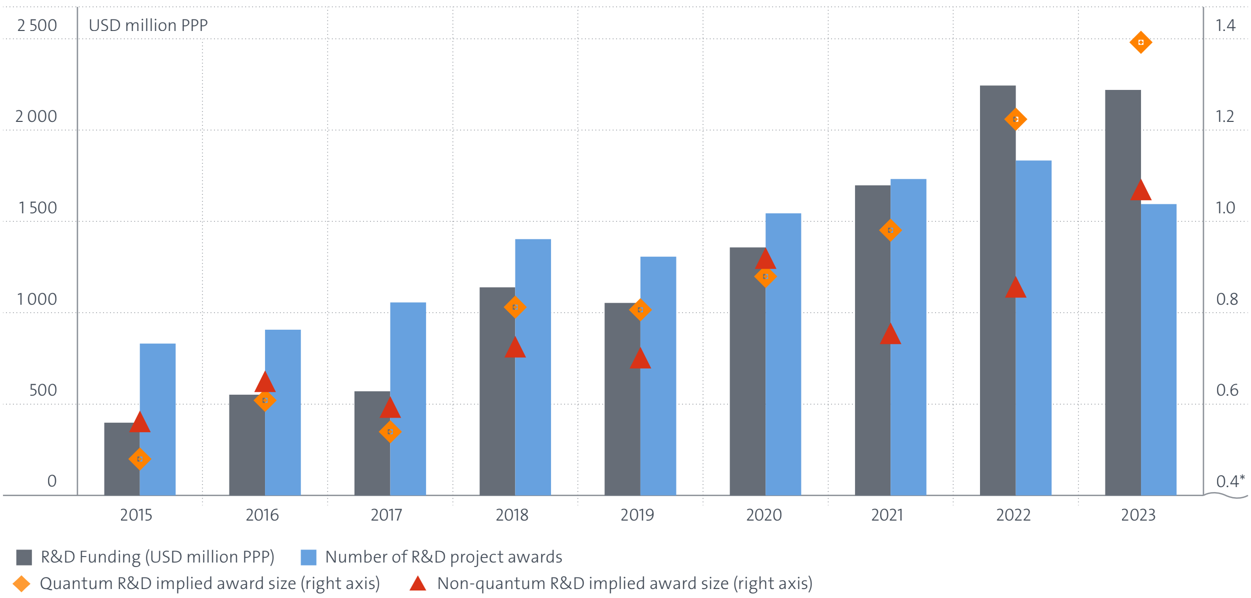
Governments have recognised that quantum technologies are still immature and that the ecosystem faces significant supply-chain vulnerabilities. In response, they have pursued a combination of policy initiatives focused not only on growing levels of public R&D funding but also on strengthening industrial competitiveness, supporting technology adoption and helping firms navigate early experimentation and commercialisation. Public support will need to continue to expand beyond innovativeness to support the ecosystem's continued growth.

The growing strategic importance of quantum technologies is evidenced by the steady adoption of national and supranational quantum strategies over the past decade, with more than 18 OECD countries having implemented such initiatives. These strategies outline priorities for technological development, risk management, stakeholder engagement, and desired policy outcomes.

Consistent with the adoption of formal quantum strategies that emphasise investment in research and innovation, public funding for quantum R&D has risen sharply in recent years. This increase extends beyond countries with dedicated strategies, as many others have also committed significant resources to develop and deploy quantum technologies. Figure E11 shows that the share of quantum R&D funding relative to total R&D funding in the OECD Fundstat database (which covers Government Budget Allocation for R&D) increased steadily over the last decade, from approximately 0.4% in 2015 to 1.1% by 2023, with a peak of 1.2% in 2022. In parallel, the share of quantum-related project awards grew proportionally, reaching nearly 0.8% of all funded projects by the end of the observed period. Notably, the implied award size for quantum R&D peaked in 2023 and has consistently exceeded that of non-quantum R&D projects since 2018 (except in 2020, potentially due to shifting priorities during the COVID-19 pandemic).

Figure E11

Estimated annual quantum R&D size: funding and implied award size 2015-2023



Notes: The OECD Fundstat database comprises R&D funding project award data from 19 OECD countries (AU, AT, BE, CA, CH, CZ, DE, EE, FIN, FR, GB, IR, JP, LT, LV, NO, PT, SE, US) and the European Union (EU) – European Commission (EC) programmes. Over the reference period 2015-2023, during which data coverage is stable, the database covers approximately 51% of the government budget allocation for R&D (GBARD) in these 19 countries (excluding general university funds, GUF), as reported in the Main Science and Technology Indicators (MSTI) Database, oecd.org/sti/msti.htm. R&D funding award data reflect authorisations rather than actual commitments or expenditure. Analysis performed on R&D project awards with available funding information.

Source: OECD analysis of the OECD Fundstat database (v.2024), October 2025

1. Introduction

Quantum developments in communication, computing (including simulation) and sensing represent foundational next-generation technologies poised to drive substantial economic and security impacts. Quantum technologies promise to dramatically increase computing speed, enabling rapid problem-solving in fields like complex optimisation and molecular modelling. Enhanced security in quantum communication, especially through quantum key distribution, promises to offer considerably strengthened encryption that ensures that any intercepted key is rendered invalid for use. Additionally, high-precision quantum sensing provides groundbreaking advancements for applications in medical imaging, navigation and environmental monitoring Finally, quantum networks will enable the interconnection of quantum sensing and computing devices, thereby expanding the overall capabilities of quantum technologies.

Despite their great promise, quantum technologies vary in their stages of development, with transformative economic applications still some way off due to the field's low technological maturity. Current quantum development focuses on competing for ideas, as stable computing conditions and standard platforms have not yet been established. Researchers are exploring early uses, but revolutionary applications remain out of reach. Many governments have acknowledged the potential of quantum technologies and developed ad-hoc strategies and initiatives, such as the National Quantum Initiative Act (NQIA) by the United States and the Quantum Technologies Flagship (QTF) by the European Union. However, while governments are investing in basic and applied research, quantum technologies require private-sector involvement if they are to advance beyond basic research to industrialisation and early commercialisation.

This report seeks to provide a comprehensive overview of the quantum ecosystem, mapping the diverse stakeholders active in this field and the linkages that connect them. Its aim is to present a rich snapshot of the ecosystem's current state. To do so, the report examines not only the main developers of quantum technologies in communication, computing (including simulation) and sensing, but also those advancing key enabling technologies such as photonics and cryogenics. It highlights contributors from adjacent fields, as well as users of quantum technologies. The analysis presents an overview of innovation activity in the field based on patent data, describes the characteristics of firms active in the quantum ecosystem (including but not limited to patent holders), analyses investment patterns and skills demand, and presents initial evidence on trade flows related to equipment, goods and raw materials that are relevant for quantum technologies. Finally, the report also presents an assessment of government efforts to promote and stimulate the development of quantum technologies (OECD, 2025a; OECD, 2025c; OECD forthcoming).

The report is structured as follows. Section 2 introduces a technology mapping of the quantum ecosystem, starting from the underlying quantum phenomena such as superposition and entanglement and the hardware platforms that exploit them, for example ion traps and quantum dots. It then focuses on three quantum technology areas (communication, computing (including simulation) and sensing), explaining how technologies can be applied across application sectors, including defence, pharmaceuticals, energy, finance and logistics. Section 3 examines the international patenting landscape in quantum, including cross-country differences in patenting, the distribution of patents across technological areas, firm-level segmentation and an identification of leaders based on RTA. Section 4 presents an analysis of the firms active in the quantum ecosystem and its core component in particular, defined as firms whose core activity is to focus specifically on quantum technology. It offers an overview of their key characteristics and provided complementary evidence on their patenting activity, founders and funding received. Section 5 focuses on finance providers, analysing their geographical distribution and breaking down investment into core firms by stage of financing. It also examines investment and acquisitions made by corporate players and highlights the role of government investment. Section 6 documents the skills and occupations required by quantum-focused firms, and more generally analyses skills requested in job postings seeking expertise in quantum and enabling technologies, illustrating recent trends in available job profiles. Section 7 investigates international trade flows of quantum-relevant goods, including raw materials and equipment. While these flows remain limited and the identification of quantum-relevant goods is still at an early stage, the section provides descriptive evidence on traded volumes by country and product, as well as insights into concentration, specialisation and dependencies.

Finally, Section 8 describes the policies already enacted by governments in the quantum area, with a focus on public R&D, support for commercialisation activities and technology adoption initiatives.

The report highlights several characteristics of the quantum ecosystem, starting with its early stage of development – an insight confirmed across multiple indicators. These include the continued presence of numerous competing platforms within each core quantum technology, the relatively small number of active companies (and corresponding job postings) and the significant role of early-stage investment and government funding. At the same time, the report underscores the sector's growth, reflected in new firm entry, rising levels and types of investment (including by corporate players) and increasing innovation, as shown by patenting activity. It also reveals the exceptional characteristics of quantum firms, whose founders are typically highly educated and whose workforce demands advanced skills. The ecosystem itself is diverse in terms of the type of active companies, but high-tech firms play a preponderant role. From a geographical point of view, several countries are active in the development of quantum technologies, but the United States stands out as the leading player.

Recent trends in funding and firm creation (which must be interpreted cautiously) suggest that momentum may have reached a plateau in recent years. The need to find avenues towards commercialisation (which is starting to be visible in firms' job postings), as well as the importance of defining dominant paradigms supporting technological advancement, are top priorities for governments aiming to foster this ecosystem.

2. Mapping quantum technologies

The objective of this section is to provide a concise overview of quantum technologies. **Quantum phenomena** such as superposition and entanglement (defined below) form the underlying physics that distinguish quantum from classical behaviour. These phenomena are exploited through **hardware platforms,** which provide the engineered means to manipulate them. By doing so, the platforms enable **three quantum technology areas** – communication, computing (including the crucial sub-technology simulation) and sensing – that deliver new capabilities.[1] Importantly, this chapter focuses on quantum information science and technologies (QIST), which emerged as the defining technologies of the second quantum revolution. These technologies can then be applied across **sectors,** including defence, pharmaceuticals, energy, finance and logistics. The section is structured accordingly, by first discussing quantum phenomena, followed by an overview of the most important hardware platforms and lastly a discussion of the advantages and challenges of the three quantum technology areas.

1 In this report, simulation is included under quantum-computing to align with the patent quantum search adopted in Section 3. Nevertheless, given its relevance and peculiarity, it is the subject of particular attention in this section.

2.1 A brief overview of quantum phenomena

Quantum technologies rely on quantum mechanics, the theoretical framework that describes how particles, waves and fields – the building blocks of matter, energy and information – behave at very small scales. **Quantum phenomena** such as superposition, entanglement, tunnelling and quantisation, are predicted by that theory (OECD, 2025a). Table 2.1.1 provides an overview of selected quantum phenomena that helps understand the quantum technologies.

Table 2.1.1

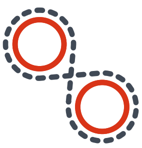
Overview of selected quantum phenomena

SUPERPOSITION & WAVE-PARTICLE DUALITY

Quantum particles, like electrons and photons, exhibit both particle and wave-like behaviour. They also exist in multiple states simultaneously, a property called superposition. Superposition lets particles explore many possibilities at once, and their wave-like nature causes these possibilities to add up or cancel out – called quantum interference – which shapes measurement outcomes (Nielsen & Chuang, 2010).

Analogy: A spinning coin appears to be simultaneously both heads and tails until it lands and is seen to be one or the other (superposition). Like water acting as both droplets and waves, quantum objects can behave like discrete particles or like continuous waves depending on how they are observed (wave-particle duality). Noise-cancelling headphones generate matching sound waves that cancel out external noise (quantum interference).

Application: in **quantum computing,** qubits[2] – the quantum equivalent of classical binary bits – use superposition to represent and process vast amounts of information simultaneously, offering the potential for immense computational power.



QUANTUM ENTANGLEMENT

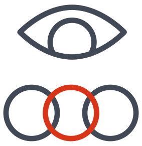
Two quantum particles can become intricately linked, forming a single shared quantum state in which measuring one instantly reveals information about the other, regardless of distance. The states of entangled particles are correlated in ways that have no counterpart in classical physics and can be used to influence other systems in ways that would be impossible classically (Gisin, Ribordy, Tittel, & Zbinden, 2002).

Analogy: Two magical coins that are linked. When one lands heads, the other instantly becomes tails, no matter the distance. Neither coin has a predetermined result until measured.

Application: quantum cryptography (like quantum key distribution, QKD)[3] for secure communication.

2 A qubit is the basic unit of quantum information; unlike a classical bit fixed as 0 or 1, it can exist in a superposition of both, making it a direct manifestation of quantum phenomena and the building block implemented by hardware platforms.

3 QKD is a secure communication method that uses quantum mechanics to allow two parties to generate a shared secret key that cannot be intercepted or copied without detection.

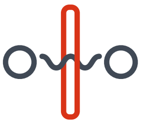


THE UNCERTAINTY PRINCIPLE[4]

It is impossible to simultaneously know complementary properties of a particle, like its exact position and momentum, with perfect accuracy (Griffiths & Schroeter, 2018).

Analogy: a quantum particle is like a shy person at a party – the harder you try to pin down a specific trait (e.g. location), the more jittery and unpredictable their other linked traits (e.g. speed) become. This is not a consequence of clumsy measurement tools – the particle itself becomes restless when scrutinised.

Application: quantum noise squeezing manipulates the uncertainty in measurements, reducing it for one variable at the expense of another, leading to more sensitive detectors.



QUANTUM TUNNELLING

A particle can pass through an energy barrier that it classically should not have enough energy to overcome. This allows nuclear fusion by enabling atomic centres to jump their electrostatic barrier, even when their energy is not enough to classically do so (Sze & Ng, 2006).

Analogy: A tiny ball can appear on the other side of a hill it did not have enough energy to roll over. This is analogous to the ball "ghosting" through the hill rather than going over it.

Application: Tunnelling is used to move electrons through an insulating barrier to store data in flash memory cells (e.g. USB sticks and SSDs); **scanning tunnelling microscopes** use tunnelling to image individual atoms.

QUANTISATION

At the quantum level, properties like energy, charge and spin (magnetic orientation) can only exist in discrete, specific amounts, rather than as continuous values. Electrons can only occupy specific orbits, and they can "jump" between these levels by absorbing or emitting exact amounts of energy (i.e. photons) (Ludlow, Boyd, Ye, Peik, & Schmidt, 2015).

Analogy: A staircase where energy can only exist on specific steps, never between them, similarly to a person that can only stand on step 1, 2, or 3 – never on step 1.5.

Application: Lasers produce light when electrons move between set energy steps, releasing matching light particles. **Atomic clocks** rely on the precise frequency of these electron movements for accurate timekeeping.

4 Often called the Heisenberg indeterminacy principle.

Various hardware platforms seek to harness these five fundamental quantum phenomena: superposition, entanglement, uncertainty, tunnelling and quantisation. Each physical implementation, from superconducting circuits to trapped ions or photonic systems in the case of quantum computers, is an engineering effort to control and exploit one or more of these phenomena in a reliable and scalable way. Understanding how these abstract phenomena translate into specific technological platforms helps shed light on the link between the theory of quantum mechanics and the emerging technologies that support today's quantum ecosystem.

2.2 How hardware platforms create, observe and manipulate quantum phenomena

The quantum technology ecosystem is still relatively young. As a consequence, it is characterised by pervasive experimentation with different technology platforms, for instance ion traps and superconducting circuits. While all these platforms exploit the same quantum phenomena, they do so in very different ways, and with considerable variation in the physical materials and engineering skills required (European Quantum Industry Consortium, 2025). The platforms in turn underpin technologies such as quantum communication, computing and sensing.

Table 2.2.2 provides an overview of the main hardware platforms currently under development for quantum communication, computing (including simulation) and sensing. The table illustrates how recent the quantum technology ecosystem is: multiple hardware platforms are still being matched to specific uses and their advantages and drawbacks mapped, and rapid shifts in focus are likely as technical bottlenecks are solved or new ones emerge.

The first column (Platform) lists the twelve most common hardware platforms currently being explored, developed or commercialised. In the context of quantum technologies, a hardware platform refers to the physical implementation that enables quantum phenomena such as superposition and entanglement to be realised and controlled for communication, computation (including simulation) and sensing purposes. Unlike the underlying quantum principles, which are abstract and universal, hardware platforms take the form of tangible systems such as superconducting circuits, trapped ions or photonic chips. This distinction is important for policy and economic analysis; quantum phenomena themselves cannot be traded across borders, but the hardware platforms that embody them are physical goods and components and thus fall within the global trade flows examined in Section 7.

These hardware platforms group several sub-technologies together. For example, optical traps cover optical tweezers, optical lattice clocks and Rydberg-atom arrays.[5] Superconducting circuits include transmon and fluxonium qubits and microwave-resonators, which are used to store, couple or read out qubits.[6] For simplicity's sake, they are aggregated under broader umbrellas, but all these sub-technologies face distinct development hurdles, even though they share the same underlying fabrication methods and general technological approach.

The following two columns, ultra-high vacuum (UHV) and cryogenics (millikelvin), give an indication of the hardware platforms' infrastructure requirements. Some – such as optical, magnetic and electromagnetic traps for atoms and ions – require ultra-high vacuum (i.e. reaching pressures below about 10^{-9} millibar) to preserve quantum behaviour. Others – like quantum dots and superconducting circuits – rely on cryogenic cooling, often to millikelvin temperatures, to achieve the same goal. Trapped atoms and ions may also use laser cooling techniques to reach ultra-low effective temperatures.[7]

For the first infrastructure option, UHV chambers ensure a one trillion-fold reduction in molecules per cubic meter. The emptiness inside the chamber relative to outside is as extreme as comparing one second to 30 000 years, ensuring stray gas molecules almost never collide with a trapped atom.

For the second type of infrastructure, a platform relying on cryogenics would require a cryogenic dilution refrigerator at 50 millikelvin to lower the thermal energy of each quantum bit about six thousand-fold compared with a room-temperature lab (Kjaergaard, et al., 2020). Unsurprisingly, these infrastructure requirements are considerably different in terms of both equipment and the expertise required. Their complexity and cost make it challenging for current-generation quantum technologies to achieve commercial scale. Both columns refer to established, stateoftheart conditions and indicate the conditions typically required to reach current bestinclass performance; future designs may relax these.

The fourth column (What is being manipulated) identifies the precise quantum entity each hardware platform controls. Quantum entities are the physical systems used to encode quantum information, which explains the associated need for lasers, microwave lines, cryogenics or vacuum infrastructure. In some platforms, the quantum entity is an entire particle – such as a neutral atom[8] captured in a laser trap or a single photon guided through a waveguide – and that particle's position or phase carries the information. In others, the information is embedded in a solid, for example the tiny magnetic orientation ("spin") of an electron at a crystal defect or the circulating current in a superconducting loop.

The How it works column briefly describes the core idea underlying each platform, i.e. an intuitive idea of what the hardware is doing to control its quantum entity (e.g. trapping atoms with light or guiding single photons on a chip).

The last four columns (Communication, Computing, Computing-Simulation and Sensing) represent a heatmap reflecting the level of research advancement of a given hardware platform within each application area (not overall technological or commercial maturity). Commercial readiness and the maturity of specific subtechnologies may be higher or lower than the score suggests. Table 2.2.1 provides a brief definition of each ranking:

5 Optical tweezers: a tightly focused laser beam that traps and moves single neutral atoms like microscopic tweezers; optical-lattice clocks: millions of ultracold atoms held in a laser standing wave act as an extremely stable time reference; Rydberg-atom arrays: neutral atoms pinned by optical tweezers are excited to high-energy "Rydberg" states whose strong mutual forces form a programmable grid of qubits.

6 Transmon: a tiny superconducting loop that acts like an artificial atom for microwaves; fluxonium: a superconducting loop with extra inductance that makes its quantum states more stable; microwave-resonator qubit: a single microwave photon trapped between superconducting mirrors stores the quantum state.

7 Laser cooling reduces particle motion but does not cool the apparatus itself and is therefore not marked in the Cryogenics column (Browaeys & Lahaye, 2020).

8 A neutral atom is an atom in which the number of negatively charged electrons equals the number of positively charged protons, giving it no overall electric charge.

Table 2.2.1

Scale used to classify the research stage of hardware platforms within different quantum technologies

Score	Research stage	Definition
0	No current role	Not practically used within this technology.
1	Exploratory	Proof-of-concept experiments only; usefulness for this technology remains uncertain.
2	Validated	Proven through reliable and reproducible results, but not yet broadly adopted within this technology.
3	Mature	Widely adopted as a standard research tool and central to ongoing progress in this technology.

Notes: The scores (0-3) indicate the extent of demonstrated use in research, not commercial maturity.

Because each application area has markedly different states of advancement, the same score can conceal very different absolute readiness. For example, a score of 2 in communication may already involve kilometrescale fibre links and early pilot products, while a 2 in computing can still mean a few fragile qubits in a laboratory rack, years from any commercial system. The technical hurdles, capital needs, regulatory pathway and expected timetomarket behind these 2 scores are therefore not comparable. The heat map is designed to show relative position within each column (application area), not to rank platforms across different application areas on a single commercial readiness scale.

Example 1: The heat map shows optical traps scoring 3 for quantum computing-simulation and lower values for sensing (2), computing (2) and communication (1). Given that no other platform reaches a value of 3 in the computing-simulation column, optical traps can be viewed as the primary (highest aggregate research use) platform for quantum computing-simulation as of 2025.

Example 2: Several hardware platforms – quantum dots, topological materials and molecular magnets/complexes – do not achieve a score of 3 in any application area. This implies that, as of 2025, they are established but not yet primary.

Insights

The following list offers a set of selected insights drawn from the table, based on the analysis of the broader quantum technology ecosystem.

— **Many scores of 1 and 2 signal active exploration**

The fact that most hardware platforms fall into categories 1 ("promising but still experimental") and 2 ("proven in the lab, not yet the dominant choice") indicates that researchers are still testing which hardware platforms are best suited for specific uses. This breadth of trial and error suggests that the quantum sector has not yet converged on a dominant paradigm.

— **Hardware platforms draw on fundamentally different physical effects, equipment and skill sets**

To take one example, magnetictrap sensors and siliconcarbide defect sensors both earn a mature score for sensing, even if they rest on completely different technological foundations. Magnetic traps use clouds of ultracold atoms held in an ultrahigh vacuum chamber by carefully shaped magnetic fields; their response to external forces is read with multiple stabilised lasers, large coils, vibration isolation and racks of control electronics, demanding expertise in atomic physics and vacuums. Siliconcarbide devices instead measure changes in the spin (magnetic orientation) of a single crystal defect inside a roomtemperature chip, using only a small excitation laser or LED, simple microscope optics and microwave drive electronics drawing on solidstate materials and optical spectroscopy skills.

The shared sensing role therefore hides sharply different physical effects, equipment sets and specialist teams.

— **Several hardware platforms benefit from semiconductor production processes**

Several platforms (highlighted in grey in the table) build on semiconductor manufacturing processes, though to different degrees (Awschalom, Hanson, Wrachtrup, & Zhou, 2018). Superconducting circuits and quantum dots can be patterned across full silicon wafers using mostly standard chip fabrication steps, then packaged for cryogenic use. Integrated photonic chips, optical cavities and waveguides are made in the same type of facilities using routine etching and deposition. Siliconcarbide and silicon defect devices also use these tools, while diamond and topological (Majorana) devices still need more specialised processing, which is currently affecting their production readiness.

Compared with the extremely complex requirements of atom and ion traps, semiconductorbased platforms offer clearer paths to scale (Bruzewicz, Chiaverini, McConnell, & Sage, 2019). They can be fabricated at wafer scale for identical replication, integrate photonics, qubits and control electronics on or near the same chip, and many (such as siliconcarbide defects or some photonic circuits) operate at room temperature without daily vacuum or laser maintenance. The resulting devices are more compact, easier to deploy outside specialised labs, and benefit from existing semiconductor supply chains – even when, in some cases, cryogenic cooling is still needed.

— **Quantum hardware mixes platforms depending on the use case**

In today's prototype quantum computers, all logic qubits are built from one platform because combining platforms within the same processor multiplies noise and calibration effort. By contrast, quantum communication is inherently hybrid; a stable matter qubit stores information, while photons carry it through fibre, so solid-state spins or ions are routinely integrated with photonic chips. Quantum sensors sit in the middle; they rely on a single quantum element, then couple it to conventional optics or electronics for readout rather than adding a second quantum platform.

Table 2.2.2

Overview of most important hardware platforms for quantum technologies

Platform	Vacuum (UHV)	Cryo (millikelvin)	What is being manipulated	How it works	Communication	Computing	Computing-Simulation	Sensing
Optical traps	✓		Neutral-atom internal states	Focused laser light forms tiny traps confining single neutral atoms in vacuum.	1	2	3	2
Magnetic traps	✓		Neutral-atom internal states	Precisely shaped magnetic fields create low-energy regions that hold selected atoms in place.	0	1	2	3
Electromagnetic traps	✓		Trapped-ion internal states	Oscillating electric fields generate a stable potential well that suspends individual ions.	2	3	2	2
Superconducting circuits		✓	Superconducting current (loop state)	Cryogenic superconducting loops create controllable microwave circuits that act as quantum bits.	1	3	2	2
Quantum dots		✓	Single-electron spin (magnetic orientation)	Nanoscale semiconductor islands isolate one electron whose energy or spin can be individually controlled.	2	2	1	1
Diamond NV centres			Defect electron spin	A nitrogen-vacancy defect in diamond hosts a spin that can be set and read optically, even at room temperature.	2	1	1	3
Diamond SiV centres		✓	Defect electron spin	Silicon-vacancy defects in diamond emit ultra-pure photons for linking distant quantum nodes.	3	1	0	1
Silicon carbide defects			Defect electron spin	Crystal defects in silicon carbide provide long-lived spins on wafers compatible with standard chip processes.	2	1	0	3
Topological materials		✓	Majorana quasiparticle states	Engineered materials encode information in protected quantum states resistant to many local errors.	0	1	1	0
Optical cavities			Single photons	Highly reflective mirrors trap light between them, boosting its interaction with atoms or solid-state emitters.	3	2	1	2
Optical waveguides/ networks			Single photons	On-chip glass or silicon channels route single photons with minimal loss to build scalable light-based circuits.	3	2	1	1
Molecular magnets/ complexes			Molecular-electron spin	Tailored molecules lock an electron's magnetic orientation, forming customisable quantum units at moderate temperatures.	0	1	2	2

Notes: Scores reflect current research adoption (mid 2025), not a crosscolumn commercial readiness ranking. 0 – No current role: not practically used within this technology; 1 – Exploratory: proof-of-concept experiments only, usefulness for this technology remains uncertain; 2 – Validated: proven through reliable and reproducible results, but not yet broadly adopted within this technology; 3 – Mature: widely adopted as a standard research tool and central to ongoing progress in this technology.

The discussion so far has highlighted how the quantum ecosystem is still largely in an exploratory phase. Several very different approaches are competing to solve the same problems, and no single platform has emerged as the clear frontrunner. This diversity spreads risk and accelerates learning, but it also means that performance, cost and timelines differ widely across platforms and uses. The next section examines each quantum technology, highlighting where quantum approaches already promise advantages over classical systems, and the main technical and economic challenges that remain.

2.3 Overview of quantum technologies

Table 2.3.1 summarises how quantum phenomena might create fundamental advantages across various technologies: communication, computing, simulation (a part of computing) and sensing. Each technology leverages different quantum phenomena which in future might achieve capabilities surpassing those of classical approaches. It is important to note that quantum technologies provide revolutionary advantages for specific applications where quantum effects are either the basis for security (communication), enable exponential speedup (computing), form the subject of study (simulation) or provide sensitivity at fundamental limits (sensing), but these do not extend to every conceivable task; for many applications, quantum technologies complement rather than replace classical technologies (National Academies of Sciences, 2019), not least due to their current limitations.

Table 2.3.1

Overview of quantum technology areas

Technology	Key quantum phenomena	Potential advantage	When advantage applies	Current limitations
Quantum communication	Entanglement/uncertainty principle	Detectable eavesdropping via physical laws; direct transmission of information encoded in quantum states; networked quantum devices	Key distribution with strengthened security Quantum networks Distributed quantum computing Clock synchronisation Sensor arrays	Limited distance without repeaters Low data rates (Mbps) No signal amplification QKD has a slow generation rate and is difficult to perform over long distances
Quantum computing	Entanglement Quantum interference Superposition	Quantum algorithms promise polynomial to exponential speed-ups over classical algorithms.	Factoring large integers or computing discrete logarithm Quantum system simulation Specific optimisation problems Unstructured search	Limited to specific problem classes High error rates Many platforms need extreme cooling
Quantum computing -simulation	Entanglement Quantum interference Superposition	Model quantum systems without the exponential computational cost that limits classical simulations	Strongly correlated materials Complex molecules Photosynthesis Superconductivity Quantum phase transitions	Quantum systems only Requires many measurements Limited qubit counts Significant error correction overhead Specialised for one problem
Quantum sensing	Quantum interference Superposition Uncertainty principle	Surpasses classical sensitivity limits by orders of magnitude for specific measurements	Single photon detection Magnetic fields below femtotesla Gravitational waves Neural signals Inertial navigation	Best for extreme precision only Implementation complexity Higher cost than classical Some require cryogenics

Quantum communication

Quantum communication as a field encompasses applications with different core advantages: security-focused applications like quantum key distribution (QKD) and quantum cryptographic protocols, and capability-focused applications such as quantum teleportation for transmitting quantum states, distributed quantum computing networks and quantum sensor arrays. Current practical deployments are predominantly QKD systems.

Securely agreeing on a secret lies at the core of numerous security mechanisms to ensure the confidentiality, integrity and authenticity of communications. Traditional communication systems use algorithms often relying on the computational difficulty of problems such as factoring large numbers or computing discrete logarithms. However, their security fundamentally depends on these complex mathematical problems remaining computationally intractable – an assumption that the existence of large-scale quantum computers would challenge. Post-quantum cryptographic (PQC) algorithms are being developed to resist quantum attacks and can be deployed widely on existing communication infrastructures. PQC is expected to provide the main defence against future quantum attacks, as it is scalable, cost-effective, and compatible with existing architectures.

By resting its security on physical laws rather than the computational complexity of mathematical problems, QKD offers alternative security. Any attempt to tamper with quantum links (such by wiretapping or observing) necessarily disturbs quantum states due to the uncertainty principle, thereby alerting users to the possibility of eavesdropping – a feature that cannot be achieved with classical communications (Bennett & Brassard, 2014). However, QKD only addresses secure agreement on secrets (e.g. encryption keys); it does not provide for encryption methods. The security of data communication based on secrets exchanged through QKD typically still relies on theoretically secure classical information algorithms (e.g. the one-time pad) or classical computationally secure cryptographic algorithms.[9]

Quantum communication as a whole also faces substantial practical limitations. Classical networks can transmit terabits per second across continents using signal amplifiers and wavelength division multiplexing,[10] while quantum transmission distances are typically limited to hundreds of kilometres in fibre or thousands of kilometres via satellites (all without true quantum repeaters).[11] Data rates are typically megabits per second, compared to terabits for classical channels. Quantum signals cannot easily be amplified due to the no-cloning theorem,[12] and specialised equipment may require expensive cryogenic environments (though some systems operate at or near room temperature).

Given these distance and bandwidth limitations, current quantum communication applications like QKD are primarily suited for specialised applications where the physics-based security guarantee justifies the significant constraints: military communication, financial transactions between major institutions, diplomatic channels or protecting state secrets. For most everyday communication, quantum-resilient security will be achieved through PQC integrated into classical communication systems, which continue to offer the required speed, range, and scalability. Rather than replacing classical communication, quantum technologies will complement them by addressing specific security or capability requirements that classical systems cannot meet.

Quantum computing

Modern AI accelerators and supercomputers achieve extraordinary performance through classical parallelism – deploying thousands or even millions of processing cores that work simultaneously on different parts of the same problem. However, each individual core still processes one definite value at a time; a core working on pixel data processes either a red value or a blue value, never both simultaneously. This approach can be scaled by adding

9 Encryption works by transforming a readable message into coded text using a shared "secret key," which functions like a unique password; only someone with the same key can reverse the process and recover the original message. QKD securely distributes this secret key, but the actual encoding and decoding of the message still rely on conventional encryption methods.

10 Wavelength division multiplexing (WDM) is a method in fibre-optic networks where multiple signals are carried simultaneously on different light wavelengths (colours), greatly increasing total data capacity.

11 True quantum repeaters would extend quantum links by storing, correcting and relaying fragile quantum states; unlike classical repeaters they cannot simply copy signals because the no-cloning theorem forbids duplicating unknown quantum states, making them technically very challenging.

12 The no-cloning theorem states that an arbitrary, unknown quantum state cannot be copied exactly. This fundamental limit preserves quantum uncertainty and prevents perfect duplication of quantum information (Wooters & Wojciech, 1982).

more processors, but while it is enormously powerful it remains fundamentally sequential at the individual processor level.

Quantum computing exploits quantum phenomena to achieve a qualitatively different form of parallelism: simultaneity. Through superposition, individual qubits can exist as both 0, 1 or any value in between simultaneously until measured, enabling the system to explore multiple solution paths at once. Entanglement then links qubits together in ways that create powerful correlations, allowing the system to process these possibilities in a coordinated way (Ladd, et al., 2010). These quantum phenomena (combined with effects like quantum interference) allow quantum systems to explore solution spaces in ways impossible for classical computers, enabling a 100-qubit quantum computer to theoretically encode 2^{100} possibilities simultaneously, far exceeding what any classical parallel system could achieve.

As of today, breaking RSA-2048 encryption (a widely deployed standard encryption algorithm used by financial institutions and governments alike) remains far out of reach for both the most powerful conventional supercomputers and today's noisy intermediate-scale quantum (NISQ) devices with only a few hundred qubits (OECD, 2024). Looking ahead, it is plausible (but not guaranteed) that by 2040 quantum computers with around one million physical qubits could exist. Recent estimates suggest that such a machine, if paired with effective error correction, could break RSA-2048 encryption in less than a week (Gidney, 2025). By contrast, even if conventional supercomputers reach zettascale performance (10^{21} operations per second, roughly one thousand times today's exascale (Top500), factoring RSA-2048 would still take thousands of years using the best-known classical algorithms (Wang, 2023). This implies that large-integer factorisation will remain infeasible for classical machines for many decades, but could realistically come within reach of quantum computers in the next generation or two.

However, this quantum advantage only materialises for specific types of problem for which quantum phenomena can be effectively exploited, for example breaking encryption by factoring large numbers, solving complex optimisation problems by exploring vast solution spaces simultaneously, searching unstructured databases, simulating quantum systems like molecules and materials, and some specialised mathematical problems (OECD, 2025a). Current research indicates that quantum computers are "different computers" rather than universally "better computers"; most small to moderate-sized problems will not benefit from quantum computing (Preskill, 2018). For many computational tasks – including training AI models, processing images or running general simulations – classical parallelism will remain more effective, reliable and practical than quantum approaches, especially given the current limitations to quantum computing.

Quantum computing-simulation

Classical computers simulate complex systems by decomposing them into manageable components and executing massive parallel calculations; for example, modern weather models process tens of millions of observations to predict conditions days ahead, while pharmaceutical simulations model molecular interactions by calculating electromagnetic forces between thousands of atoms to identify potential drug candidates.

These approaches excel when physical systems follow well-understood mathematical frameworks, and they can be successful in modelling everything from aircraft aerodynamics to financial market fluctuations. However, they encounter fundamental barriers with certain quantum many-body systems.[13] Some quantum problems, such as those involving strongly correlated electrons in materials like high-temperature superconductors, require computational resources that grow exponentially with system size, making them intractable even for today's high-performance computing (HPC) clusters.

To illustrate the challenge, the computational cost of simulating quantum systems doubles with each particle added; a system of 10 quantum particles requires tracking 1 024 possible states, 50 particles exceed one quadrillion (10^{15}) states, and 300 particles surpass 10^{90} states – more than the number of atoms in the observable universe. Storing and processing this information would require more memory and computing power than any conceivable classical supercomputer, highlighting why some quantum problems remain fundamentally intractable with classical methods.

To overcome these limits, researchers pursue quantum simulation, a broad term that covers both digital simulations performed on general-purpose quantum

13 Quantum many-body systems are collections of many interacting quantum particles – such as electrons in a material – where their properties cannot be understood by looking at each particle separately, but only by considering the system as a whole.

computers and analogue simulations using controlled quantum systems designed to simulate specific materials or interactions.

Quantum simulators harness quantum phenomena (superposition and entanglement) as computational resources, rather than obstacles. This approach comes in two forms: analogue quantum simulators use precisely controlled quantum systems like ultracold atoms to directly emulate target materials, while digital quantum simulators employ programmable quantum circuits to model various quantum systems.

The fundamental advantage lies in natural representation. Where classical computers have to approximate quantum correlations using exponentially large data structures, quantum simulators inherently operate in quantum superposition states (Georgescu, Ashhab, & Nori, 2014). Current analogue devices manipulate around 1 000 atoms with remarkable control, while digital platforms today offer a few dozen logical error-corrected qubits (based on many more physical qubits).

However, quantum simulators face significant practical challenges. Extracting meaningful data requires hundreds of thousands of repeated measurements due to the probabilistic nature of quantum mechanics. Present-day devices remain noisy and limited in scale, restricting their application to proof-of-concept demonstrations rather than industrial problem-solving.

The quantum advantage targets specific classes of problem: strongly correlated quantum materials, complex chemical catalysts, and systems where quantum effects dominate macroscopic behaviour. Applications include modelling unconventional superconductors for lossless power transmission, understanding photosynthetic energy transfer for improved solar cells, and discovering novel quantum phases of matter. For most computational tasks – fluid dynamics, optimisation problems and traditional engineering simulations – classical computers maintain superior performance, reliability and cost-effectiveness.

Quantum sensing

Traditional sensors achieve high performance through sophisticated engineering, deploying precision electronics, advanced materials and signal processing to detect physical quantities such as magnetic fields, temperature, pressure or acceleration. A conventional magnetometer might use thousands of precisely calibrated components working together to measure magnetic field strengths, while GPS systems rely on networks of atomic clocks to achieve meter-level positioning accuracy. However, these classical sensors are fundamentally limited by physical noise sources, thermal fluctuations and gradual drift over time that degrades their calibration. Each sensor component must be individually optimised and maintained, and their performance is bounded by the standard quantum limit (the fundamental noise floor imposed by the granular nature of physical measurements).

Quantum sensors are capable of turning these limitations into advantages. They exploit phenomena such as superposition and entanglement, allowing them to extract more information per measurement and achieve sensitivities beyond what classical sensors can reach. Entanglement enables multiple quantum particles to become correlated across space, allowing common noise sources to be cancelled out while amplifying the actual signal being measured. These effects allow sensors to surpass the standard quantum limit[14] and achieve sensitivities that are orders of magnitude better than classical approaches in certain applications; quantum magnetometers can detect magnetic fields billions of times weaker than that of the earth, while quantum atomic clocks are so precise they would lose only one second in 30 billion years, roughly twice the age of the universe (Degen, Reinhard, & Cappellaro, 2017).

However, this quantum advantage is primarily apparent for applications requiring extreme precision or measurements in challenging environments where classical sensors fail entirely: detecting gravitational waves from distant black holes, measuring neural activity in the brain without invasive electrodes, navigating in

14 The standard quantum limit is the sensitivity threshold imposed by the random noise that arises when measuring many uncorrelated quantum particles, such as photons or atoms. In classical sensors, averaging over more particles only gradually improves precision, whereas quantum techniques like entanglement or squeezing correlate particles to suppress this noise and exceed the limit.

GPS-denied environments[15] or detecting dark matter. For most everyday sensing applications (monitoring temperatures in buildings, measuring speed in vehicles or detecting motion in smartphones) classical sensors remain more practical, robust and cost-effective than their quantum counterparts.

2.4 Conclusion

This section has highlighted how the technologies that underpin the quantum ecosystem are still nascent, albeit highly dynamic and with remarkable potential across a host of uses. Multiple hardware platforms are being developed in parallel as researchers investigate which combinations of performance, manufacturability and operating overhead offer the best opportunity to scale. This exploratory intensity is a feature of an early market phase; no single technological winner has emerged, and investments of time, talent and capital are spread across options to reduce risk and maximise learning.

Despite their immense potential, quantum technologies will not displace classical computing, sensing and communication infrastructure for the foreseeable future; instead they will operate alongside it, delivering selective advantages (e.g. specialised speed-ups, ultra-sensitive measurements, secure key distribution and accurate simulation of quantum matter) when tightly integrated with mature classical systems (OECD, 2025a).

The following sections quantify this early-stage landscape by examining the evolving patent geography by country, the startup and venture capital ecosystem, trade flows in critical inputs, and the skills base required to sustain progress, providing a data-driven view of how this exploratory phase is being resourced worldwide.

15 GPS-denied environments are settings where satellite navigation signals are unavailable, unreliable or deliberately disrupted, such as underwater, inside buildings, in space, or in military zones affected by jamming or spoofing.

3. Quantum patent landscaping

This section presents a comprehensive mapping of quantum patents and analyses the main features of the quantum innovation landscape. Patents provide a powerful lens for tracking innovation in strategic and highly dynamic fields such as quantum technology. As a key mechanism for translating scientific advances into market applications, patenting activity offers an early indicator of future industrialisation and commercialisation in technologies that are still at an embryonic stage.

A distinctive strength of the quantum patent cartography lies in both its breadth, covering the three main areas of quantum technologies (communication, computing and sensing), and its depth, offering a high level of granularity that identifies key fields and subfields within each area. This dual approach makes it possible to combine broad perspectives with detailed insights in those quantum domains where innovation is most dynamic.

The section proceeds as follows. Section 3.1 describes the scope of the quantum areas, fields and subfields covered, explains the methodology used to identify relevant patents, and presents the dataset that underpins the analysis. Section 3.2 explores patenting dynamics over time, first providing a global overview and then examining developments within specific quantum areas. Section 3.3 analyses country-level patterns, including absolute levels of activity, shifts in relative importance, national specialisation, and internationalisation strategies. Section 3.4 investigates the roles of companies, startups, universities and PROs. Finally, Section 3.5 examines how quantum inventions influence other technological fields and countries, underscoring

Box 1: Methodology, data sources and final mapped dataset

The mapping of patents to the quantum concepts relies on carefully developed search strategies designed by EPO expert examiners specialised in quantum technologies. These combine meaningful keywords with relevant patent classification symbols and have been iteratively refined to balance two key objectives: ensuring high recall, i.e. comprehensive coverage of relevant patents while minimising noise i.e. the inclusion of unrelated applications. Patent families may be linked to one or more quantum concepts, depending on the invention's technical characteristics. EPO worldwide patent data was used as the central source of patent information for the analysis. This includes bibliographic and other information on more than 150 million patent documents from more than 100 patent authorities on all continents (more information is available at epo.org/searching-for-patents). Patent searches were carried out using EPO worldwide patent data via the EPO's internal data platforms and search interfaces, the basic dataset resulting from the quantum mapping exercise was combined with data from the EPO's worldwide statistical database PATSTAT (Spring 2025 edition).

The patent analysis throughout the report is based on patent families, distinguishing between international patent families (IPFs) and non-IPFs. An IPF refers to a set of published patent applications filed with at least two authorities, the EPO or under the Patent Co-operation Treaty (PCT) to protect the same invention. Non-IPFs correspond to patent families filed with only one patent authority. Grouping applications into families allows all filings for the same invention to be counted as a single observation, while focusing on IPFs neutralises national biases, enables meaningful international comparisons and provides a selection of higher values' patents. IPFs usually indicate technologies that applicants see as commercially relevant and worth protecting in multiple markets.

Unless specified, the reference year for all statistics is the earliest publication year of each patent family, usually 18 months after the first application. In most figures, the country breakdown corresponds to the location of the applicants. Unless noted otherwise, this report applies fractional counting whenever a patent family is assigned to multiple entries within a category (for example, several concepts, applicant countries, or applicant sectors).

The mapped quantum patent dataset includes 31 700 families of published patent applications with earliest publication years between 2005 and 2024, each mapped to at least one quantum concept. This dataset serves as the primary input for the analysis. Table A1.2 of Annex A.1 provides a sample of highly cited mapped quantum patents.

their role as upstream enablers with spillovers across industries such as artificial intelligence, cybersecurity, life sciences, automotive and finance.

3.1 Mapping quantum patents

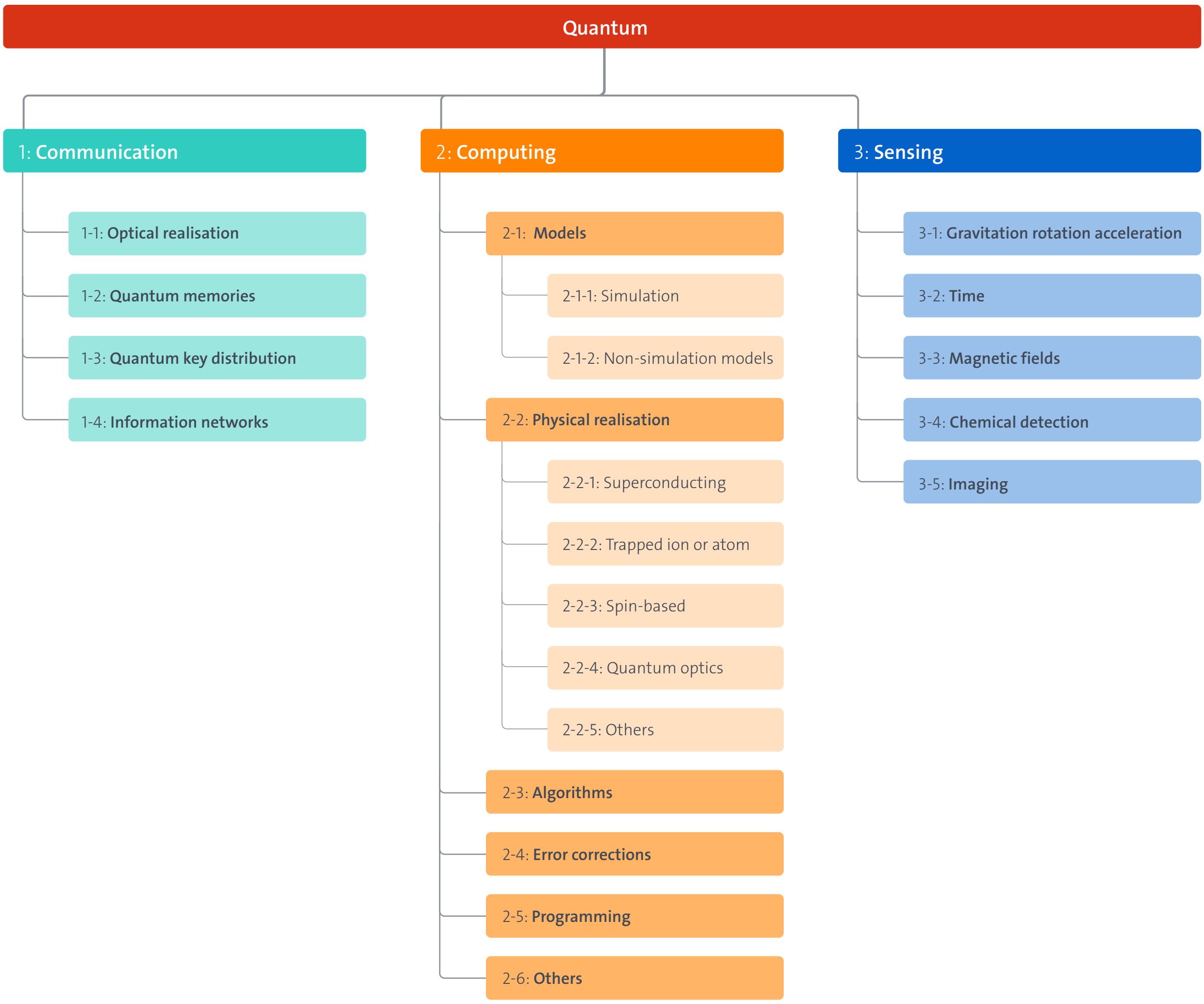
This section sets out the scope of the quantum areas, fields and subfields covered in the cartography, explains the methodology used to map patents to specific concepts, and describes the underlying data sources. It also presents an initial overview of the mapped dataset, which provides the foundation for the analysis.

3.1.1 Quantum patent cartography: scope and methodology

The cartography aims to identify all published patent applications for inventions in the three main quantum technology areas: quantum communication, computing (including quantum simulation) and sensing. Within each of these broad areas, fields and specific subfields have been identified by subject matter expert examiners, resulting in a granular cartography that highlights key technological areas of interest. The granularity of the cartography is an important contribution of the mapping exercise. Concept definitions are provided in Table A1.1 of Annex A.1.

Figure 3.1.1

Quantum cartography



Source: EPO, October 2025.

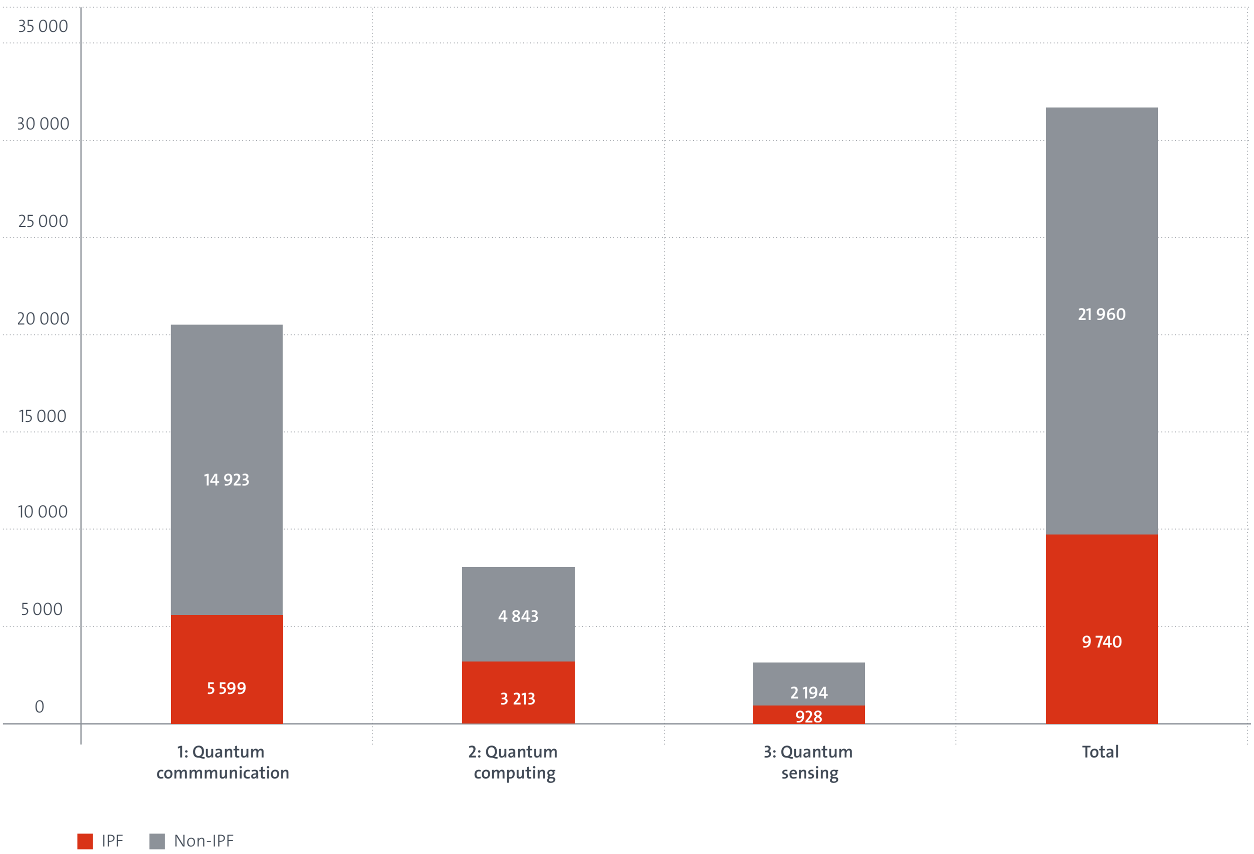
3.1.2 General overview of quantum patent families

Figure 3.1.2 shows the total number of patent families and the distribution across the three main quantum areas: communication, computing and sensing. While the focus is on IPFs, about two-thirds of quantum patent families include filings with only one national patent office. The majority of these national-only filings originate from Chinese applicants filing via the China National Intellectual Property Administration (CNIPA), particularly in quantum communication. This area dominates the landscape, with over 20 000 families, including 5 599 IPFs. Quantum computing follows with 8 056 families, of which 3 213 are IPFs, while quantum sensing remains the smallest area with 3 122 families and 928 IPFs.

Figure 3.1.3 gives the distribution of IPFs across detailed quantum technology areas. Within communication, the highest concentration of IPFs is in QKD, followed by information networks, while optical realisations and quantum memories remain more specialised niches. In computing, there is significant activity under simulation and non-simulation models, as well as in physical realisations, where superconducting technologies hold the lead among competing platforms such as trapped ions, spin-based and optics. Algorithms, error correction and programming also contribute notable shares of IPFs. Quantum sensing shows the lowest overall volume, but within this area precise time measurement stands out as the most active subfield, ahead of applications in gravitation, magnetic fields, chemical detection and imaging.

Figure 3.1.2

Number of patent families by quantum area: 2005-2024

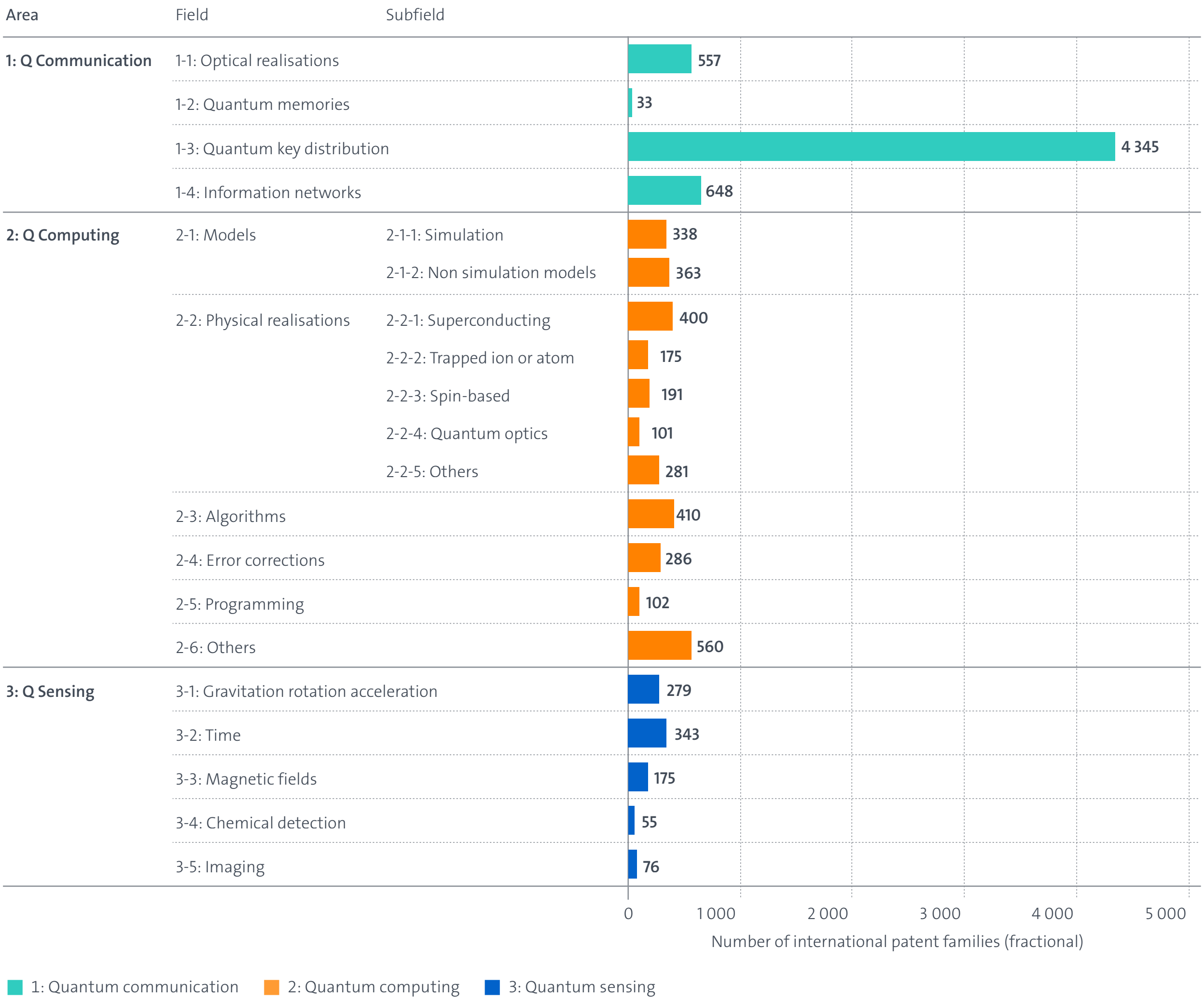


Notes: The graph shows the number of published patent families with earliest publication year between 2005-2024, differentiating between international (IPF) and national (non-IPF) patent families.

Source: EPO, October 2025.

Figure 3.1.3

Number of IPFs by quantum area, field and subfield: 2005-2024



Source: EPO, October 2025.

Box 2. Tracking quantum innovation with the EPO technology platforms

The EPO provides a series of technology platforms designed to make it easier for scientists, researchers, innovators, policymakers and the general public to explore patent information in specific technical fields. Each offers direct access to curated collections of patent documents in Espacenet, organised into well-defined concepts reviewed and classified by EPO patent examiners.

The new technology platform on quantum technologies provides an interactive real-time view into the state of innovation in the areas of quantum computing, quantum communication and quantum sensing and metrology, as well as their narrower fields and subfields, mapped on the occasion of this study. It allows users to identify quantum patents and their bibliographic information, display descriptive statistics for each quantum concept and adapt queries to specific research or commercial needs.

The EPO technology platforms can be freely accessed online: epo.org/technology-platforms.

3.2 Trends in quantum innovation

This section examines trends in quantum innovation. It first looks at quantum technologies, comparing the growth of quantum patenting with benchmarks from all technological fields to provide a broad overview. It then zooms in on the main quantum areas to highlight trends in specific fields and subfields. This approach helps capture both the overall trajectory of quantum innovation and the distinctive dynamics shaping its different areas, providing valuable insights into where technological progress is most concentrated.

Figure 3.2.1 shows the trend in patenting activity in quantum technologies between 2005 and 2024, measured by the number of published patent families by earliest publication year. The results show a steady but modest level of activity up to around 2014, followed by a marked acceleration thereafter in terms of both IPF and non-IPF publication.

Figure 3.2.2 compares trends for IPFs in quantum relative to all technology fields. Over the past two decades the number of IPFs has increased more than sevenfold, with the bulk of this growth concentrated in the last decade. Between 2005 and 2014 patenting activity in quantum technologies did not deviate significantly from the general trend across all technologies. During this period, quantum IPFs grew only modestly, with a CAGR of 3%, slightly below the 4% recorded for all technologies.

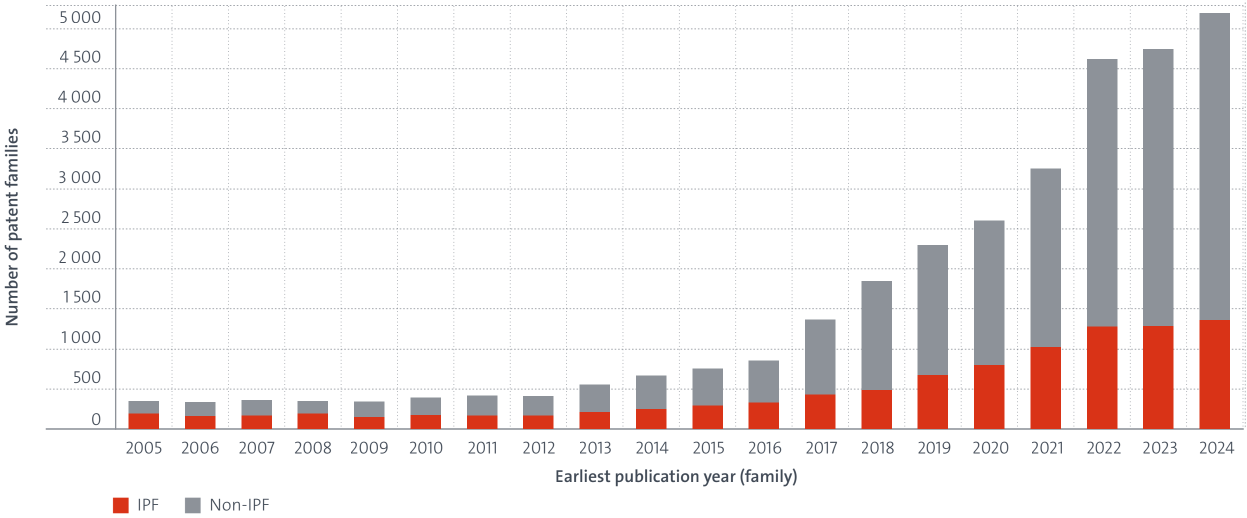
From 2014 to 2023, by contrast, quantum IPFs expanded at an exceptional CAGR of 20%, while all technologies grew at only 2%.

Figure 3.2.3 disaggregates IPF trends by area. Quantum communication consistently accounted for the largest share until 2022, with the number of IPFs increasing by about 4.6 times from 2005 to 2024. Quantum computing, although smaller in absolute terms, has shown the most dynamic growth, expanding nearly 60-fold over the same period and emerging as a major driver of recent quantum innovation. Quantum sensing remains the smallest area, but has nevertheless grown 2.4 times compared to 2005.

Figure 3.2.4 further disaggregates trends by fields and subfields within quantum areas. Quantum communication (Panel A) has grown steadily since 2014, driven primarily by QKD, while information networks and optical realisations remain smaller but emerging segments. Quantum sensing (Panel B) has also shown steady growth since 2010, though at lower absolute levels, with magnetic field measurement emerging as a particularly dynamic area. Quantum computing (Panels C and D) has accelerated most sharply since 2015, dominated by physical realisations and followed by models and algorithms, with smaller yet essential contributions from error correction.

Figure 3.2.1

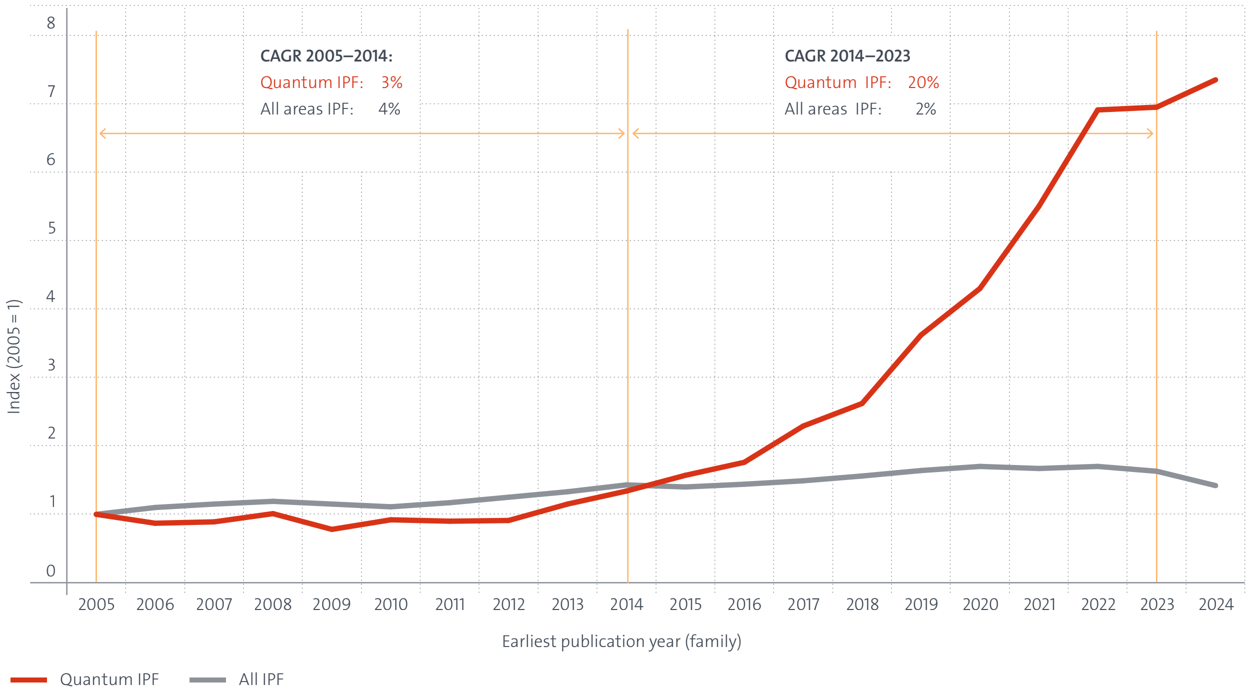
Patent families in quantum technology over time



Source: EPO, October 2025.

Figure 3.2.2

Normalised trends for IPFs in quantum technologies vs all technology domains

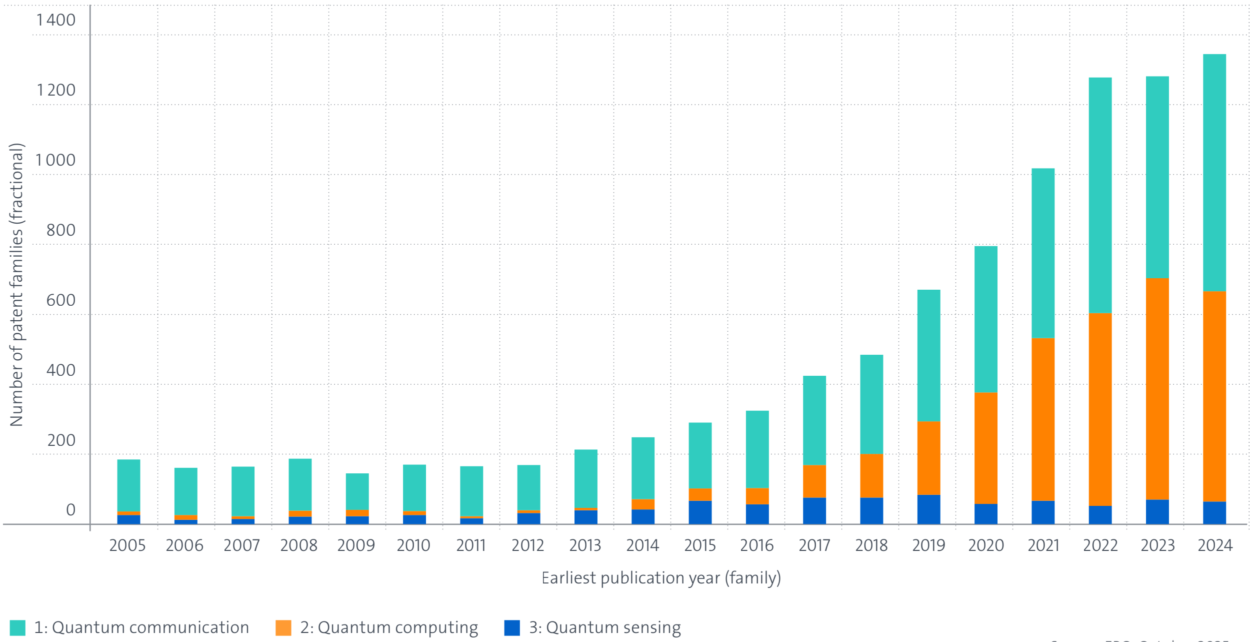


Notes: The graph shows the growth in the number of international patent families (IPFs) in quantum technologies compared to all technology domains as a benchmark. The y-axis indicates the multiplier relative to the number of IPFs with earliest publication year in 2005 (e.g. a value of 7 in 2023 means that the number of quantum IPFs published in that year was seven times higher than in 2005). The boxes at the top of the figure report the compound annual growth rate (CAGR) for two periods: 2005-2014 and 2014-2023.

Source: EPO, October 2025.

Figure 3.2.3

Trends in IPFs in quantum technologies by quantum area



Source: EPO, October 2025.

Figure 3.2.4

Trends in IPFs by quantum field and subfield

Source: EPO, October 2025.

3.3 Geography of quantum patenting

This section examines the relevance of quantum patenting across countries. It first considers absolute levels for quantum as a whole and for the three main technology areas. It then traces the evolution of country relevance over the past two decades. Next, it analyses national specialisation in quantum innovation and its subfields. Finally, it reviews cross-country differences in the propensity to seek international patent protection across subfields.

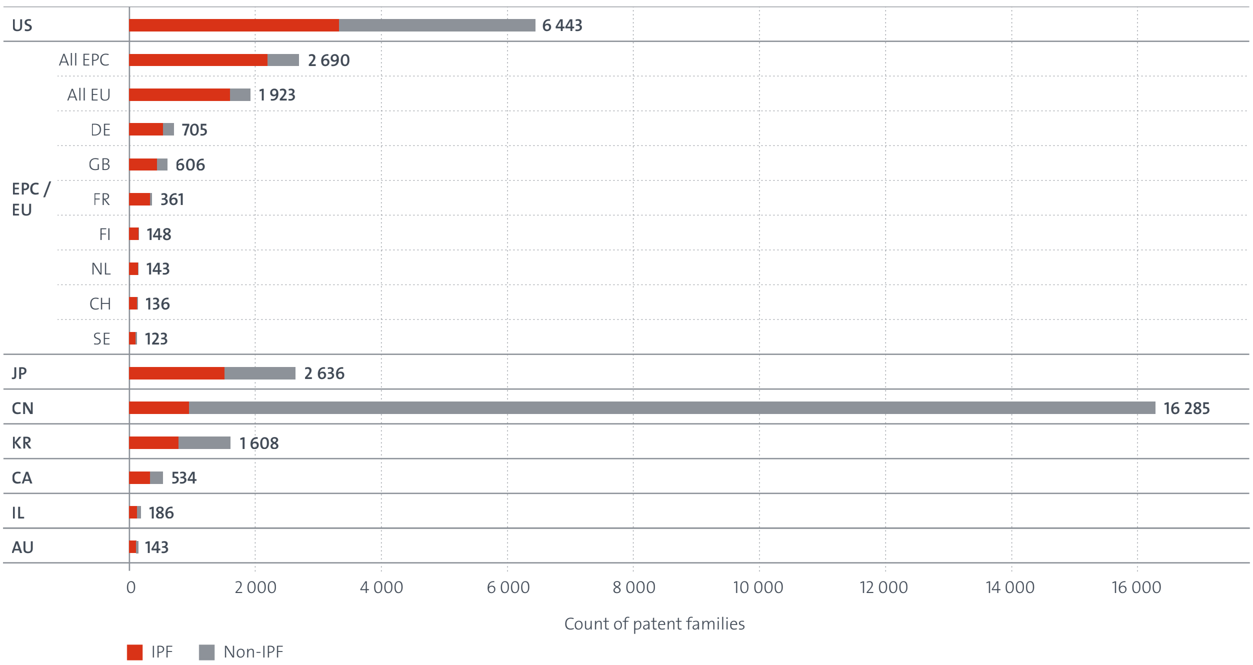
3.3.1 Country relevance in quantum innovation

Figure 3.3.1 shows the distribution of patent families in quantum technologies by country. Overall (Panel A), applicants from China account for the largest number of families (over 16 000), though most are confined to national filings. The United States follows with around 6 400 families, while European Patent Convention (EPC) member states collectively account for 2 690, with Japan (2 636) and Korea (1 608) also contributing substantially alongside active European countries such as Germany, France and the United Kingdom. When focusing on IPFs, in Panel B, the picture changes: the United States leads with 3 330 IPFs, followed by the EPC states (2 193) and Japan (1 519). China ranks fourth with 947, while Korea (782), Germany (534), the United Kingdom (447), Canada (334), France (334) and the Netherlands (136) also make significant contributions.

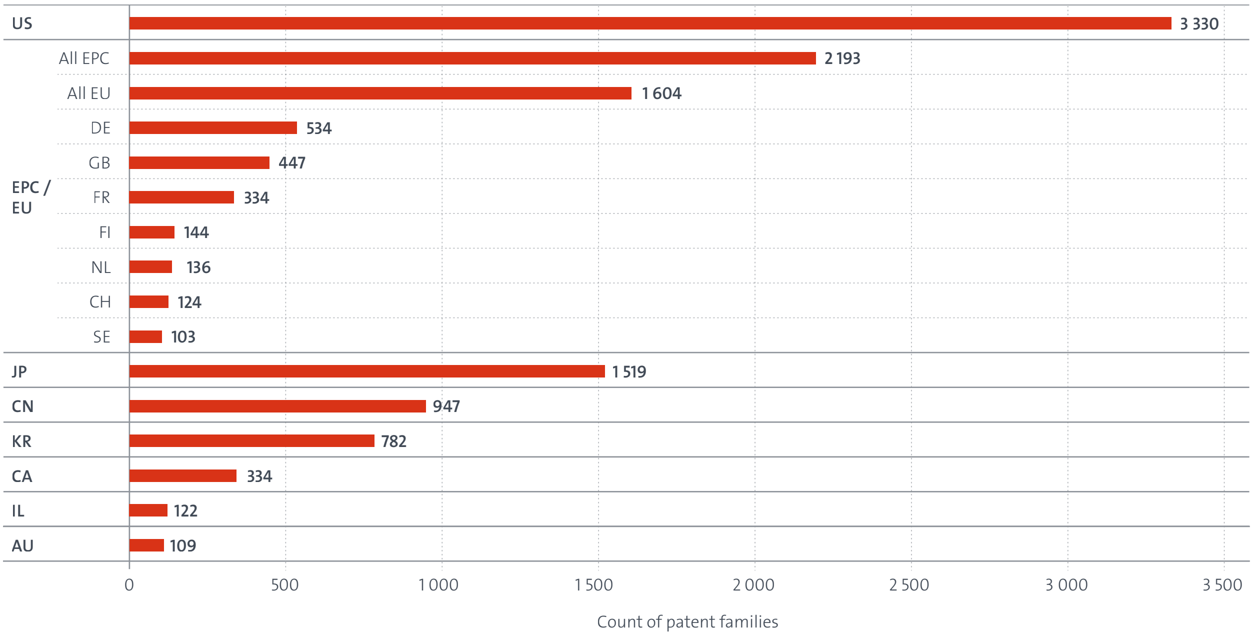
Figure 3.3.1

Patent families in quantum technology by applicant country: 2005-2024

Panel A) All patent families



Panel B) International patent families



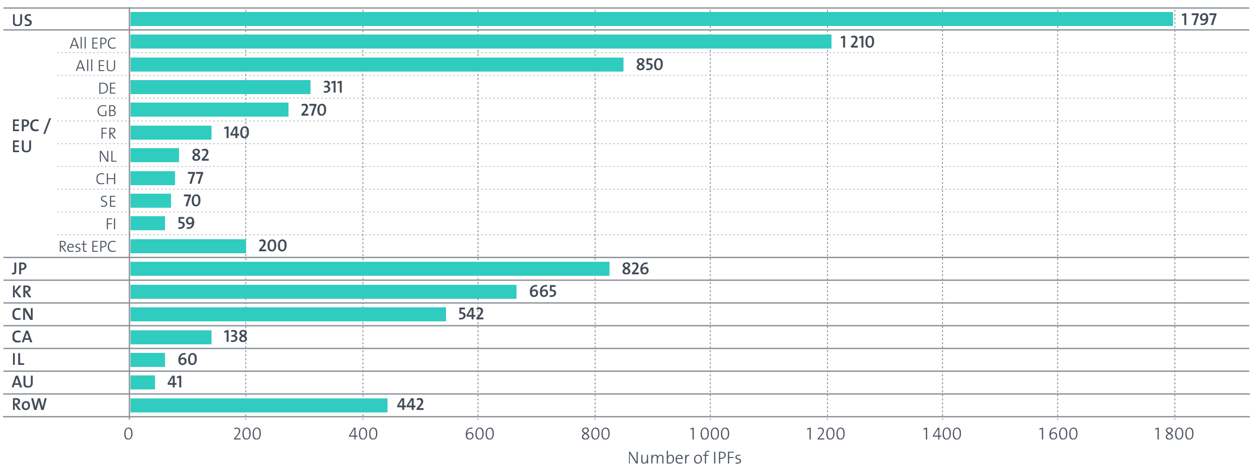
Source: EPO, October 2025.

Figure 3.3.2 shows the number of IPFs by country and quantum areas, with the US, EPC member states and Japan occupying the top three positions across all three areas. In communication (Panel A), these regions are followed by Korea and China, with the United Kingdom and Germany leading within Europe. In quantum computing (Panel B) they are followed by China, while the United Kingdom and Germany again stand out in Europe alongside contributions from Canada, France and Korea. In quantum sensing (Panel C) the top three are followed again by China, Germany and France.

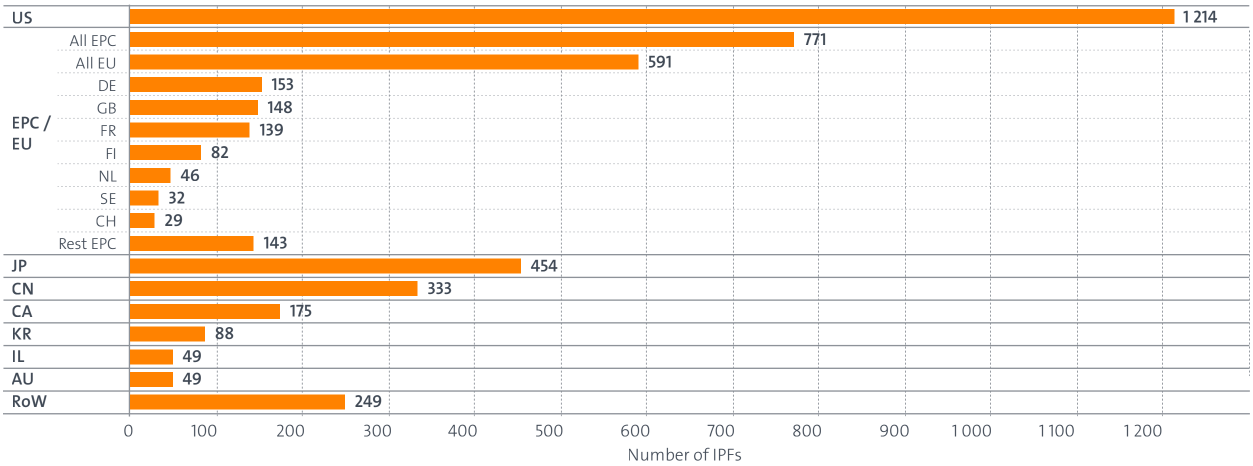
Figure 3.3.2

Top applicant countries by quantum area IPFs: 2005 -2024

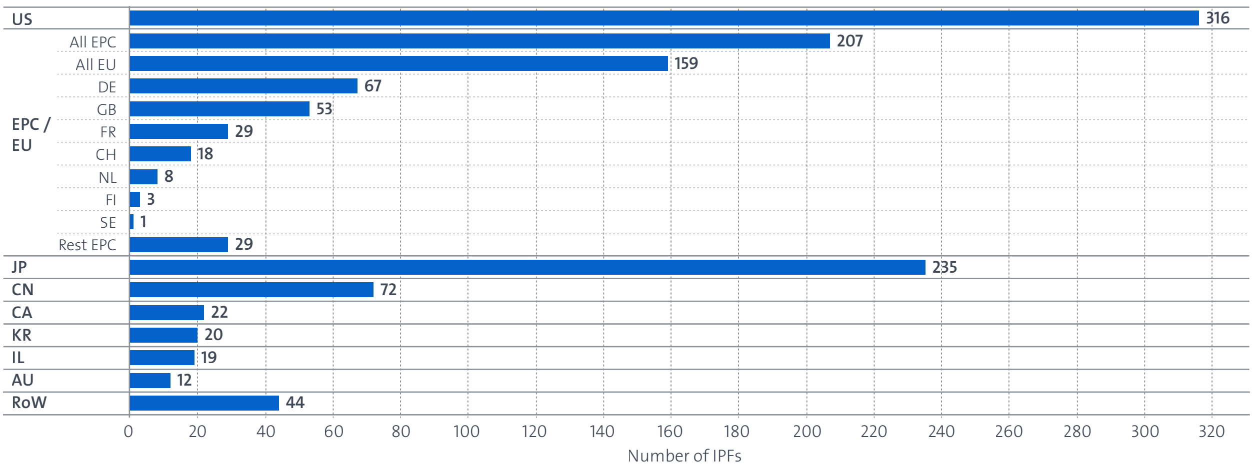
Panel A) Quantum communication



Panel B) Quantum computing



Panel C) Quantum sensing



Source: EPO, October 2025.

3.3.2 Changes in country relevance in quantum innovation

Figure 3.3.3 further assesses country relevance in quantum innovation and how it has changed over time by showing the number of quantum IPFs that received at least one forward citation within five years of publication, broken down by applicant country. Forward citations are widely regarded as an indicator of the technological importance of inventions (Trajtenberg 1990, Hall et al. 2005, Harhoff 2003). Because the citation window is deliberately narrow, the figure captures applications that are particularly relevant and quickly taken up in subsequent innovation.[16] The influence in quantum innovation, as measured through these early forward citations, is concentrated in a few major countries, with the balance shifting over time from the US to China in some important dimensions.

Since 2015-2019 China has accounted for the largest number of forward-cited quantum IPFs, while the United States has a higher share of highly cited IPFs, suggesting particularly strong uptake of its patents in follow-on innovation. Japan and Korea rank next in the number of forward-cited IPFs, with the United Kingdom and Germany also showing a notable presence. The most recent period (2020-2024) should be interpreted with caution, as these applications have not yet had the full five-year window to accumulate citations.

16 Forward-citation analysis has limitations too, as citation behaviour can be strongly influenced by national legislation and citation ecosystems that are not globally representative.

Figure 3.3.3

Number of forward-cited patent families within five years of publication

Notes: This figure shows the number of quantum IPFs with at least one forward citation within five years of publication (bar length) and the number of forward citations received by these applications within the same time window (bar colour label), based on the applicant's place of residence. Such citations might originate either from applicants or examiners of the citing patent. The decline over the period 2020-2024 is due to the fact that recently published patents have not had sufficient time to collect citations and/or the citing patents are not yet fully available in the current databases.

Source: EPO, October 2025.

3.3.3 Country specialisation in quantum: RTA analysis

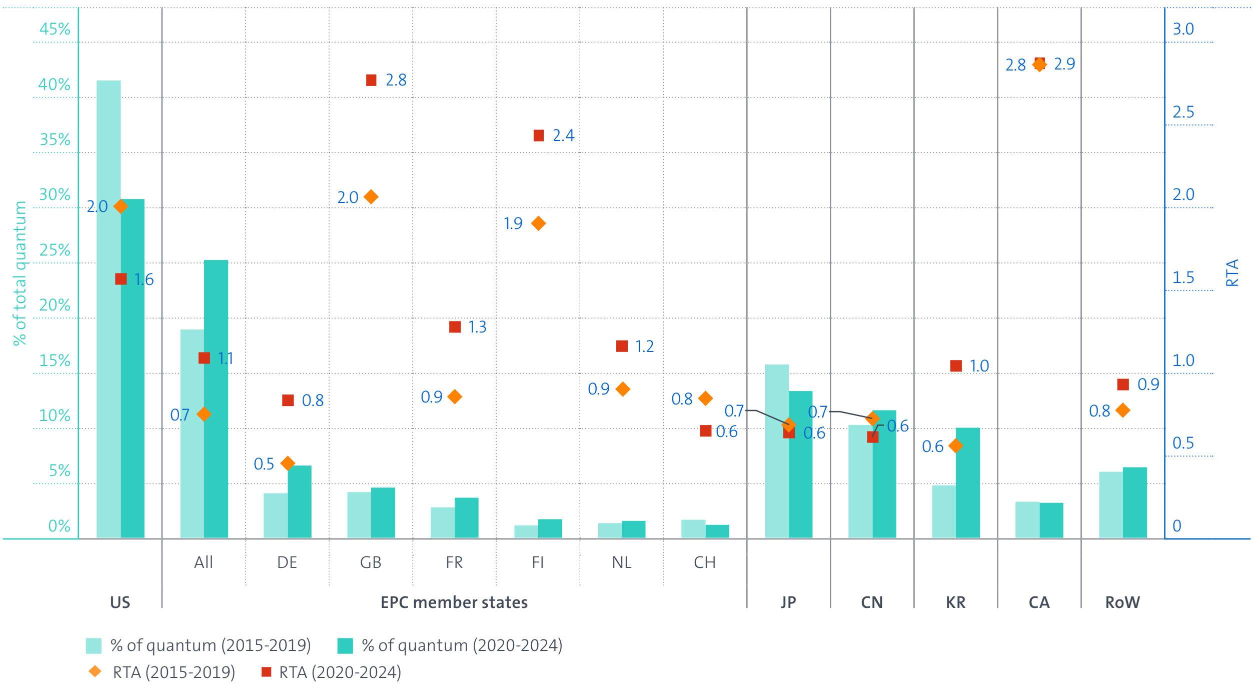
The revealed technological advantage (RTA) indicates a country's specialisation in terms of technological innovation relative to its overall innovation output. It is defined as a country's share of IPFs in a particular field of technology divided by the country's share of IPFs in all technology domains. An RTA above one reflects a country's specialisation in a given technology.

Figure 3.3.4 shows the percentage contribution of each country to global quantum IPFs, together with their degree of specialisation as measured by the RTA. In the two time periods investigated (2015-2019 and 2020-2024) US applicants account for 41% and 31% of all IPFs and show RTAs of 2.0 and 1.6 – i.e. well above 1, indicating a strong specialisation in quantum. Europe follows and shows an increasing IPF share and RTAs increasing from 0.7 to 1.1, with Germany, the United Kingdom and France the main contributors. Within Europe, the RTA is particularly high for the United Kingdom and Finland, while Germany and Switzerland are below the global average. Japan is the second-largest national IPF filer, followed by China and Korea. Canada has the highest RTA.

Figure 3.3.5 provides RTAs for narrow quantum subfields, showing that US applicants exhibit above-average specialisation in most quantum computing areas, quantum memories and measurement of magnetic fields. Japan shows a strong focus on ultra-precise time measurement, while China specialises in chemical detection. Korea stands out in information networks and chemical detection and Germany shows notable specialisation in magnetic field measurement, imaging and spin-based computer realisations, as well as magnetic field measurement. The sorting of the applicant locations is according to their number of IPFs.

Figure 3.3.4

Contribution of quantum IPFs by region with RTA by region



Notes: The graph shows the percentage of global IPFs on the left and the revealed technological advantage (RTA) on the right by applicant country for two time periods. The RTA indicates each country's degree of specialisation in quantum by comparing its patent share in quantum to its global patent share. An RTA above one indicates that the country is more specialised in quantum than the global average.

Source: EPO, October 2025.

Figure 3.3.5

RTA across quantum subfields: 2005-2024

Level 1	Level 2	Level 3	US	JP	CN	KR	DE	GB	CA	FR	FI	NL	CH	IL	AU	SE	AT	SG	TW	RU	ES	IT	KY	IN	MY	DK	RoW	%
1: Quantum communication	1-1: Optical realisations		0.7	1.2	1.2	1.0	0.8	1.6	0.7	1.0	1.5	0.8	1.5	1.4	0.4	0.8	1.8	1.3	0.8	1.8	1.7	2.1	0.4	0.6	2.3	1.3	1.3	5.7
	1-2: Quantum memories		1.7	0.3	0.8	0.8	0.5	1.4	0.7	0.6	1.0	0.0	0.0	2.0	3.9	0.0	0.9	0.0	1.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3
	1-3: Quantum key distribution		1.0	0.9	1.0	1.4	1.0	1.0	0.7	0.7	0.6	1.1	1.0	0.8	0.6	1.3	0.5	1.2	1.2	1.7	0.7	1.0	1.3	1.0	1.7	0.8	1.3	44.7
	1-4: Information networks		0.7	0.8	1.0	2.9	1.0	1.1	0.7	0.8	0.4	1.3	1.1	0.5	0.8	0.9	0.3	1.1	0.9	0.4	1.1	1.2	1.6	1.4	1.3	0.5	0.6	6.7
2: Quantum computing	2-1: Models	2-1-1: Simulation	1.2	0.7	1.1	0.3	0.9	0.8	2.5	1.1	1.2	1.1	0.9	0.8	0.9	1.0	1.1	0.4	1.1	0.3	1.9	0.3	0.7	2.0	0.0	1.6	1.1	3.5
		2-1-2: Non simulation models	1.1	0.7	1.6	0.4	0.7	1.0	1.2	1.3	1.9	0.7	0.4	1.7	1.6	0.8	1.6	1.5	0.9	0.0	1.8	0.8	0.8	0.7	0.0	1.5	0.4	3.7
	2-2: Physical realisations	2-2-1: Superconducting	1.0	1.1	1.1	0.2	0.8	0.7	1.9	1.2	5.0	1.1	0.6	0.9	0.9	0.7	2.0	0.9	0.3	0.0	0.4	0.2	1.4	0.1	0.0	1.0	0.6	4.1
		2-2-2: Trapped ion or atom	1.2	0.3	0.6	0.2	1.3	1.8	0.6	2.7	0.7	1.1	0.9	1.8	2.4	0.3	12.1	0.7	0.5	0.0	0.9	0.2	0.6	0.9	0.8	1.1	0.4	1.8
		2-2-3: Spin-based	1.1	0.7	0.5	0.2	1.4	1.1	1.8	2.2	1.3	2.2	0.5	1.5	5.8	0.6	1.2	0.1	0.9	0.0	0.4	0.2	0.6	0.1	0.7	2.6	0.4	2.0
		2-2-4: Quantum optics	1.2	0.4	0.5	0.3	1.2	1.5	1.8	1.9	1.9	2.3	0.9	3.1	1.1	0.3	1.8	0.8	0.5	0.0	2.3	4.5	0.1	0.2	0.0	1.2	0.1	1.0
		2-2-5: Others	1.1	0.9	1.4	0.3	0.8	1.0	1.6	0.9	1.8	0.7	0.8	1.4	1.7	1.2	2.1	0.7	1.6	0.2	1.3	0.4	1.4	0.1	0.0	1.3	0.8	2.9
	2-3: Algorithms		0.8	1.6	1.0	0.4	1.3	0.9	2.0	0.8	0.6	0.8	0.9	0.6	0.6	2.3	1.2	0.5	0.5	0.1	4.0	0.1	0.4	1.5	0.0	1.4	0.7	4.2
	2-4: Error corrections		1.3	0.6	1.3	0.5	0.6	1.4	1.0	1.2	1.3	0.5	0.8	1.6	1.8	0.6	0.7	0.5	0.7	0.0	0.7	0.4	1.0	0.4	0.0	1.2	0.6	2.9
	2-5: Programming		1.2	0.7	1.1	0.4	0.8	0.9	1.5	1.4	1.0	0.7	0.3	3.8	0.7	0.6	0.4	2.2	1.5	0.0	1.6	0.0	1.0	0.0	0.0	0.3	0.9	1.0
	2-6: Others		1.2	1.1	0.9	0.4	0.6	0.9	1.3	1.1	1.2	1.2	0.6	0.4	0.4	0.7	0.6	0.5	1.0	0.1	0.7	0.3	0.8	3.0	0.0	1.7	0.6	5.8
3: Quantum sensing	3-1: Gravitation rotation acceleration		1.1	0.8	0.8	0.4	1.1	0.9	0.8	3.0	0.5	1.1	1.0	1.1	3.9	0.2	0.6	0.8	0.0	2.2	0.5	3.1	0.0	0.0	0.0	0.1	1.7	2.9
	3-2: Time		0.7	3.5	0.6	0.1	0.3	0.3	0.7	1.3	0.2	0.2	1.8	1.3	0.5	0.0	0.3	0.1	0.1	0.4	0.2	0.5	0.0	0.0	0.0	0.0	0.1	3.5
	3-3: Magnetic fields		1.4	0.4	0.4	0.0	3.9	1.0	0.3	0.5	0.0	1.0	2.9	0.9	2.4	0.0	0.0	0.0	0.7	0.0	0.0	1.6	0.0	0.0	0.0	3.3	1.4	1.8
	3-4: Chemical detection		1.0	0.1	3.1	1.6	0.5	0.4	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	4.6	0.0	0.5	0.0	0.0	4.8	0.0	0.0	3.3	0.6
	3-5: Imaging		1.3	0.2	1.0	0.6	1.5	1.2	0.8	1.9	0.0	0.9	0.0	1.1	0.0	0.0	2.3	1.8	1.8	0.0	0.8	6.1	0.0	1.7	0.0	0.0	1.0	0.8

Lowest 1.0 Highest

Notes: The graph illustrates specialisation in the subfields of quantum technologies relative to the overall quantum domain by applicant location. An RTA above one, coloured in green, indicates that the country is more specialised in the given quantum field. RTA is based on IPFs. Fractional counting is applied when patent families involve applicants from multiple countries. To clarify the significance of each subfield, the percentage distribution across these areas is shown on the right. For fields with low filing activity the RTA values should be interpreted as indicative, due to the small sample size.

Source: EPO, October 2025.

3.3.4 Internationalisation of quantum patenting

Understanding whether applicants seek patent protection internationally is important because it provides insight into how strategically valuable they consider a given invention to be. While national filings may reflect exploratory or domestically focused research, international patent families usually indicate technologies that applicants see as commercially relevant and worth protecting in multiple markets. Assessing differences in the internationalisation of patent families is particularly informative given the large number of non-international families in the quantum domain.

The upper part of Figure 3.3.6 compares the internationalisation rate (the share of patent families that qualify as IPFs) in quantum technologies with that of all technological domains. IPF rates in quantum are high across all locations. Even in China, which has the lowest internationalisation rate across all domains (2.0%), the internationalisation of quantum technologies is notably higher (5.8% of Chinese quantum patent families are IPFs). Overall, the weighted average internationalisation rate in quantum technologies (31.2%) far exceeds that of all patent domains (12.0%). The high internationalisation rate highlights the strategic importance that applicants across locations attribute to the quantum domain and the strong international competition between inventors.

The lower part of Figure 3.3.6 shows the relative technology internationalisation (RTI), which is a country's propensity to file patents internationally in each quantum subfield relative to the country's overall internationalisation propensity in quantum patenting. RTI indicates that Chinese applicants file large numbers of national patents in several subfields of quantum communication and quantum sensing, including QKD and information networks (both with an RTI < 1.0). By contrast, subfields of quantum computing appear to be of greater strategic importance for international protection (all with RTI values above one). A similar pattern is evident among Japanese applicants and, to a lesser extent, those from the United States. The comparison of the IPF rate in the quantum domain with patents from all technology domains (see the last two rows in Figure 3.3.6) shows the strategic importance of quantum technologies for all of these countries.

Notes for Figure 3.3.6: The upper part of the figure compares IPF rates (the percentage of patent families that are IPFs) in quantum technology areas versus in all domains, ordered by each location's share of IPFs. The lower part of the figure reports the relative technology internationalisation (RTI), which compares the share of IPFs in a given quantum subfield and applicant location with the overall IPF share for all quantum technologies filed by the companies registered in that location. It serves as an indicator on the willingness of applicants from a certain location to prioritise for international protection in certain quantum technologies. A RTI above one (coloured in green) indicates that, within the same location, inventions in a given quantum subfield are more frequently protected internationally than those in other quantum subfields.

Figure 3.3.6

RTI across quantum subfields: 2005-2024

Overall IPF rate of quantum domain per applicant country in %

US	JP	CN	KR	DE	GB	CA	FR	FI	NL	CH	IL	AU	SE	AT	SG	TW	RU	ES	IT	KY	IN	MY	DK	RoW
51.8	57.8	5.8	48.6	75.9	73.6	62.5	92.5	97.5	94.9	91.4	65.3	77.0	84.0	91.7	84.8	59.1	37.6	90.6	84.3	52.8	48.3	83.8	100.0	62.4

Overall IPF rate of all patent domains per applicant country in %

US	JP	CN	KR	DE	GB	CA	FR	FI	NL	CH	IL	AU	SE	AT	SG	TW	RU	ES	IT	KY	IN	MY	DK	RoW
42.7	28.7	2.0	20.6	50.9	41.3	49.9	62.7	66.1	71.9	73.2	53.5	36.2	77.8	67.8	56.2	18.5	5.5	37.2	45.4	24.8	57.8	36.0	72.6	24.2

Lowest Highest

Level 1	Level 2	Level 3	US	JP	CN	KR	DE	GB	CA	FR	FI	NL	CH	IL	AU	SE	AT	SG	TW	RU	ES	IT	KY	IN	MY	DK	RoW
1: Quantum communication	1-1: Optical realisations		0.9	0.9	0.7	0.9	0.7	1.0	1.2	1.0	1.0	1.0	0.9	1.1	1.1	1.1	1.0	1.1	0.6	1.1	1.1	1.0	0.9	0.5	1.2	1.0	1.1
	1-2: Quantum memories		1.2	1.0		1.6	1.3	1.0	1.3	0.7	1.0	0.0	1.1	1.5	1.3	0.0	1.1	0.0	1.7	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.6
	1-3: Quantum key distribution		1.0	0.9	0.9	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.9	1.0	1.0	1.0	1.1	1.0	1.0	0.9	1.1	1.0	1.0	1.0
	1-4: Information networks		0.7	0.9	0.8	1.4	1.1	0.9	1.0	1.0	1.0	0.9	1.0	0.4	1.1	1.2	0.6	1.0	1.1	1.2	1.1	1.2	1.2	1.5	1.2	1.0	0.9
2: Quantum computing	2-1: Models	2-1-1: Simulation	1.0	1.3	1.0	0.9	1.0	1.1	1.1	1.0	1.0	1.1	1.1	0.8	1.0	1.2	1.1	0.7	1.4	2.2	0.9	0.4	1.1	1.2	0.0	1.0	1.2
		2-1-2: Non simulation models	1.2	1.6	2.5	0.7	1.0	0.9	1.1	1.1	1.0	0.9	1.1	1.3	1.2	1.2	1.1	1.1	1.1	2.7	1.0	1.2	1.7	1.1	0.0	1.0	0.8
	2-2: Physical realisations	2-2-1: Superconducting	1.1	1.6	4.7	0.9	1.0	1.0	0.9	1.1	1.0	1.0	1.1	1.2	1.3	1.2	1.0	1.0	1.7	2.7	0.9	1.2	1.9	0.2	0.0	1.0	1.3
		2-2-2: Trapped ion or atom	1.1	1.3	2.8	1.2	1.0	1.0	1.2	1.1	0.9	1.1	1.1	1.1	1.2	1.2	1.0	1.2	1.0	2.7	1.1	1.2	1.9	1.9	1.2	1.0	1.0
		2-2-3: Spin-based	1.1	1.4	5.1	0.5	0.8	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.2	0.7	1.1	1.2	1.4	2.7	1.1	1.2	1.9	0.2	1.2	1.0	1.0
		2-2-4: Quantum optics	1.1	1.4	5.7	1.2	0.9	1.1	1.1	1.1	0.9	1.1	1.1	1.2	1.3	1.2	0.8	1.1	1.7	0.0	1.1	1.2	1.9	0.5	0.0	1.0	0.4
		2-2-5: Others	1.1	1.7	1.5	0.6	0.8	1.0	1.1	1.0	1.0	0.9	1.1	1.1	1.3	1.2	1.1	1.0	1.3	0.6	0.8	0.9	1.7	0.1	0.0	1.0	1.0
	2-3: Algorithms		0.9	1.7	1.9	0.7	1.0	1.1	0.8	1.0	0.9	1.1	1.1	0.9	1.3	1.2	1.1	1.2	1.5	1.3	1.1	1.2	1.3	0.8	0.0	1.0	0.8
	2-4: Error corrections		1.0	1.6	2.1	1.0	1.0	0.8	0.8	1.1	1.0	1.1	0.9	1.0	0.9	1.2	0.9	0.7	1.2	0.0	0.8	1.0	1.9	0.6	0.0	1.0	1.1
	2-5: Programming		1.2	1.0	0.8	0.8	0.8	1.2	1.1	0.9	1.0	0.9	1.1	1.2	0.7	1.0	1.1	0.9	0.8	0.7	0.9	0.5	0.8	1.4	0.0	1.0	0.7
	2-6: Others		1.1	1.4	0.8	0.6	0.8	1.1	1.4	0.9	1.0	1.1	1.1	1.5	1.3	1.2	1.1	1.2	0.0	0.9	1.1	1.2	0.0	0.0	0.0	1.0	0.9
3: Quantum sensing	3-1: Gravitation rotation acceleration		1.1	0.9	0.8	0.6	0.8	0.8	1.2	1.0	1.0	1.1	0.9	1.0	1.3	0.0	1.1	1.2	1.7	0.2	1.1	1.2	0.0	0.0	0.0	0.0	1.6
	3-2: Time		1.4	1.7	0.5	0.6	1.3	1.4	0.7	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.7	0.0	1.1	0.0	0.0	2.1	0.0	0.0	1.6
	3-3: Magnetic fields		1.3	1.7	2.6	0.7	1.1	1.4	0.8	1.1	0.0	0.7	0.0	1.5	0.0	0.0	1.1	1.2	0.9	0.0	1.1	1.2	1.9	2.1	0.0	0.0	1.2
	3-4: Chemical detection		0.6	1.6	3.0	0.7	1.0	1.0	0.7	1.1	1.0	1.1	1.1	1.0	1.3	1.2	0.9	1.0	1.7	0.0	1.1	0.0	0.7	0.0	0.0	1.0	0.8
	3-5: Imaging		1.3	1.7	0.9	0.0	0.9	1.2	1.6	1.1	0.0	1.1	1.1	1.3	1.3	0.0	0.0	0.0	1.7	0.0	0.0	1.2	0.0	0.0	0.0	1.0	1.6

Lowest Highest

Source: EPO, October 2025

3.3.5 International collaboration

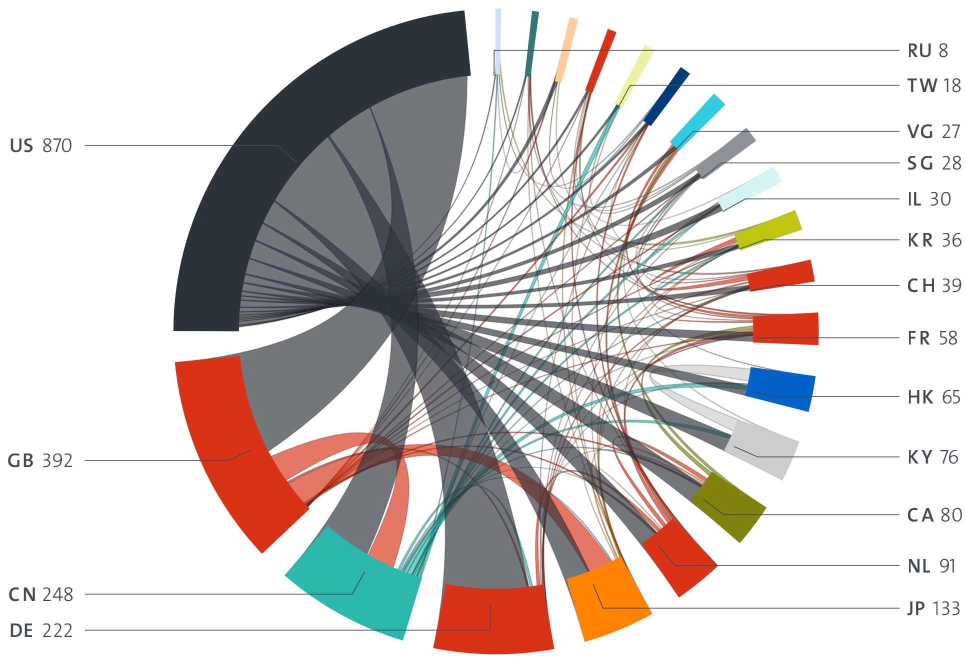
Figure 3.3.7 presents international collaboration patterns in quantum technology patenting. The United States is the central hub of international co-applicant activity, with its strongest links being with the United Kingdom (237), Germany (195), and China (118). In these bilateral pairs, the US represents 60% of United Kingdom's, 88% of Germany's, and 48% of China's international collaborations. Overall, the US is the primary partner for most countries, accounting on average for around 40% of their international co-applications. European countries (EPO member states) are the US's most frequent partners, representing approximately 60% of all US collaborations. By contrast, collaboration within Europe is comparatively limited, with European applicants engaging more often with partners in the US, China, and Japan.

It should be noted that a substantial share of these links reflects multinational firms coordinating patent filings across research entities in multiple jurisdictions – for example, IBM alone accounts for major intra-company ties such as US–GB (200), US–DE (171), US–CN (100), GB–CN (67), and US–IL (10). Tables A1.3 and A1.4 of Annex A.1 provide additional insights, into the frequency of international collaborations between applicants that are not part of the same group.

Figure 3.3.8 illustrates the filing trends of top multinational enterprises (MNEs) through their subsidiaries located in different countries. IBM shows the most geographically diversified filing strategy, with activity in eight countries, mostly in Europe, and a recent shift in filings from the United Kingdom to Germany. Filings through subsidiaries are also significant for Toshiba in Japan and the United Kingdom (45 filings), and for Alibaba in China, the United States, Hong Kong (China), and the Cayman Islands (85 filings). Similarly, Nokia shows filings in Finland and the United States (11 filings).

Figure 3.3.7

International collaboration of patent applicants: 2005-2024



Notes: Each economy's outer arc represents the total number of IPFs involving applicants from that economy and at least one other (e.g. the US has 870 IPFs involving international collaborations). The connecting chords indicate the frequency of collaboration between specific country pairs (e.g. the strongest collaboration link is US-GB with 237 collaborations).

Source: EPO, October 2025.

Figure 3.3.8

Filing trend of top quantum MNEs through subsidiaries located in different countries

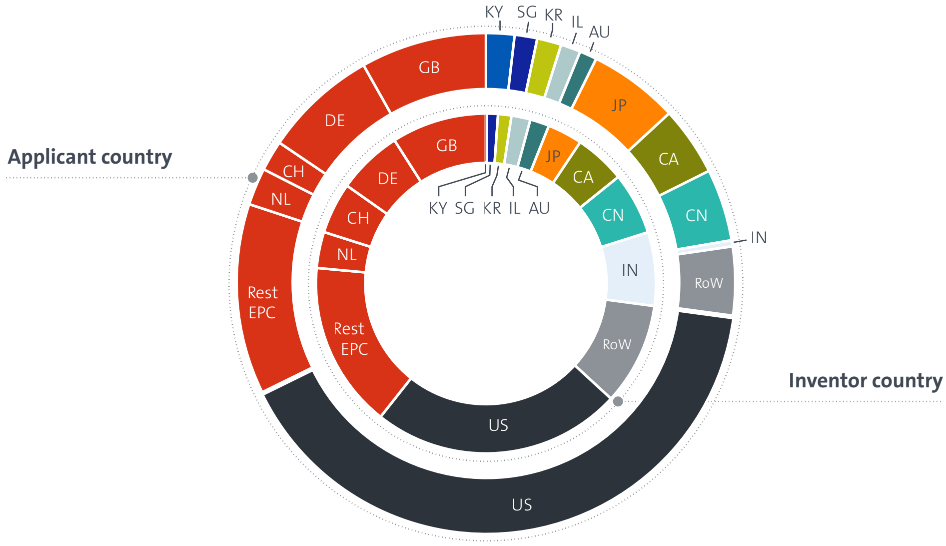
Notes: The figure displays the number of IPFs filed by the top five applicants in quantum technologies, broken down by publication year and by the country of the subsidiary responsible for the filing.

Source: EPO, October 2025.

Figure 3.3.8 compares the distribution of applicant and inventor countries in cross-country patent filings. The United States accounts for a substantially larger share of IPFs as the applicant country than as the inventor country, indicating a net appropriation of inventions originating from foreign inventors. In contrast, several European and Asian countries, such as Germany, the United Kingdom, China, and Japan, appear more frequently as inventor countries than as applicant countries, reflecting the international nature of R&D collaboration and ownership structures in quantum technologies.

Figure 3.3.9

Comparison of applicant and inventor countries: 2005-2024



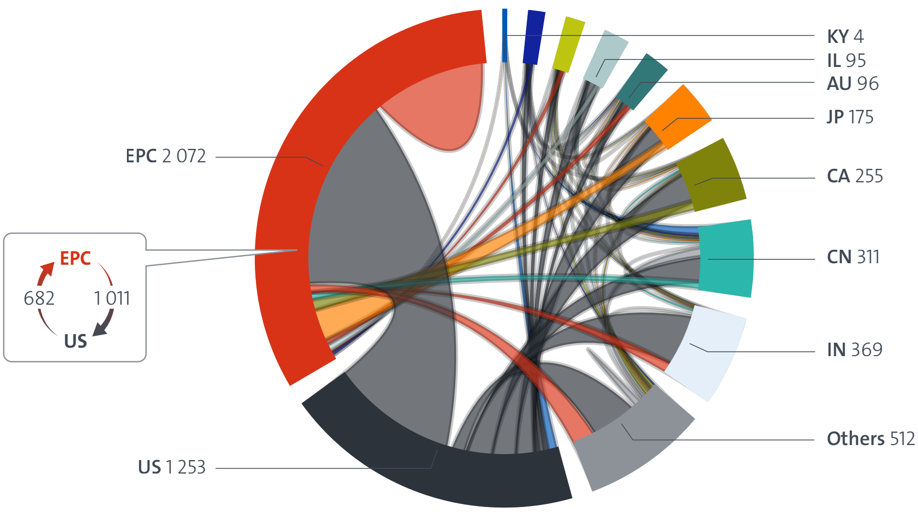
Notes: The donut chart shows the number of IPFs in cross-country patent filings by country of the applicant (outer arch) and the inventor (inner arch). Countries with fewer than 100 patent families (either as inventor or applicant country) are grouped under Rest EPC or rest of world (RoW).

Source: EPO, October 2025.

Figure 3.3.9 depicts cross-country collaboration patterns between inventors and applicants. The United States stands out as the leading applicant country with inventors from abroad. In most cases, more foreign inventors contribute to patent applications on behalf of US companies than the other way around. The US–India collaboration is the most asymmetric example: 275 patent families involve Indian inventors working for US applicants, while only eight patent families show the reverse situation. Such imbalances are visible where the link has different widths comparing start and end points. The links are coloured according to the dominant applicant country (grey for the US).

Figure 3.3.10

Cross-country collaboration between inventors and applicants: 2005-2024



Notes: The outer arc represents the number of IPFs with inventors from each country and applicants from abroad. The connecting chords illustrate cross-country collaborations, with the chord width at each country's base indicating the number of inventors from that country contributing to filings where the applicant is based in another country. For example, the chord between EPC Member States and the US has a larger base on the former reflecting that 1 011 inventors located in EPC countries are involved in patents with US-based applicants, compared to only 682 in the opposite direction. Connecting chords take the colour of the country that attracts the largest number of inventors in the relationship (e.g. grey for the EPC-US). The EPC "self link" originates from inventors living in an EPC country but working for a company based in a different EPC country.

Source: EPO, October 2025.

3.4 Main actors in quantum innovation

Quantum technologies remain in the early stages of development. However, they have progressed to a point where private-sector involvement is crucial for advancing beyond basic research into industrialisation and early commercialisation. In this situation the interaction between PROs, startups and large companies plays an increasingly important role.

This section assesses the importance of different actors in quantum innovation and their evolving roles. First it examines the evolution of broad actor types in quantum innovation. It then identifies the top applicants in each main quantum area. Finally, it provides an overview of leading PROs. This mapping can help identify strengths and gaps in the ecosystem and guide progress in quantum innovation.

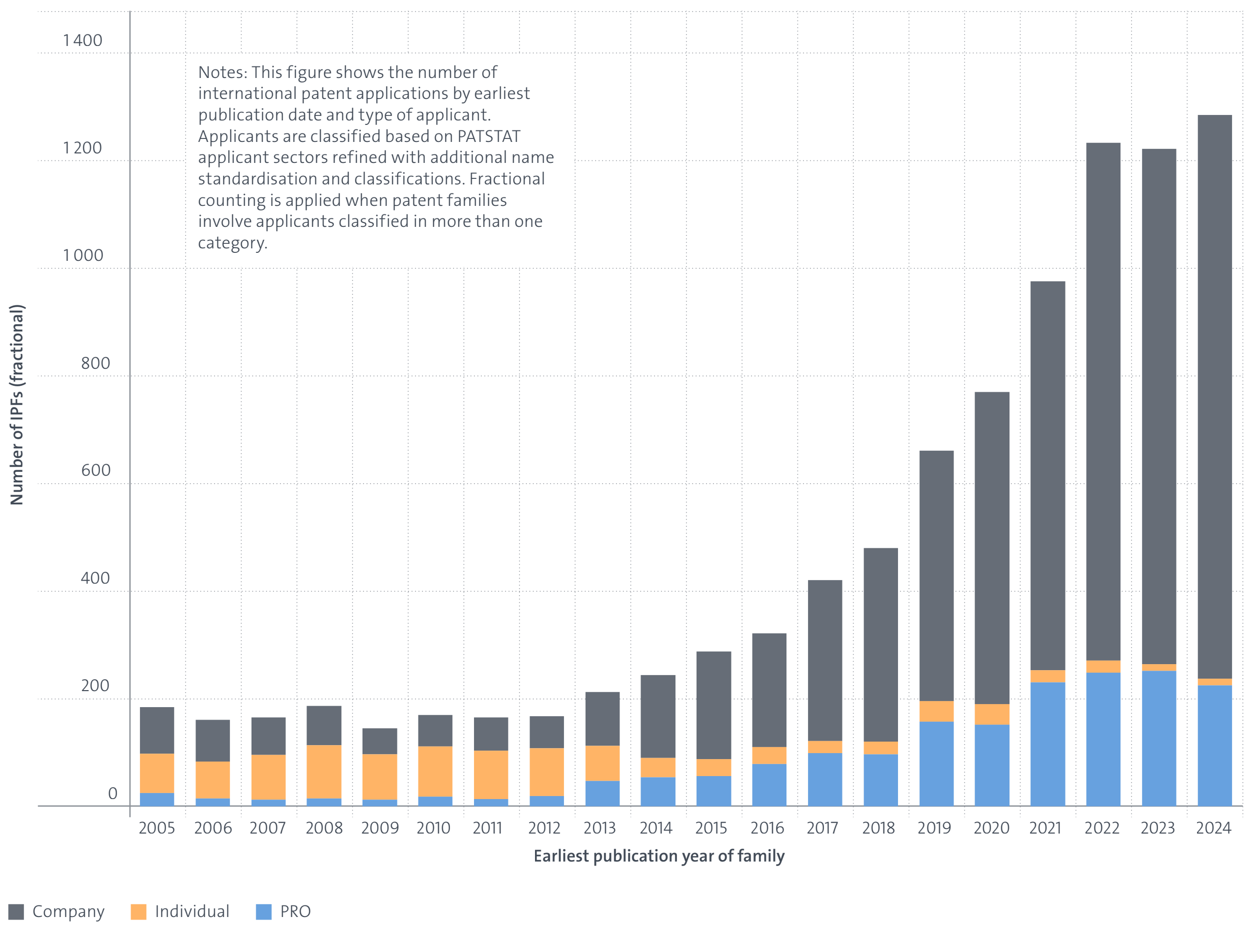
3.4.1 Changes in actor profiles in quantum patenting

Figure 3.4.1 shows changes in IPFs in quantum technologies by applicant type. Companies account for the vast majority of IPFs, and their dominance has become even more pronounced since 2015, reflecting the strong role played by industry in advancing quantum technologies towards commercialisation. PROs contribute a smaller but consistent share, underlining the importance of publicly funded research in laying the foundations of the field. Filings by individuals remain lower, with a declining trend throughout the period.

Figure 3.4.2 shows the change in the share of IPFs by type of applicant, confirming the growing importance of companies relative to universities and individuals. In the early years of the sample, universities and individuals together accounted for around 40-45% of international

Figure 3.4.1

Number of IPFs by year and applicant sector



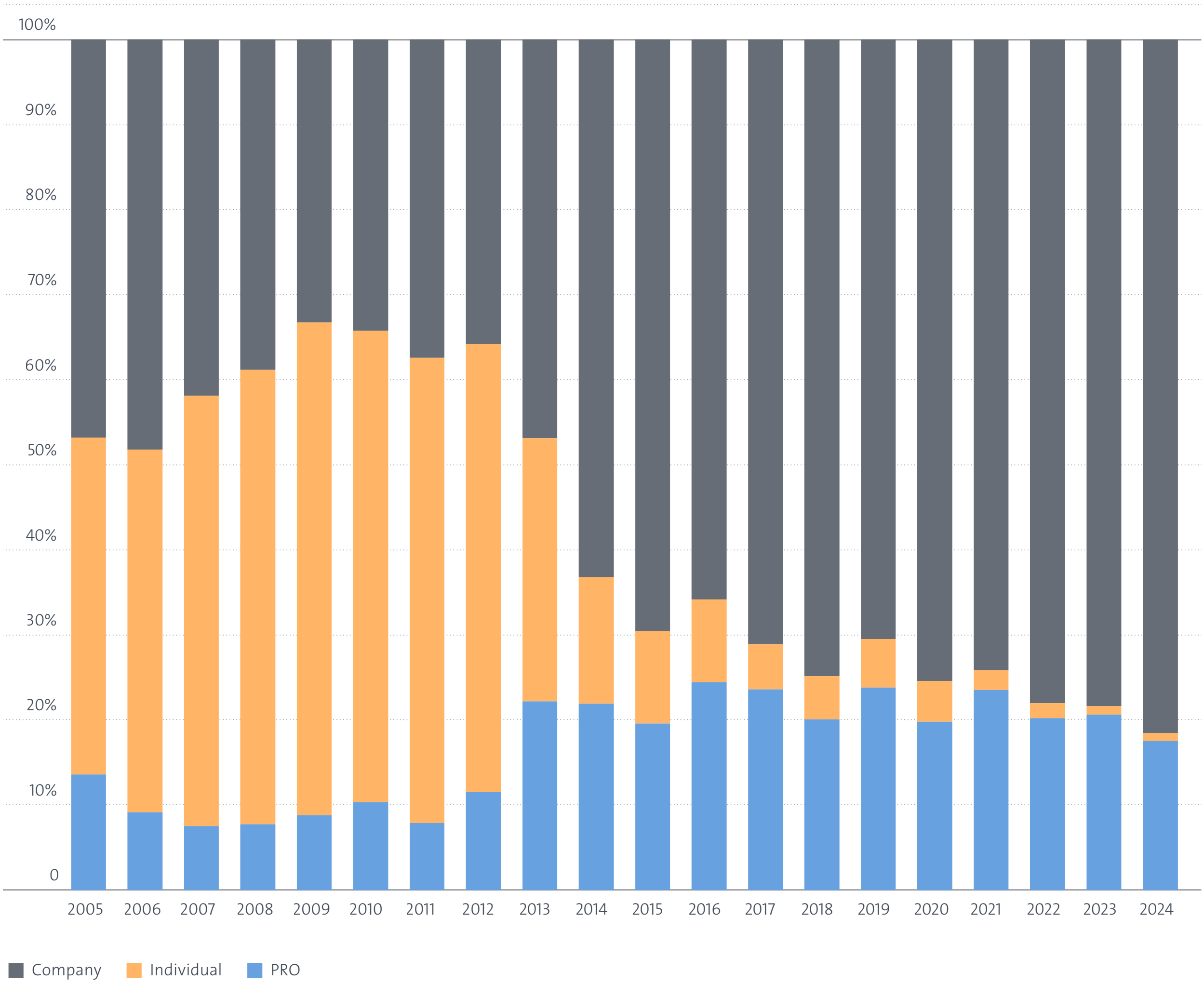
Source: EPO, October 2025.

filings, but their combined share has since fallen notably, mainly due to a sharp decline in the share of individuals. This could reflect both a shift by inventors into startups and a gradual transfer of activity from universities to corporate actors. It may also be partly explained by legal changes, such as the 2013 America Invents Act (AIA), which reduced the need for patents to be filed under the inventor's name and facilitated direct company filings, a shift consistent with filing patterns observed in other fields like digital agriculture (EPO, 2025). Companies now represent about 80% of international patenting in quantum technologies, underscoring the transition from research-driven activity to commercialisation and industrial scaling.

Figure 3.4.3 provides the distribution of patenting across applicant sectors for each quantum subfield. Startup filing activity is particularly concentrated in subfields of quantum algorithms computing like trapped ion or atom, optical realisations and modelling with particular low intensity in time measurement and magnetic fields, which are taken over by larger companies. PROs file mainly in the fields of quantum memories, physical realisations (spin-based and quantum optics) and chemical detection and imaging, which are typically more fundamental, delicate or unstable.

Figure 3.4.2

Share of IPFs by year and applicant sectors



Notes: This figure shows the percentage of IPFs by earliest publication date and type of applicant.

Source: EPO, October 2025.

Figure 3.4.3

Percentage of IPFs by quantum subfield and applicant sector: 2005-2024

Level 1	Level 2	Level 3	Startups %	Other companies %	PRO %
1: Quantum communication	1-1: Optical realisations		33	36	24
	1-2: Quantum memories		33	25	28
	1-3: Quantum key distribution		36	41	13
	1-4: Information networks		32	49	12
2: Quantum computing	2-1: Models	2-1-1: Simulation	41	41	14
		2-1-2: Non simulation models	43	41	13
	2-2: Physical realisations	2-2-1: Superconducting	34	48	14
		2-2-2: Trapped ion or atom	48	30	19
		2-2-3: Spin-based	37	34	25
		2-2-4: Quantum optics	47	21	27
		2-2-5: Others	38	42	16
	2-3: Algorithms		40	47	10
	2-4: Error corrections		39	43	16
	2-5: Programming		40	52	7
	2-6: Others		26	51	17
3: Quantum sensing	3-1: Gravitation rotation acceleration		33	36	20
	3-2: Time		16	62	12
	3-3: Magnetic fields		18	56	22
	3-4: Chemical detection		33	18	29
	3-5: Imaging		31	26	31

Notes: This figure shows the percentage of IPFs in each quantum subfield by applicant sector, using fractional counts.

Lowest Average Highest

Source: EPO, October 2025.

3.4.2 Top applicants by quantum area

While this subsection focuses on top quantum applicants, it is important to note that concentration in quantum patenting is fairly low in all three areas, with a Herfindahl-Hirschmann index (HHI, Hirschman 1945; Herfindahl 1950) of 25 for quantum communication, 80 for quantum computing and 77 for quantum sensing.[17] These values well below 100 indicate a highly competitive environment where inventive activity is spread over many applicants.

Figure 3.4.4 shows the trend in IPFs across quantum areas for the top 20 quantum applicants. These include large technology corporations such as IBM, Intel, Microsoft, Google and Huawei, which have built substantial portfolios in quantum computing and communication, with an acceleration of filing activity in 2015. Seiko and Honeywell are the only companies in the list with portfolios predominantly in the sensing area.

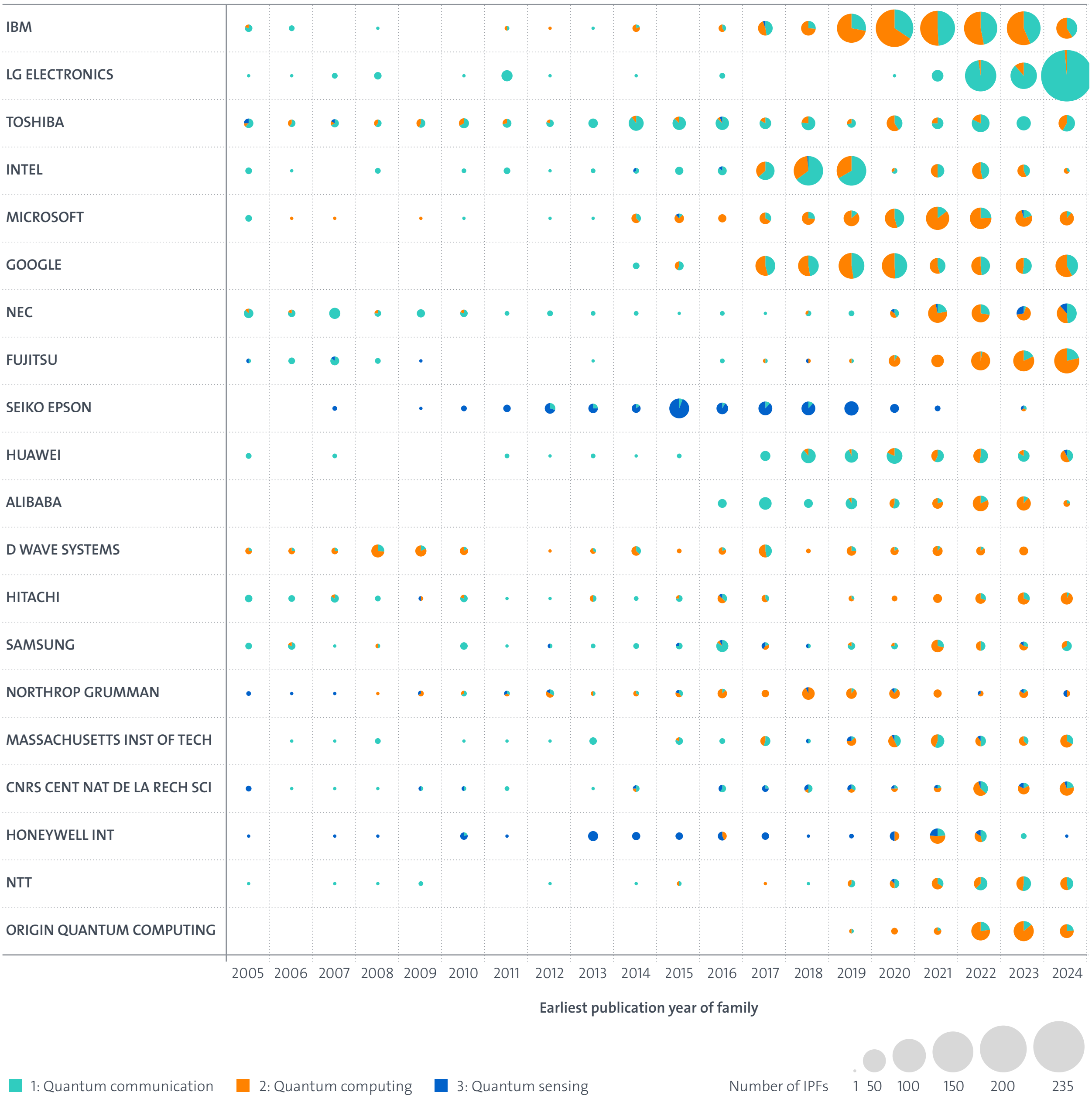
17 $HHI_j = \sum_{i=1}^{N} s_{ij}^2$ where s_{ij} is the market share of economy *i* for a given product *j*.

Figure 3.4.5 shows the top 20 applicants for each quantum area in more detail with non-fractional counting. In quantum communication (Panel A), the applicant landscape is diverse, with LG Electronics standing out as the clear leader with more than 400 IPFs. Other major contributors include IBM, Toshiba, Intel and Google, alongside Asian players such as Huawei, NEC and Samsung. The presence of big tech firms (IBM, Intel, Google, Microsoft), telecom companies (LG, Huawei, NTT) and research institutions (MIT, ETRI) underscores the combined role of industry and academia in this field.

In quantum computing (Panel B), the landscape is dominated by large US technology firms, led by IBM, Microsoft and Google, which together account for a substantial share of IPFs. Hardware-focused companies such as Fujitsu, Intel, D-Wave and NEC also play central roles, while a second tier of applicants includes specialised startups (IonQ, Rigetti, IQM, Origin Quantum, Quantinuum) and Chinese technology firms (Tencent, Baidu, Alibaba), signalling the entry of both deep tech

Figure 3.4.4

Number of IPFs by year and quantum area for top 20 applicants



Source: EPO, October 2025

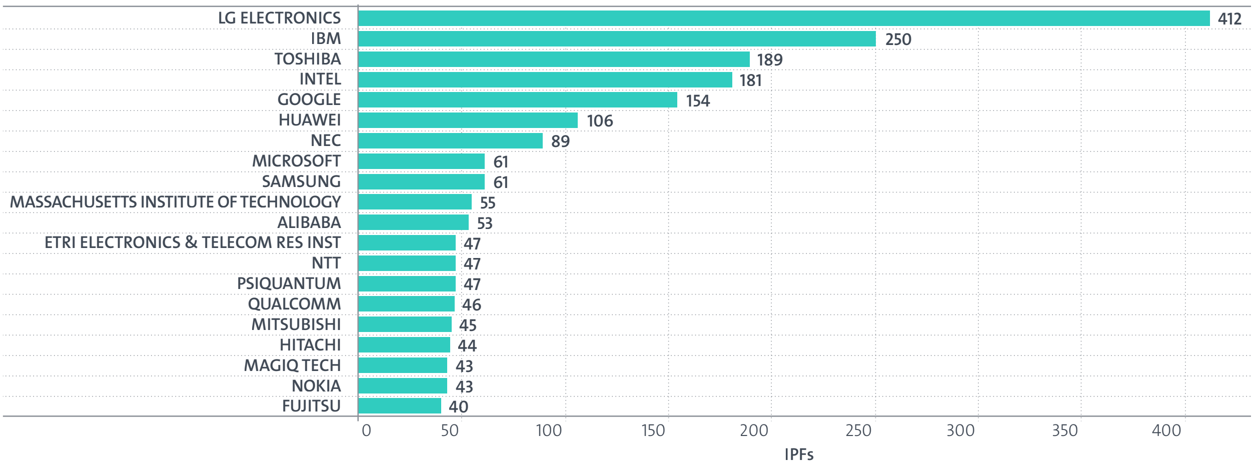
and platform companies. PROs such as CEA and MIT also appear among the leaders, highlighting the continuing contribution of academia.

In quantum sensing (Panel C), the applicant base is more heterogeneous. Industrial players dominate, led by Seiko Epson, Honeywell, Lockheed Martin, Bosch and Northrop Grumman, reflecting the close connection between sensing and defence, aerospace and manufacturing applications. Universities and PROs, including Harvard, CNRS and RIKEN, also feature prominently, while the role of specialised startups is less visible, showing that sensing remains more closely anchored in established industries and research institutions.

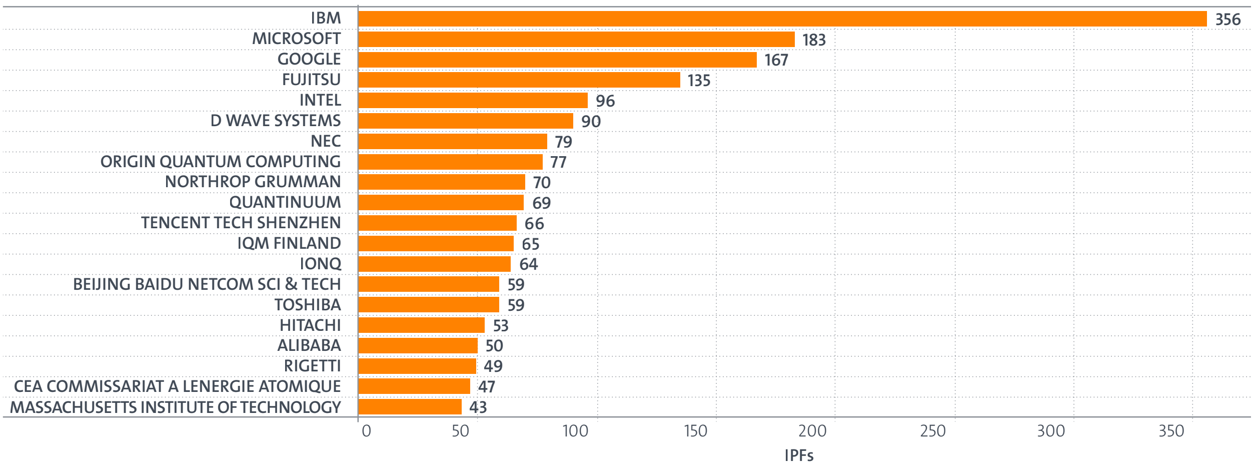
Figure 3.4.5

Twenty top applicants in each quantum area: 2005-2024

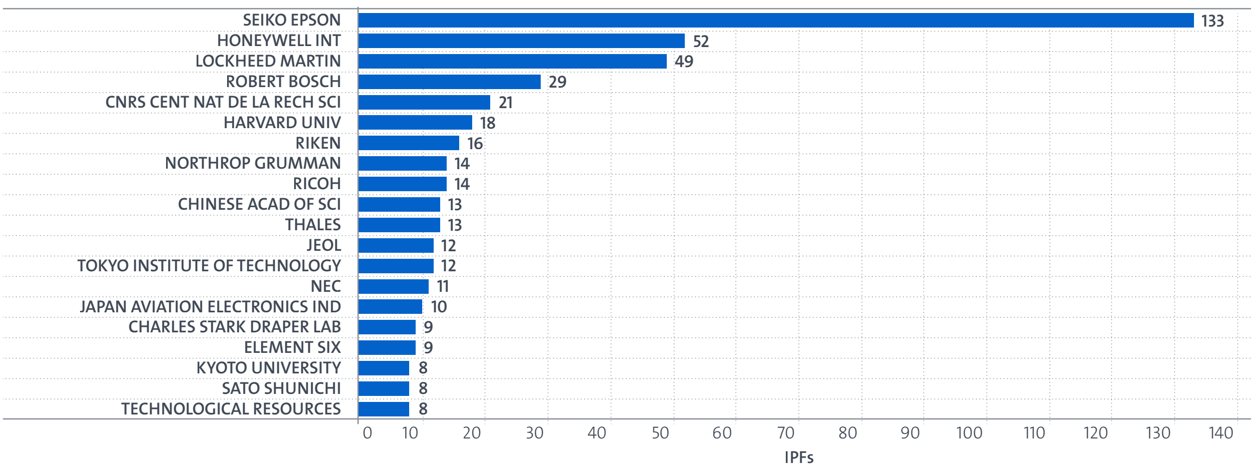
Panel A) Quantum communication (29% of all IPFs)



Panel B) Quantum computing (42% of all IPFs)



Panel C) Quantum sensing (33% of all IPFs)



Notes: The charts above show the top applicants in the quantum areas using non-fractional IPF counts.

Source: EPO, October 2025.

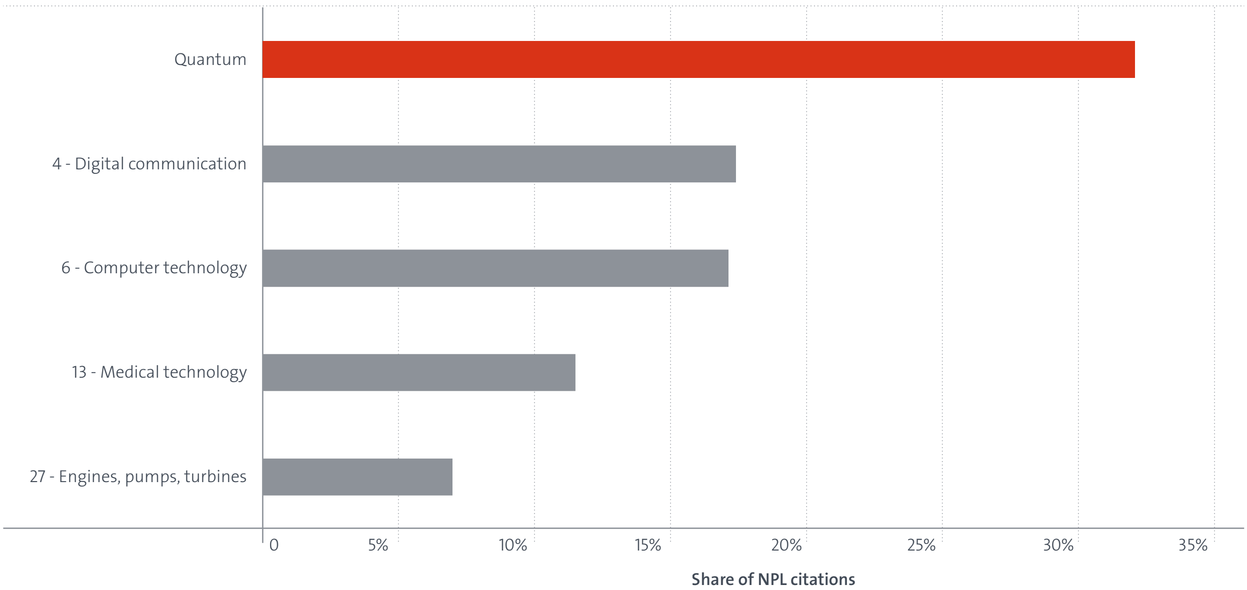
3.4.3 Quantum and proximity to science: top universities in quantum innovation

Figure 3.4.6 shows that the share of non-patent literature (NPL) citations in the quantum domain is significantly larger compared with other WIPO technology fields (Schmoch 2008, WIPO 2025). This pattern suggests a strong proximity between quantum IPFs and science, since NPL citations reference mostly scientific journals, conference papers and other outputs stemming from basic research (Callaert et al. 2006, Cassiman et al. 2008, Branstetter, 2005). Quantum patents exhibit an NPL citation rate of around 33%, substantially higher than in most other technological areas. This is roughly three times the level observed in medical technology, and many times higher than in traditional engineering fields such as engines and pumps. Even relative to closely related high-tech domains such as computer technology and digital communication, the share of NPL citations in quantum patents is about twice as high.

Figure 3.4.7 highlights the leading universities worldwide in terms of quantum IPFs that received at least one forward citation between 2004 and 2024. US institutions dominate the ranking, with 14 of the top 30 universities and a combined total of around 18 500 forward citations. The Massachusetts Institute of Technology (MIT) leads by a wide margin, followed by Harvard, the University of Michigan and the University of California, all of which show not only large numbers of cited IPFs but also a significant share of highly cited patents (with more than ten forward citations). Asian universities, including several Chinese institutions, KAIST and the University of Tokyo feature prominently, while Europe is represented by Delft University of Technology (NL) and the University of Oxford (GB).

Figure 3.4.6

NPL backward citation rate in quantum vs other technology fields: 2005-2024

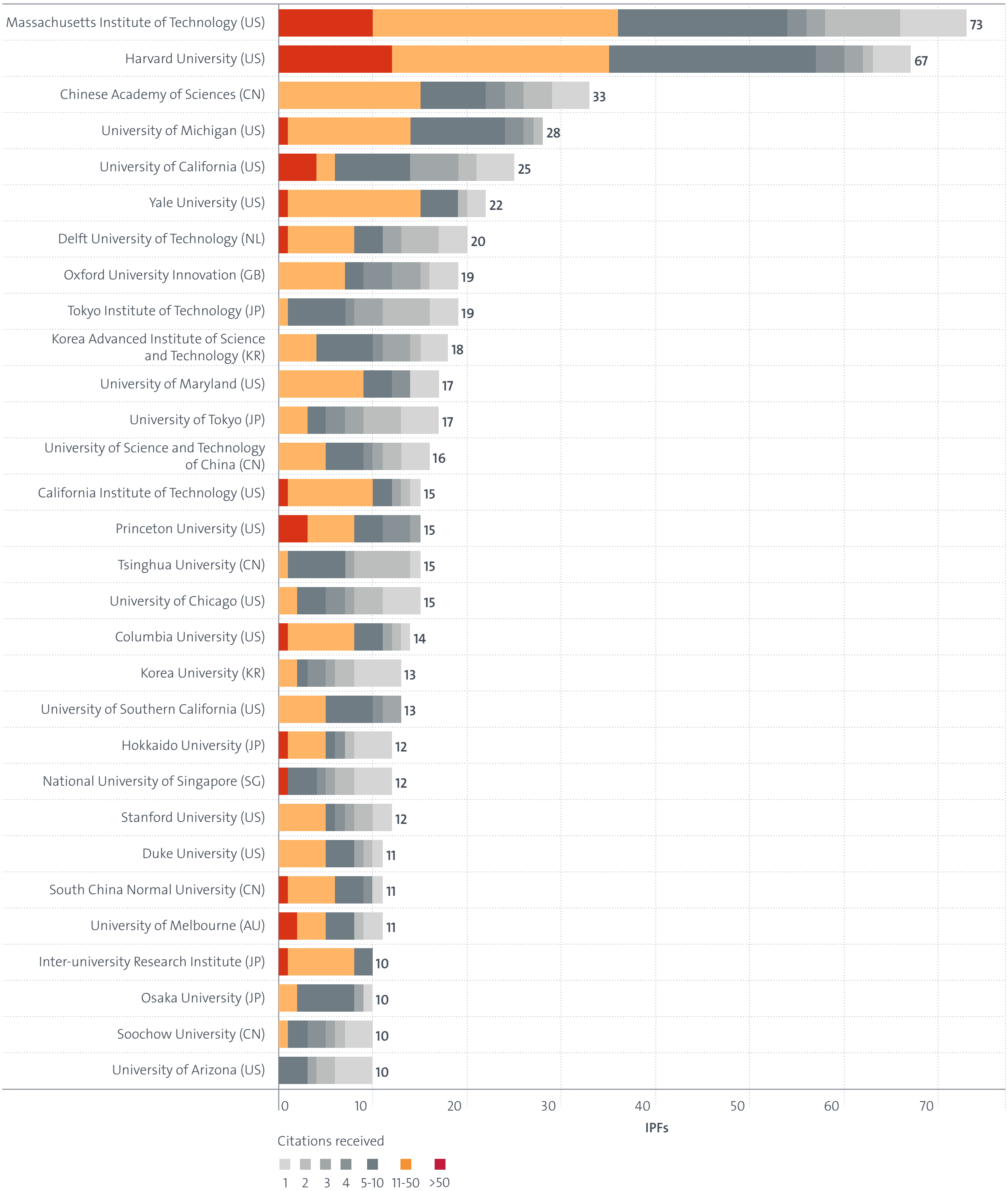


Notes: This figure shows the percentage of citations in the patent application to non-patent literature (NPL) out of the total number of backward citations by both quantum patents (in red) and a selection of other major technological areas (in grey) according to the WIPO classification.

Source: EPO, October 2025.

Figure 3.4.7

Top 30 universities by number of cited IPFs: 2005-2024

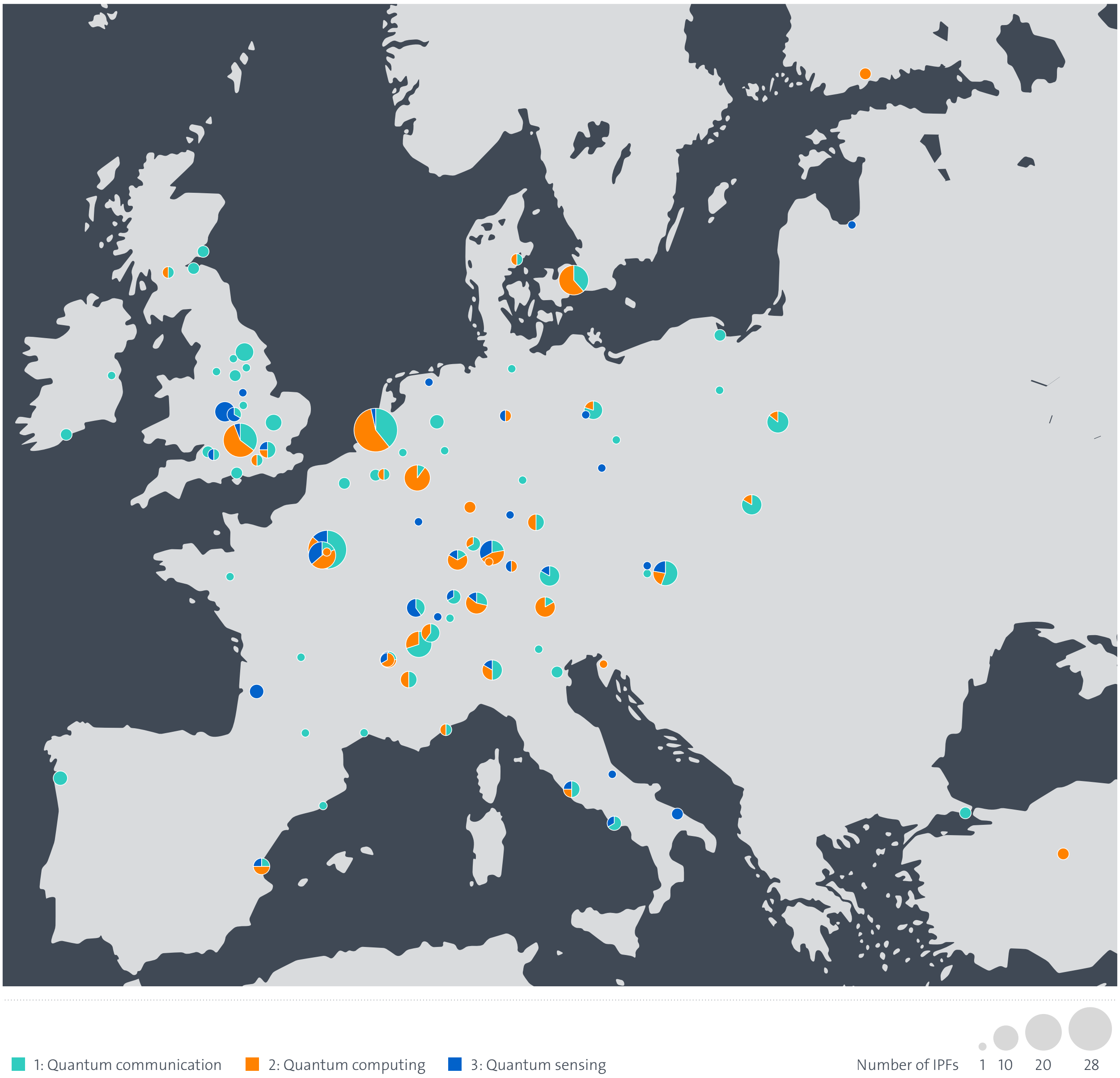


Notes: This figure shows the number of quantum IPFs with at least one forward citation (bar length) and the number of forward citations they receive (bar colour) for the top 30 universities, ranked by their number of cited IPFs between 2004-2024.

Source: EPO, October 2025

Figure 3.4.8

Quantum patents from European universities from the Deep Tech Finder: 2005-2024



Notes: This figure shows the geographical distribution of quantum patents held by European universities. Circle size reflects the size of the respective patent portfolios, while colours indicate the quantum area.

Source: EPO, October 2025.

Figure 3.4.8 shows the geographical distribution of quantum patents held by European universities that fulfil the conditions of the Deep Tech Finder. Quantum innovation is concentrated in a few hubs, with larger portfolios clustered in countries such as Germany, France, the Netherlands, Switzerland and the United Kingdom, while smaller but notable contributions are spread across Scandinavia and Southern and Eastern Europe. Colour coding reveals that quantum computing dominates the largest university portfolios, followed by communication and sensing, though some institutions show a more balanced spread across all three quantum areas. Many smaller portfolios are focused almost entirely on quantum communication.

Box 3. Discover quantum startups with the EPO's Deep Tech Finder

The EPO Observatory on Patents and Technology (epo.org/observatory) offers the Deep Tech Finder, a digital platform designed to make it easier to find startups in EPO member states that have filed European patent applications, as well as related university patents and the investors backing these startups.

This tool is designed for startups, investors, researchers and other key stakeholders in the innovation ecosystem. It allows users to identify startups based on the technologies covered by their patents.

The quantum patent filters have been added to the Deep Tech Finder, making it possible to discover startups with quantum patents or applications and their investors.

By focusing on specific technology fields, the tool is invaluable for discovering potential partners, investors or the next groundbreaking invention and startup to invest in.

The Deep Tech Finder can be freely accessed online: dtf.epo.org.

3.5 Diffusion of quantum innovation: analysis of citation flows

This subsection studies the diffusion of quantum inventions across technological fields and geographical locations. Quantum technologies act as upstream enablers with the potential to transform a wide range of industries. Beyond their immediate applications, advances in quantum can spill over into fields such as artificial intelligence, cybersecurity, life sciences, automotive and finance. Understanding how knowledge flows from quantum patenting in other technology domains and across countries provides critical insight into which areas are absorbing quantum advances, how innovation ecosystems are interconnected, and where opportunities for industrial leadership and economic growth may arise.

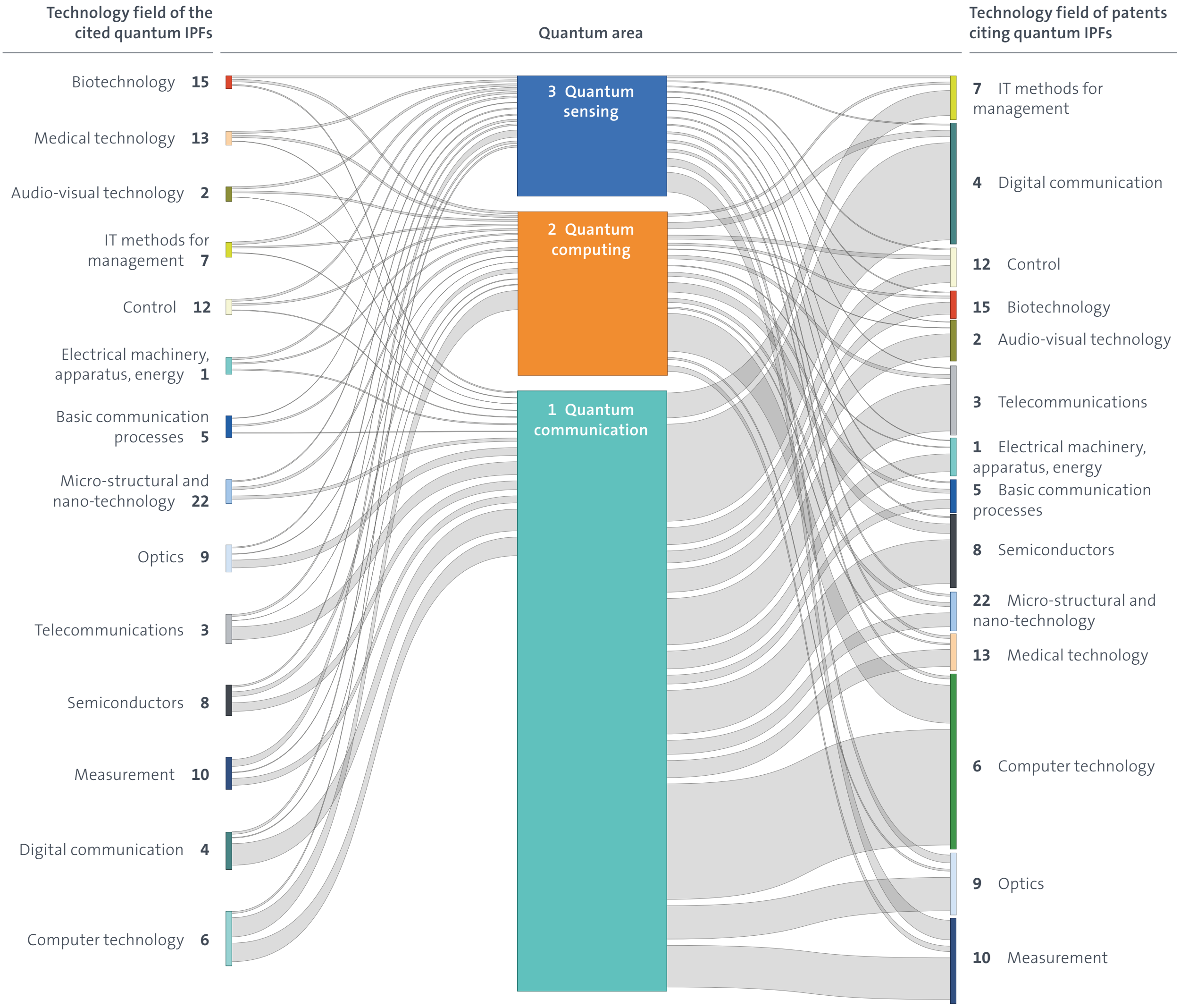
3.5.1 Diffusion of quantum innovation across technology fields

Figure 3.5.1 uses forward citation analysis to trace how inventions in quantum technologies have an impact on other technical domains. The left-hand side of the diagram shows that quantum patent families are concentrated in fields such as computer technology, digital communication, measurement, semiconductors, telecommunications, optics, microstructures and nanotechnology. The right-hand side shows that while many forward citations come from these same quantum-related fields, a significant share also originates in adjacent areas such as medical technology, biotechnology, electrical machinery, control systems, audio-visual technology and IT methods for management. This broad reach indicates the diffusion of quantum knowledge into a wide set of industries.

Notably, quantum communication exhibits both a higher number and a broader spread of forward citations, reflecting its wider technological reach compared to quantum computing, which shows fewer forward linkages. This points to the growing importance of quantum cryptography and its application across various technological domains, particularly in securing communication systems. Overall, the analysis highlights the position of quantum technologies as upstream enablers within innovation supply chains. While much of the impact remains within the quantum-related areas themselves, diffusion into diverse sectors shows how quantum, and particularly quantum communication, is becoming a foundational layer of innovation with possibly far-reaching industrial applications.

Figure 3.5.1

Technology fields and knowledge flows in quantum



Notes: The diagram maps (i) on the left, the WIPO technology fields to which quantum IPFs published from 2005 to 2024 belong; (ii) in the centre, the three quantum areas; and (iii) on the right, the WIPO technology fields of the patent families citing quantum IPFs. Only WIPO technology fields accounting for more than 1% of the citing IPFs are displayed.

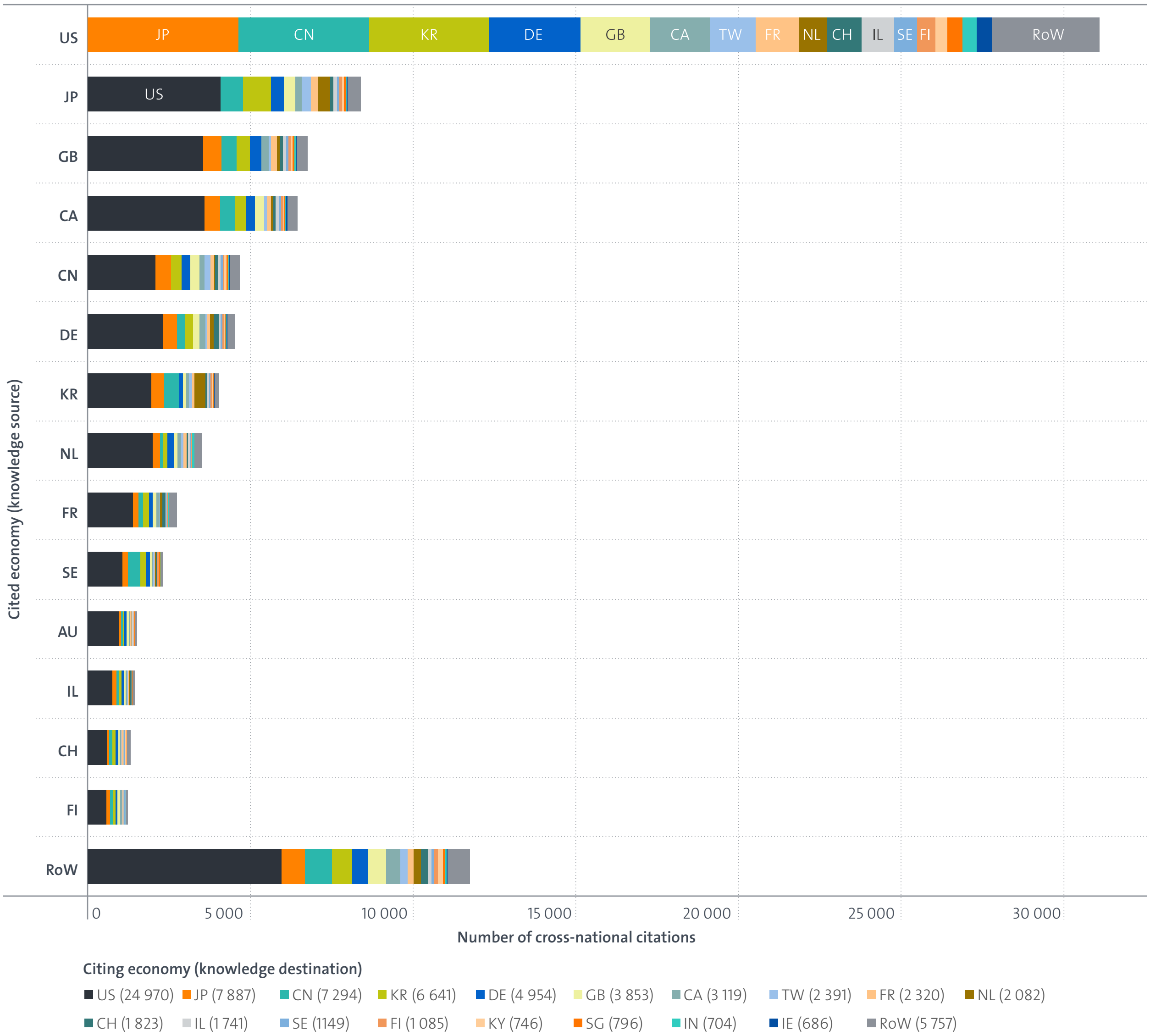
Source: EPO, October 2025.

3.5.2 Diffusion of quantum knowledge across countries

Figure 3.5.2 focuses on cross-national knowledge flows, which helps avoid possible biases due to geographical specificities. The United States stands out both as the largest source and main absorber of quantum knowledge, followed by Japan. The United Kingdom and Canada also rank relatively high as knowledge sources, while China and Korea show a stronger profile on the absorption side, reflecting the uptake of quantum inventions developed abroad. European economies, including Germany, France, the Netherlands and Switzerland, contribute consistently as both knowledge sources and absorbers, though on a smaller scale compared with the United States and Asian economies.

Figure 3.5.2

Cross-national citation flows of quantum applications published: 2005-2024



Notes: This figure shows the cross-national citation flows of applications published between 2005 and 2024. The y-axis indicates the knowledge source (the location of the applicant whose quantum applications are cited). The x-axis indicates the number of citations to quantum patents from the knowledge source. The colour boxes indicate the knowledge recipient (the location of the applicant who cites quantum applications), ranked by their importance as recipients as measured by their total number of citations to quantum patents.

Source: EPO, October 2025.

3.6 Conclusion

Quantum patenting has grown rapidly, especially since 2014, with IPFs increasing more than sevenfold over the past two decades. This growth far exceeds that of overall technologies, confirming quantum as one of the most dynamic innovation fields.

Among the three quantum areas, communication is still the largest, though computing is the fastest growing recently even overtaking the number of patent filings in communication. Sensing is progressing steadily on a smaller scale between 60 and 80 annual IPFs being filed. Quantum fields and subfields show different dynamics: QKD dominates communication, physical realisations drive computing, and sensing patents cluster around magnetic fields, gravitation, and time measurement.

Applicants from different countries reveal different strategies with regards to where they file their patents. Chinese applicants account for the largest number of overall patent families, but applicants from the United States and EPC countries lead in number of international patent families. US applicants also stand out on the intensive margin, with their patents receiving more citations, while Chinese applicants lead on the extensive margin with the highest number of forward-cited families. Within Europe, Germany, United Kingdom, and French applicants are the most important contributors, with the United Kingdom and Finland showing specialisation in quantum. Japanese, Korean and Canadian applicants also are important players.

The degree of internationalisation of patent families differs considerably across areas. Patent applications in Computing applications are most often protected globally, while many filings in communication and sensing, especially from Chinese applicants, remain domestic. US companies dominate cross-country collaboration with applicants and inventors from other countries, whereby standing out are Indian as an inventor country working for US applicants.

Companies now generate about 80% of IPFs, reflecting the shift from research-driven to commercially driven innovation. The shares of universities and individuals have declined, while PROs remain steady contributors. High shares in company filing activity can be found in quantum algorithms and programming. Comparably high shares of PRO activity are seen in quantum memories, physical realisations (spin-based and quantum optics) chemical detection and imaging.

The applicant landscape differs across quantum areas; big tech firms dominate in computing, a mix of telecom and electronics companies drive communication, and sensing is shaped by industrial and aerospace firms, with universities playing a significant role in early-stage innovation. Startups are also emerging as important players, particularly in computing, where they pioneer hardware and software approaches and often act as bridges between academic research and commercial development. Quantum patents also show unusually close ties to science, with one-third citing NPL, highlighting the research intensity of the field.

Finally, forward citation analysis confirms that quantum acts as an upstream enabling technology. knowledge from quantum patents, particularly in communication, diffuses into adjacent fields such as medical technology, biotechnology, electrical machinery, control systems, audio-visual technology and IT methods for management. Cross-national citation patterns show the US as both the leading source and absorber of quantum knowledge, with Japan ranking second in the two roles. China and Korea emerge as net absorbers.

Overall, the findings point to a rapidly expanding and diversifying innovation landscape. Quantum technologies are progressing from research to industrialisation, with clear global leaders emerging and knowledge flowing across countries and sectors.

4. Startups and other organisations active in the quantum ecosystem

Organisation – including startups, other businesses, universities and others – engaged in quantum ecosystems can be segmented in two parts. First, there is a set of core quantum companies whose emphasis is on developing technologies essential to the quantum landscape. These include both firms directly engaged in creating quantum technologies based on the principles of quantum physics, and enablers whose products provide critical inputs to support the work of core companies, for example in photonics, cryogenics and nanomaterials. Second, there is also a broad ecosystem of organisations – including MNEs, but also universities and PROs – that contribute to developing quantum technologies, but whose primary business objectives may lie outside the quantum field.

For the first group, the core sample of quantum and quantum-enabling companies (henceforth defined as "core") was identified based on data from Crunchbase and Dealroom matched with PATSTAT by combining five search strategies.[18] First, companies were identified based on keyword searches in the description of firms' activity. Keywords included terms strictly linked to quantum technologies, as well as terms linked to key enabling technologies like photonics and cryogenics (see Annex A.2 for the detailed search strategy). To exclude firms with no real evidence of meaningful economic activity, only companies that had filed at least one patent or received some form of funding (e.g. a venture capital investment) by 2021 were retained.[19] Second, a list of manually identified quantum firms found in previous OECD work was added. Third, companies that have received funding from the EU Commission for quantum-related research activities as recorded in Cordis database were identified manually. Fourth, any company listed in Crunchbase or Dealroom with at least half of their patent portfolio comprised of quantum patents was identified. Finally, companies not listed in Crunchbase or Dealroom – for which less information is available – were considered for inclusion if they held at least two quantum patents and had at least 65% of their patent portfolios comprised of quantum technologies. To minimize false positives, the companies identified through the various search strategies were all manually reviewed, ensuring that only those primarily focused on quantum technologies and key enabling technologies were included in the core. These search strategies resulted in a combined core sample of 830 quantum companies (for a breakdown of how many companies were found using the different strategies, see Annex A.2).[20]

The broader quantum industrial ecosystem (henceforth defined as "ecosystem") includes all core companies identified through the search strategies described above, as well as all other organisations – including also universities and PROs, that are excluded from the core – that have filed at least one quantum patent. These organisations may not be present in Crunchbase and Dealroom, but some information on them may be available from Orbis, which is also part of the OECD/STI Microdata Lab. Overall, the broader quantum industrial ecosystem includes a total of 4 622 organisations (see Annex A.2 for additional information).[21]

This section starts by providing an overview of quantum firms' founding year, location, economic activity based on industry classifications and the type of quantum activities they engage in. It provides additional evidence on the patenting behaviour of quantum firms, before zooming in on quantum-focused firms, the background of their founders and the funding they receive.

18 Crunchbase and Dealroom are both commercial datasets focused on collecting firm level data. Both platforms emphasise collecting information on startups but also include many other types of firms. They have distinct strengths in terms of coverage, as CB tends to have higher coverage of European countries, while DR is more focused on Northern American countries. For both datasets, the latest available vintages (2025) were used.

19 The choice of retaining potentially less relevant startups for the final years of the sample was made as quality indicators like patents and investments are available with a lag. Therefore the application of the quality criterion could have resulted in the exclusion of high-quality quantum firms whose activities were simply not recorded yet.

20 It is worth noting that the keyword-based search did not identify some quantum firms included in the core sample (135 firms out of 830 in total). This is mainly due to two factors. Firstly, around 28% of these missing matches lack any description in either Crunchbase or Dealroom. For the remaining cases (approximately one third identified through patents and two thirds manually, with some overlap between the two methods), it is common to find only a single, broad keyword. According to the approach described in Annex A.2, a single reference to a general concept – such as "quantum computing" – is not sufficient to include it in the keyword-based sample. While this choice was intended to limit false positives, it also reduces the method's recall. Finally, some companies' descriptions may not explicitly indicate quantum-related activities, even though a high share of quantum patents in their portfolios or their manual identification may suggest an increasing focus on the sector.

21 The broader ecosystem also includes numerous universities, which are not represented in the core segment of the ecosystem as they are unlikely to meet the requirement that at least 50% of their total patent portfolio consists of quantum patents.

4.1 A bird's eye view of the quantum industrial ecosystem

Figure 4.1.1 shows the yearly number of quantum firms founded during the period 2000-2024 (see Annex A.2 for details on the definition of quantum companies and the data consolidation process). The figure includes information on both the entire industrial ecosystem, as well as core firms. For companies in the broad industrial quantum ecosystem that were established well before the emergence of quantum technologies (such as IBM or Intel), the figure reports the year of entry into the quantum ecosystem instead of the company's founding year. Entry into the quantum ecosystem is defined as the year in which a firm obtained its first quantum patent, if such a patent exists.

The figure shows that the number of new quantum firms has increased substantially since 2013.[22] A peak was reached in 2021, when around 400 organisations were either founded or filed their first patent in quantum technologies.

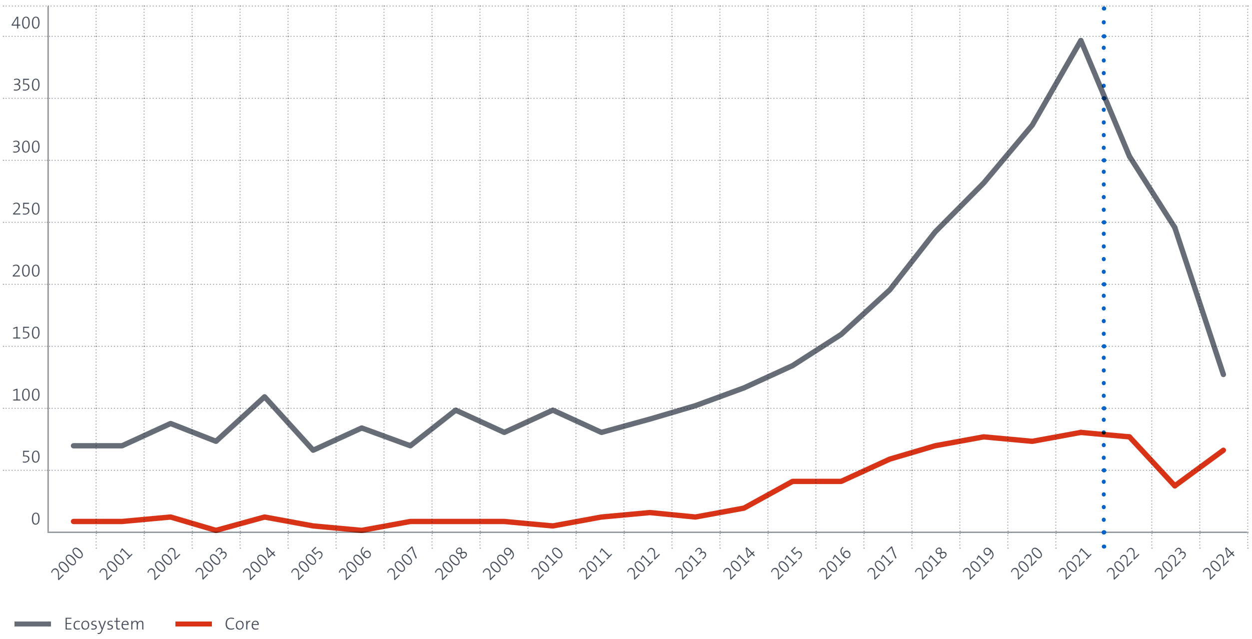
The last three years shown in the figure (2022 to 2024) are displayed after a dotted line, since the available sample of quantum firms as observed from the data may understate the true numbers of firms founded. This is because patent filings are observed with a lag. As a result, a company founded recently and filing a quantum patent in 2024 would not yet be identifiable as such. Therefore, the decreasing trend observed in the last three years should be interpreted with caution. Startup creation is observed with a shorter lag since it relies more heavily on companies' description, which explains why the number of companies founded that belong to the core ecosystem does not experience a similar drop. Nevertheless, even for core firms, the number of entries appear to have plateau in recent years. [23]

22 This work will refer to new quantum firms, or quantum firms founded, as the databases used to identify quantum firms are better at tracking market entry than exit, making the definition of a precise stock of existing quantum firms challenging.

23 Nevertheless, a reporting lag may exist, insofar as information may be entered into Crunchbase and Dealroom with some delay.

Figure 4.1.1

Quantum ecosystem companies by founding year: 2000-2024

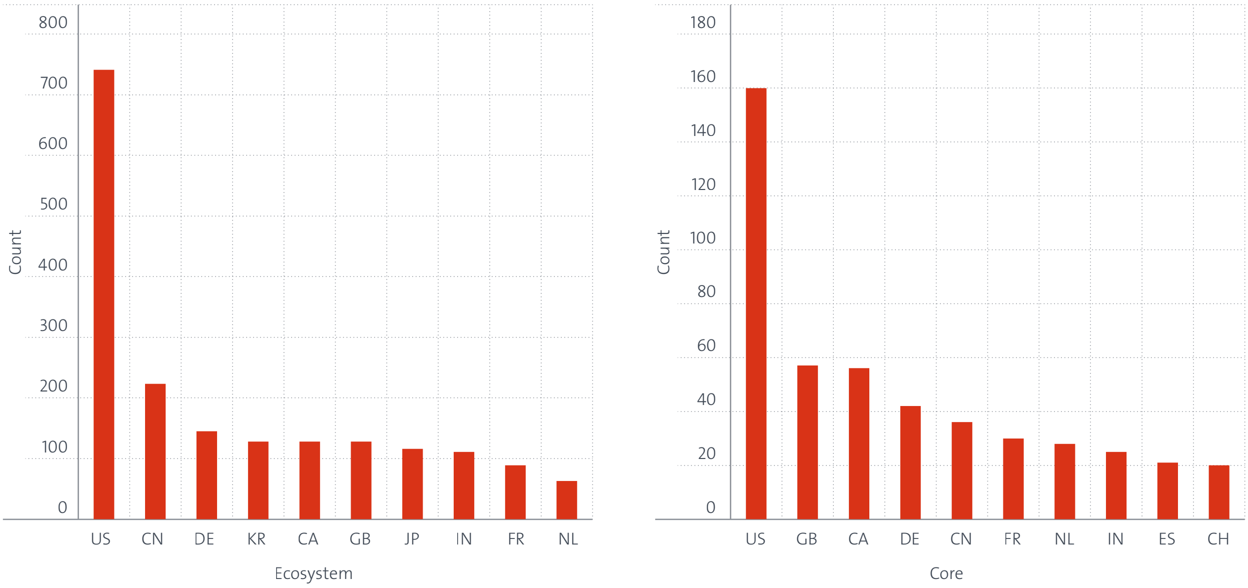


Notes: for the core segment the entry year is defined as the foundation year, whereas for the ecosystem segment the entry year is defined as the year in which a firm obtained its first quantum patent, if such a patent exists. Information on entry year for firms in the broad ecosystem is missing for 425 firms, and information on founding year is missing for 39 core firms. Firms not represented were founded before 2000 and had no quantum patents in their patent portfolios, or no patents at all.

Source: OECD calculations based on OECD, STI Micro-data Lab, and Orbis, Bureau van Dijk, October 2025.

Figure 4.1.2

Number of firms in the quantum ecosystem entering the quantum field by country: 2015-2024



Notes: The figure shows the top ten countries by total entries in the ecosystem and founding in the core portion in the period 2015-2024. This includes 1 872 of the 4 622 firms included in the quantum ecosystem, and 475 of the 830 quantum-focused firms (other firms were founded before 2015, or in 2025, or in remaining countries).

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.1.2 shows the number of new quantum firms by country over the period 2015-2024, distinguishing between the entire ecosystem (left-hand panel) and the core ecosystem (right-hand panel). Over that decade the United States played a leading role in terms of firms founded irrespective of the metric considered, followed, in the broad ecosystem, by China, Germany, Korea, Canada and the United Kingdom. Looking at the core part of the ecosystem, the United States remains the leading country, but the United Kingdom and Canada appear more prominently than in the broad ecosystem.

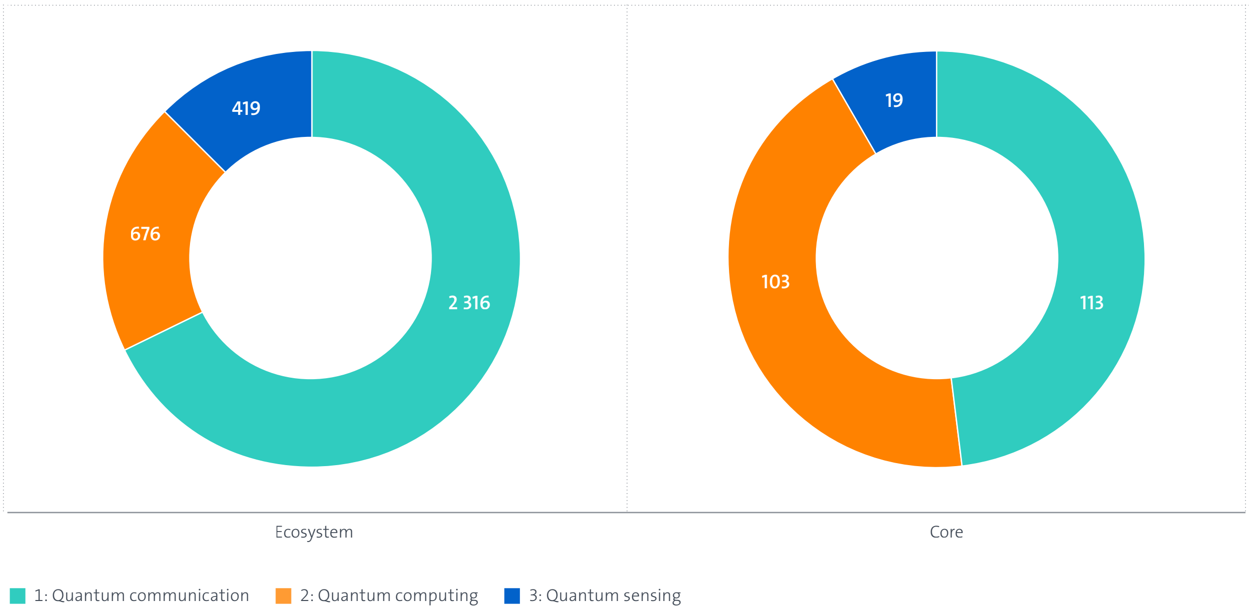
To characterise quantum firms' activities, firms in the ecosystem are categorised in line with the taxonomy presented in Section 2 and further discussed in Section 3, and split between communication, computing and sensing/metrology based on the technology in which they hold the largest share of patents. Information on these categories is available only for firms that filed at least one quantum patent (around 74% of the entire ecosystem), which restricts the sample, especially for very young firms. The overall ecosystem is depicted on the left-hand panel and the core component on the right-hand panel of Figure 4.1.3.

The majority of quantum firms in the broad ecosystem are active in communication, with computing and sensing the second and third largest groups of companies. Among core firms, the proportion of computing-focused companies appears higher up to becoming the most relevant category, while the share of sensing companies is slightly lower.

The distribution of firms across fields varies by country (Figure 4.1.4). For the broad ecosystem, the US, China and especially Korea have a higher share of firms active in communication, while in Germany and in Canada computing companies are better represented. Sensing, while less common overall, is chiefly present in Germany. In the core part of the ecosystem (right-hand panel), as noted above, computing plays a larger role among core companies than in the overall ecosystem. This is especially visible in the United Kingdom, but also in Canada. For sensing, the United States stand out as the country with the largest representation.

Figure 4.1.3

Number of quantum ecosystem firms by technology

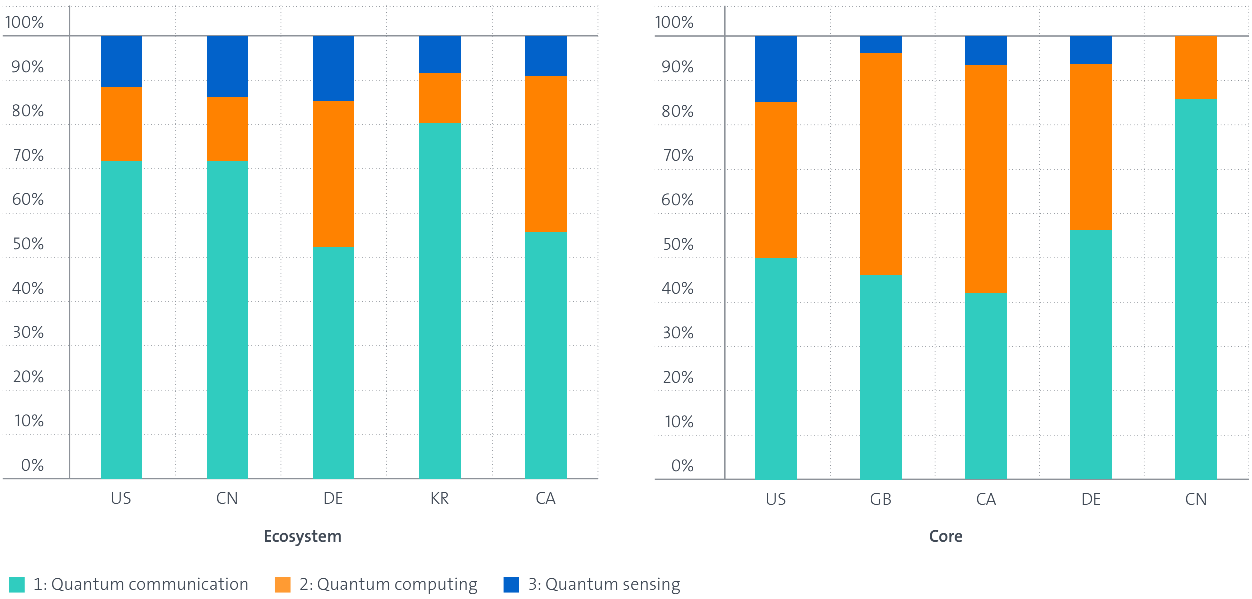


Notes: The figure shows only firms with a quantum patent. A single patent may be classified in multiple technological categories. Firms are placed in a single category based on the technology in which they hold the highest number of patents. If a firm has the same number of patents across multiple technologies, it is assigned proportionally across the categories.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.1.4

Quantum ecosystem entries by main technology for the top five countries: entire period

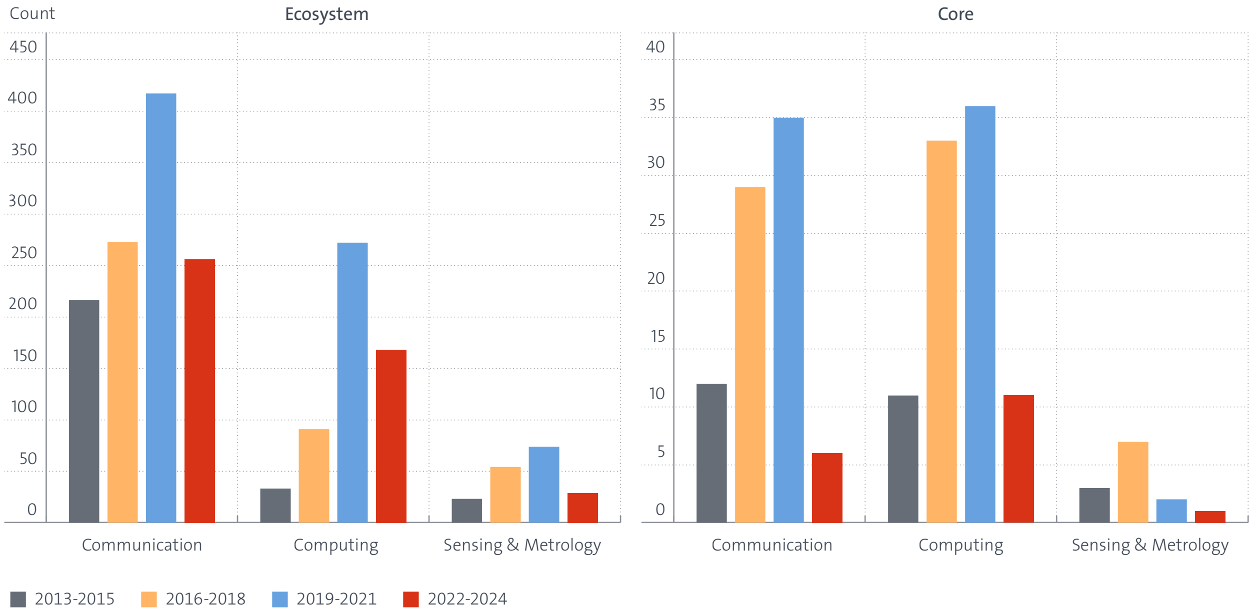


Notes: The figure shows the top five countries within the broad ecosystem and the core portion as represented in Figure 4.1.2. Only firms with a quantum patent are shown. The definition of the main technology of a company is based on the technology most strongly represented in their patent portfolio as of the latest available date (2025). If a firm has the same number of patents across multiple technologies, it is assigned proportionally across the categories.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.1.5

Quantum ecosystem entries by main technology: 2013-2024



Notes: Only firms with a quantum patent are shown. For the core segment (right panel) the entry year is defined as the foundation year, whereas for the ecosystem segment (left panel) the entry year is defined as the year in which a firm obtained its first quantum patent, if such a patent exists. The definition of the main technology of a company is based on the technology best represented in their patent portfolio as of the latest available date (2025). If a firm has the same number of patents across multiple technologies, it is assigned proportionally across the categories.

Source: OECD calculations based on OECD, STI Micro-data Lab and Orbis, Bureau van Dijk, October 2025.

The trend in the number of companies founded by segment over three-year periods is presented in Figure 4.1.5. Initially, in the ecosystem, the bulk of quantum firms were founded in communication, but computing appears to be gaining prominence, especially in the core portion of the ecosystem, up to becoming the most relevant technology. Both within the broad ecosystem and its core component, sensing is the technological area with the lowest number of organisations.

Figure 4.1.6 shows the distribution of quantum firms across industries using the Nomenclature of Economic Activities (NACE) system. Data on sectoral classification are available only for a subset (around 47%) of the companies included in the ecosystem, through matching to the Orbis database.[24] For this subset the industries with the highest number of quantum firms include *Manufacture of computer, electronic and optical products* (NACE 26), *Computer programming, consultancy and related activities* (NACE 62), *Architectural and engineering activities, technical testing and analysis* (NACE 71) and *Scientific research and development* (NACE 72), confirming that quantum firms are predominantly active in high-tech sectors. However, they are active in a broader set of industries, including *Education* (NACE 85), *Chemicals* (NACE 20) and *Finance* (NACE 64).[25 26]

Within the core, three sectors stand out even more prominently than when considering the broad ecosystem: *Manufacture of computer, electronic and optical products* (NACE 26), *Computer programming, consultancy and related activities* (NACE 62) and *Scientific research and development* (NACE 72).

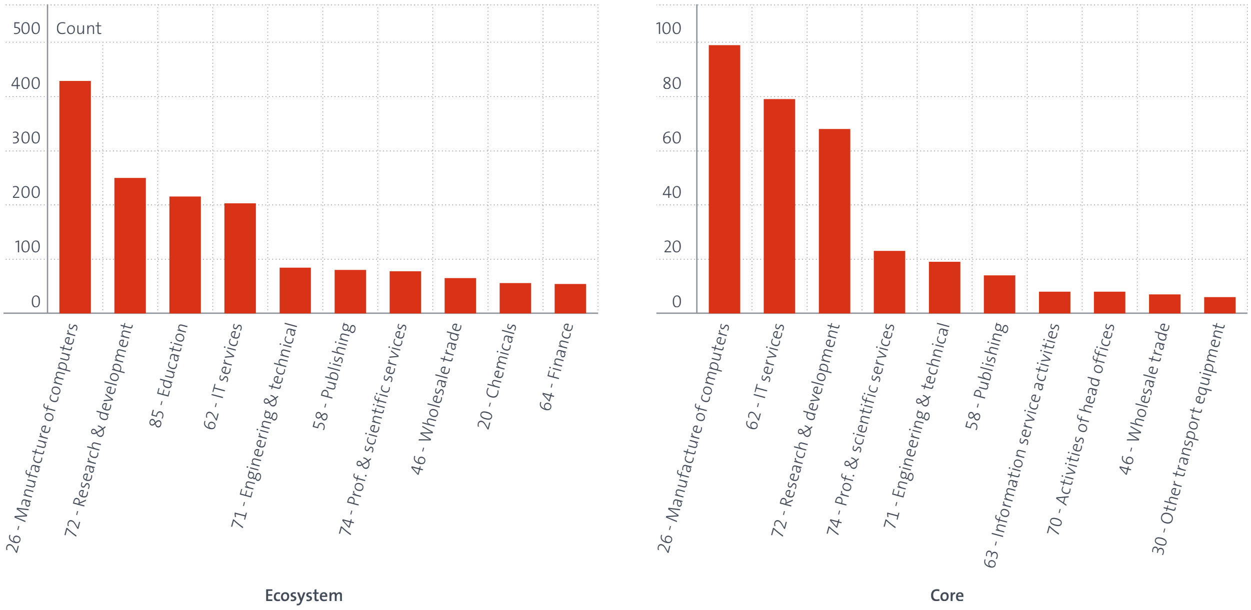
24 Orbis is a commercial database collected and managed by Bureau van Dijk (BvD), a Moody's subsidiary. Data at both company and business group level are gathered from a diverse set of sources, such as annual reports, financial filings, production surveys and business registries.

25 Wells Fargo, for instance, appears to be active in the development of patents relevant for quantum communication. Quantum communication holds significant potential for the banking sector, offering unprecedentedly secure channels for financial transactions and data protection.

26 Publishing (NACE 58) predominantly refers to *NACE 5829 – Other software publishing*.

Figure 4.1.6

Quantum firms by industries: entire period



Notes: The figure shows the ten most represented economic sectors within the broad quantum ecosystem, following the statistical classification of economic activities of the European Community (NACE, rev.2). Data on NACE sectors are available for 2 165 out of 4 622 firms in the ecosystem, and 381 out of 830 firms in the core.

Source: OECD calculations based on OECD, STI Micro-data Lab and Orbis, Bureau van Dijk, October 2025.

4.2 Quantum firms' patenting activities

Figure 4.2.1 shows the strong upward trend in patenting both within the broad ecosystem (left-hand panel) and in its core component (right-hand panel), but also highlights a slowing down in 2024, which might be partially due to data truncation. This subsection focuses on IPFs, families of patents filed in several jurisdictions.

Figure 4.2.2 zooms in on how the share of quantum patents filed by firms in the core portion of the ecosystem has changed over time. Throughout the period the share of quantum patents produced by firms focusing solely on quantum activities remained low. It increased more recently, reaching 22% in 2024, but the vast majority of patents protecting quantum technologies are still produced by companies whose primary business objectives lie outside quantum technologies.

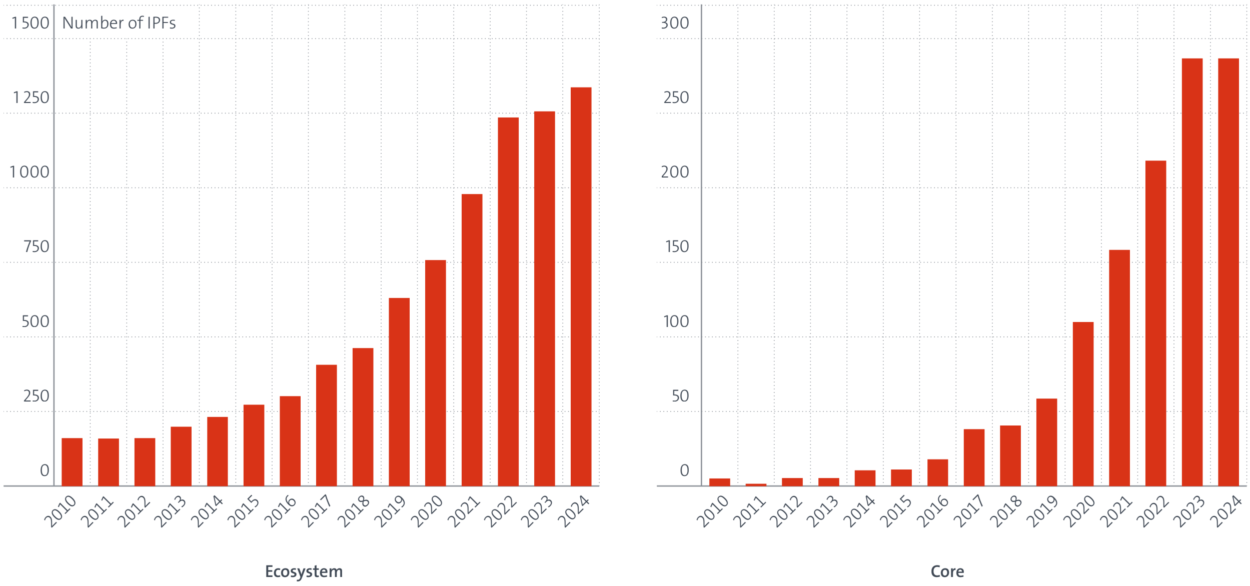
Figure 4.2.3 shows two Lorenz curves portraying the concentration of patents for quantum and patents in general. The figure suggests that concentration tends to be higher for quantum patents; 20% of patent holders filed approximately three-quarters of patents, while for patents in general, this share is closer to 63%.[27] This finding may have meaningful implications for the evolution of quantum technologies, as it indicates that a relatively small group of firms is currently driving much of the innovation. Given the broad potential impacts of quantum technologies – economic and otherwise – such concentration could pose challenges for ensuring that their development remains inclusive and widely accessible.

Core quantum firms (shown in the left-hand portion of the figure, within the shaded area) account for approximately 11% of all quantum patents. This proportion is much higher than their share of overall patents, which is comparatively small, as shown by the flat dark blue line in the shaded area, representing their share of all patents. This reinforces the idea that a substantial share of quantum development is occurring outside the boundaries of the core section, within the broader ecosystem, but at the same time it shows that core firms are much more heavily concentrated on quantum development.

27 Large conglomerates such as IBM, LG Electronics, Toshiba, Intel or Microsoft are among the top 5 companies with quantum patents (see Figure 3.4.2).

Figure 4.2.1

Quantum patents filed by quantum firms: 2010-2024

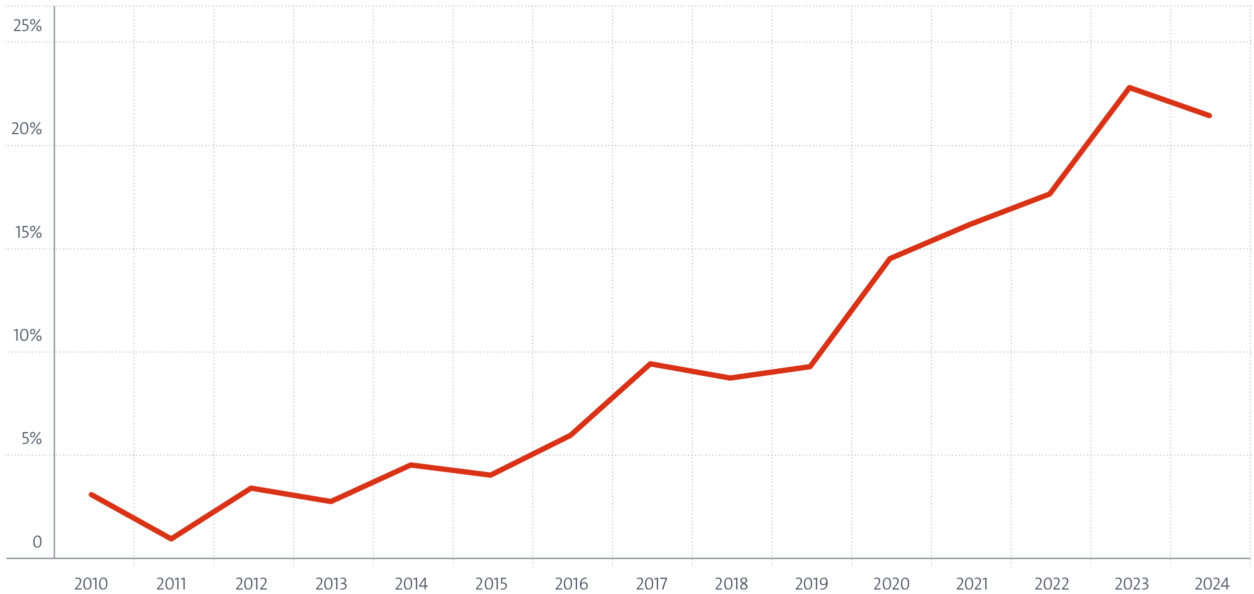


Notes: Data refer to quantum IPFs filed by quantum firms in the whole ecosystem and by core quantum firms.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.2.2

Share of quantum patents filed by core quantum firms: 2010-2024

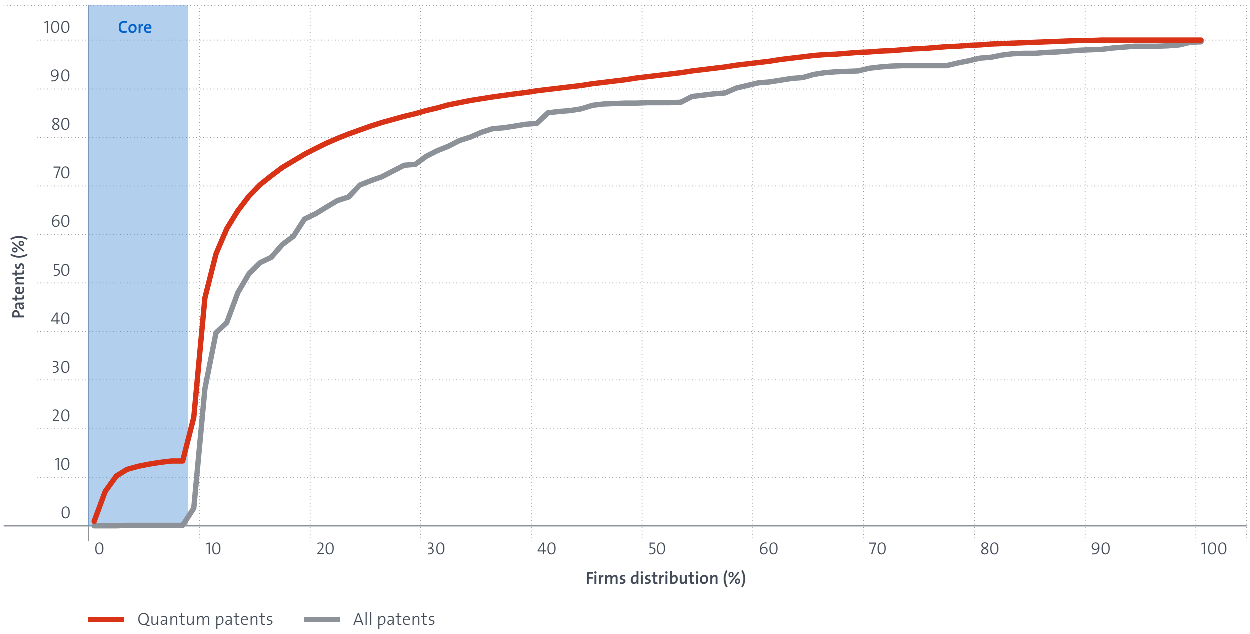


Notes: Data refer to quantum IPFs filed by quantum firms in the whole ecosystem and by core quantum startups.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.2.3

Concentration of quantum vs all patents: entire period



Notes: Data refer to the distribution of IPFs (total and quantum) among quantum firms ranked by decreasing share of quantum patents, starting with the core quantum firms and then the remaining ecosystem firms. Only quantum firms that have filed for at least one patent in any technological domain are included.

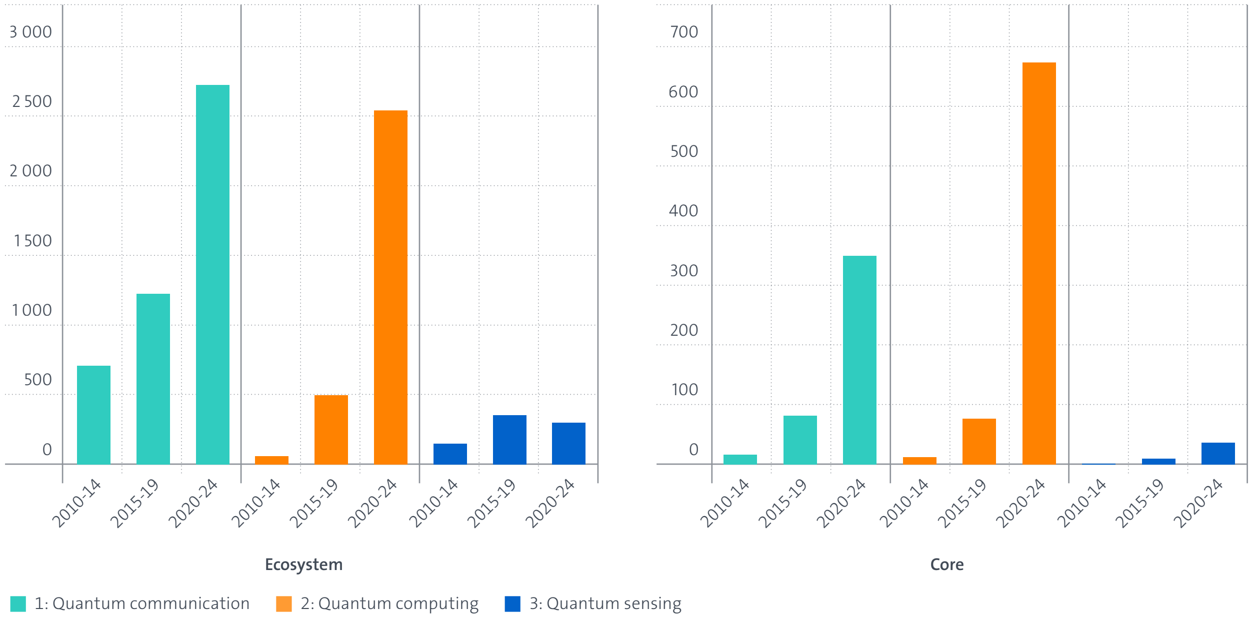
Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.2.4 confirms the insights from Figure 4.1.5, showing that communication and computing represent the largest quantum technology areas (as measured here by the number of patents) while sensing and metrology play a comparatively smaller role. Although patenting activity increased across all categories, growth has been particularly strong in computing. This trend is visible in both the broad ecosystem (left-hand panel), where communication played a much more prominent role in 2010-2014 but was caught up by computing in 2020-2024, and even more markedly in the core portion of the ecosystem, where computing patents were nearly double those in communication during the same period. Taken together with the evidence in Figure 3.3, this may suggest that core quantum firms are more likely to specialise in quantum computing, while communication-related patenting is more prevalent among large, diversified firms.

Figure 4.2.5 shows the areas beyond quantum technologies in which quantum firms – both within the broader ecosystem and in its core section – are patenting. The left-hand panel highlights that, while ecosystem organisations are considerably active in *Computer technology* (which comes as little surprise, given its proximity to quantum activities) they are also involved in a wide range of other technologies, including several where quantum technologies are chiefly applied, such as *Transport, Telecommunications and Medical technology*. Conversely, the right-hand panel shows that core companies are much more focused on *Computer technology,* with other patenting areas closely related to the quantum sector, for instance through key enabling fields such as *Optics* or *Measurement* – an area crucial for quantum sensing and metrology, among others.

Figure 4.2.4

Patents filed by quantum firms by technology: 2010-2024



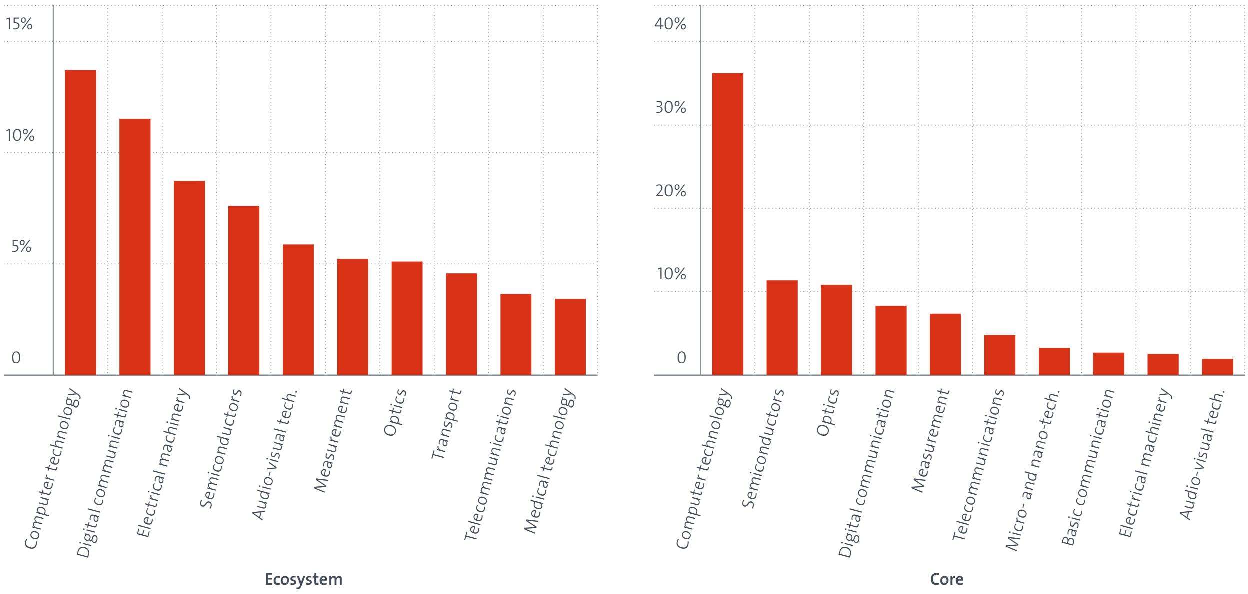
Notes: Data refer to quantum IPFs filed by quantum firms in the whole ecosystem and by core quantum startups.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025

Figure 4.2.5

Portfolio of non-quantum patents filed by quantum firms: 2010-2024

Share of patented technologies in total patents filed by quantum firms: top ten technologies



Notes: Data refer to IPFs filed by quantum firms in the whole ecosystem and by core quantum startups, by technology field. Patents are allocated to 35 technology fields based on their International Patent Classification (IPC) codes following the concordance provided by WIPO, using fractional counts.

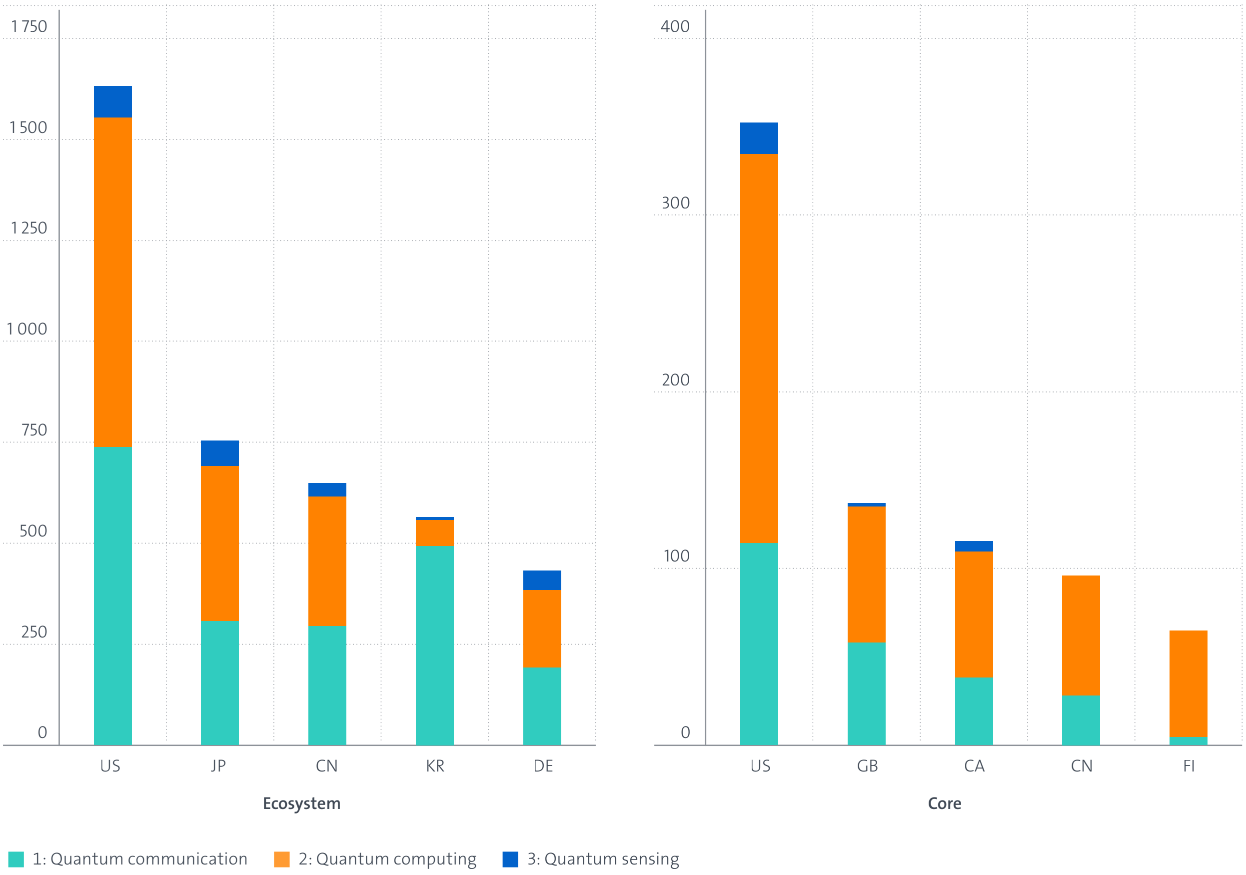
Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.2.6 shows the leading countries by number of patents in the overall ecosystem (left-hand panel) and in the core portion (right-hand panel) for the period 2020-2024, while also providing additional information on the types of patents produced. The leading role of the United States stands out even more clearly in this figure, as it filed the largest number of patents across both samples. Korea, whose prominent role in the overall ecosystem was already noted, appears unique in its strong focus on communication technologies, while in other countries, computing patents tend to dominate. Within the core portion of the ecosystem, sensing and metrology patents are almost absent except in the United States, while Canada, China and Finland have particularly high shares of computing patents over their total quantum patents.

In terms of sectors, Figure 4.2.7 shows that over the period 2020-2024 computing patents accounted for the majority of quantum-related patents across most industries. The distribution is more balanced in *Manufacturing of computers* (NACE 26) and *Research and Development* (NACE 72), where communication patents are more prevalent, as well as in *Education* (NACE 85). *Retail trade* (NACE 47) displays the highest share of sensing and metrology patents.

Figure 4.2.6

Top five applicant countries with quantum international patent filings by quantum firms: 2020-2024

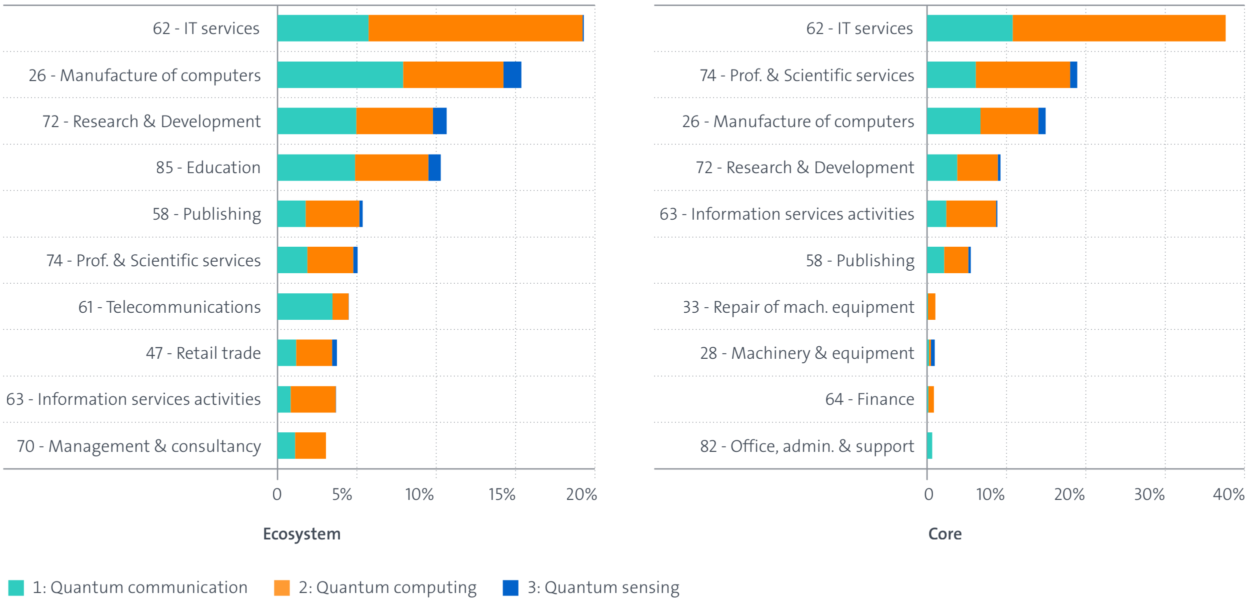


Notes: Data refer to quantum IPFs filed by quantum organisations in the whole ecosystem and by core quantum firms.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.2.7

Quantum patent portfolio by industry and technology: 2020-2024



Notes: Data refer to quantum IPFs filed by quantum firms in the whole ecosystem and by core quantum startups. The figure shows the top 10 quantum patenting sectors, following the statistical classification of economic activities of the European Community (NACE, rev.2). Data on firms' NACE sectors are available for 2 165 out of 4 622 firms in the ecosystem, and 381 out of 830 firms in the core.

Source: OECD calculations based on OECD, STI Micro-data Lab and Orbis, Bureau van Dijk, October 2025.

4.3 The founders of quantum firms

Analysing the founders of quantum firms can provide insights into the background necessary to succeed within the quantum ecosystem. Information on founders is available only for core quantum firms, and not even for all of them. Throughout this section, founders of quantum firms are compared to founders of all firms in Crunchbase (henceforth "CB").

Figure 4.3.1 shows the distribution of the number of founders of core firms.[28] Most of these were established by either one or two founders. Nevertheless, 29% of quantum firms had more than two founders (up to nine). Teams with multiple founders are more prevalent in quantum firms than the general sample, suggesting that establishing a company in this industry requires a broader portfolio of skills or network.

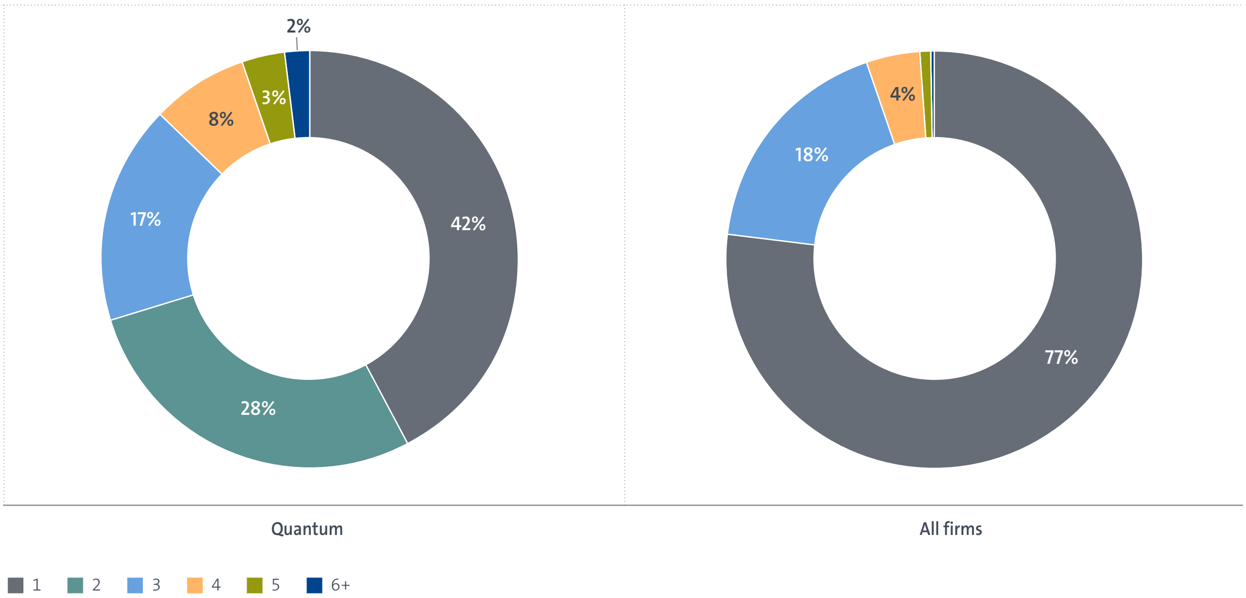
Figure 4.3.2 shows the highest educational achievement of core quantum firms' founders. A very high proportion of them (58% of founders with available education information) have earned a PhD. This pattern is remarkably different from the general CB population, where founders with a PhD constitute a much lower number of founders (around 10% of founders with available education information). This reinforces the idea that quantum firms strongly rely on advanced scientific knowledge.

Quantum company founders studied at a wide range of universities (Figure 4.3.3). Among these, a few institutions stand out: MIT, Oxford and Stanford are particularly well represented. This is in line with the high concentration of quantum startups in the United States and the United Kingdom, and with the fact that MIT and Oxford are among the leading universities for quantum patents produced (see Section 3). Within the United Kingdom, the University of Cambridge and Imperial College also appear prominently, underscoring the country's role as a major hub for quantum innovation. In continental Europe, the Technical University of Munich ranks first in terms of the number of quantum founders among its alumni, followed by institutions such as the Technical University of Denmark and ETH Zurich, which come from countries less prominently represented in the ecosystem but that nonetheless provide a strong technical foundation.

28 From now on, the analysis will focus on core firms as study of both founders and later investment received are more meaningful for this category.

Figure 4.3.1

Number of founders in quantum firms

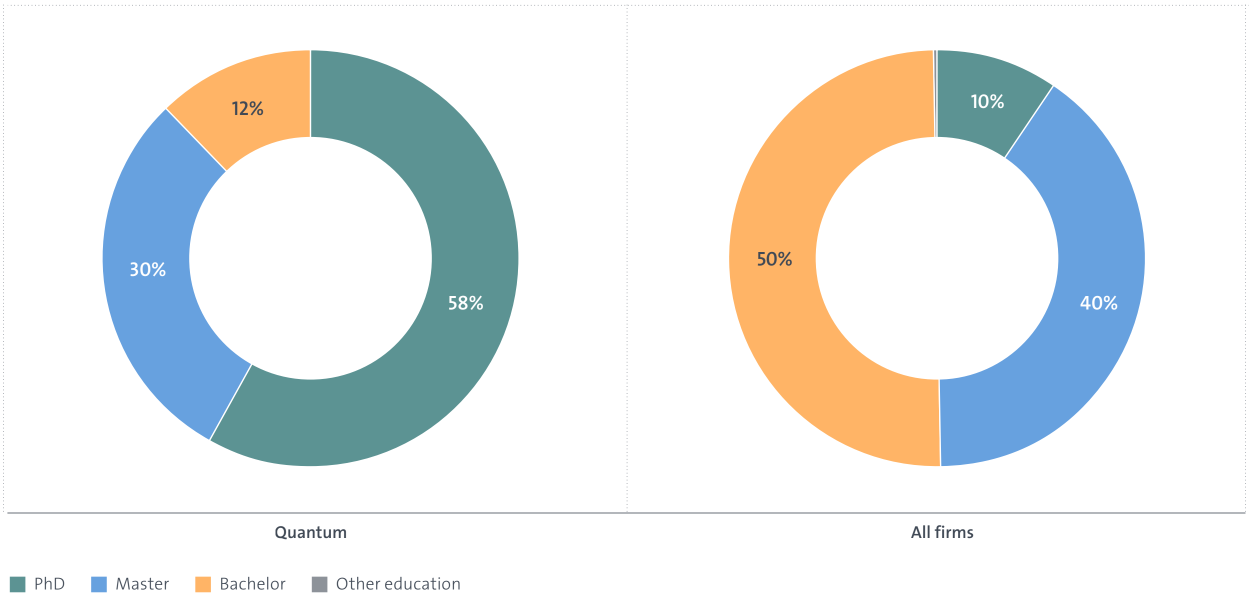


Notes: Information on founders is available for 545 core quantum firms, corresponding to 1 112 distinct founders deduplicated across Dealroom and Crunchbase datasets. All firms refer to all companies with founder information available in Crunchbase.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025

Figure 4.3.2

Highest educational achievement of quantum firms' founders

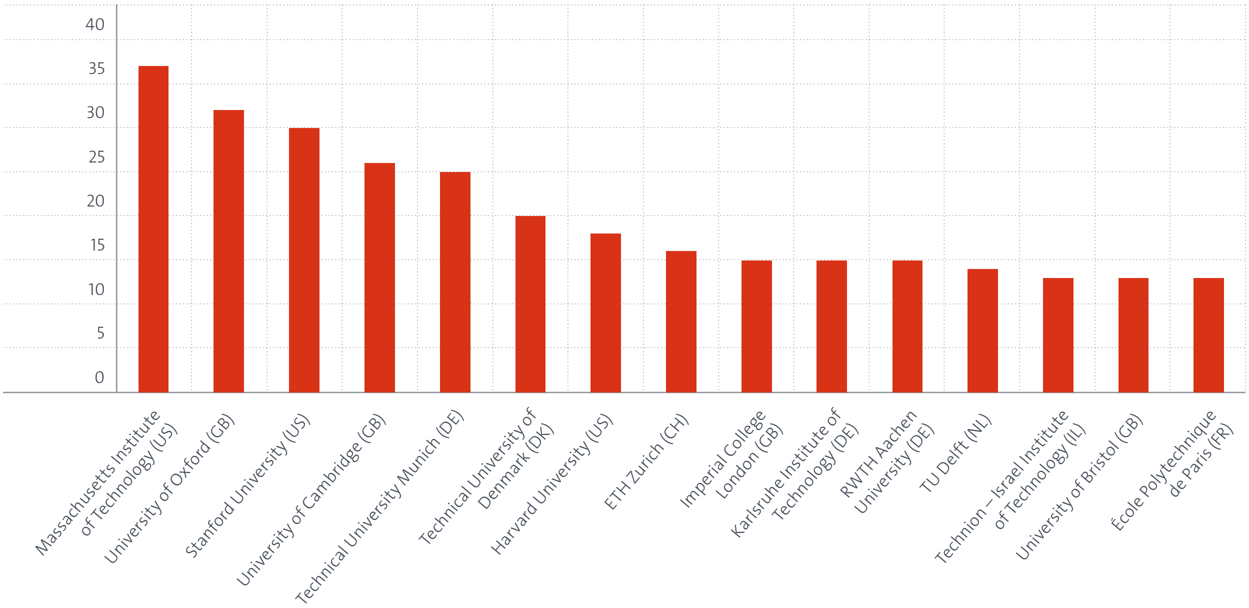


Notes: The figure includes information on 592 out of 1 112 identified founders of core quantum firms; for the remainder, information on maximum education achievement is unavailable. Other education includes high school; Bachelor includes bachelor's, graduate, JD and DUT degrees; Master includes Master, MBA, MSc, postgraduate and LLM degrees; PhD includes PhDs. All firms refer to all companies with founder information available in Crunchbase.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.3.3

Universities attended by quantum firms' founders



Notes: The figure includes information on 707 out of 1 112 identified founders of core quantum firms; for the remainder information on universities attended is unavailable. Founders can attend more than one university. University names were converted to lowercase to ensure consistency across Crunchbase and Dealroom, which use different capitalisation conventions. Business schools are considered separate entities.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

4.4 Investment in quantum firms

A considerable number of core quantum firms (587 out of 830, or around 71%) received some form of funding, including grants, venture capital, debt-linked funding, IPO-related funding and other less common forms (for additional information on the type of funding included, see Annex A.4).[29] Figure 4.4.1 shows the growth in investment that took place over the last ten years in terms of the number of startups financed and funding received. Most recent years have been by far the most successful for firms' funding, with close to USD 5 billion raised in both 2021 and 2024.

Despite the overall increase, 2022 and 2023 saw a decline in funding amounts in line with the decrease in firm entries highlighted in Figure 4.1.1. This is due to a decrease in the average size of deals, as the number of firms that received some form of funding (the diamonds) remained broadly stable at around 300 per year. Nevertheless, investment recovered strongly in 2024.

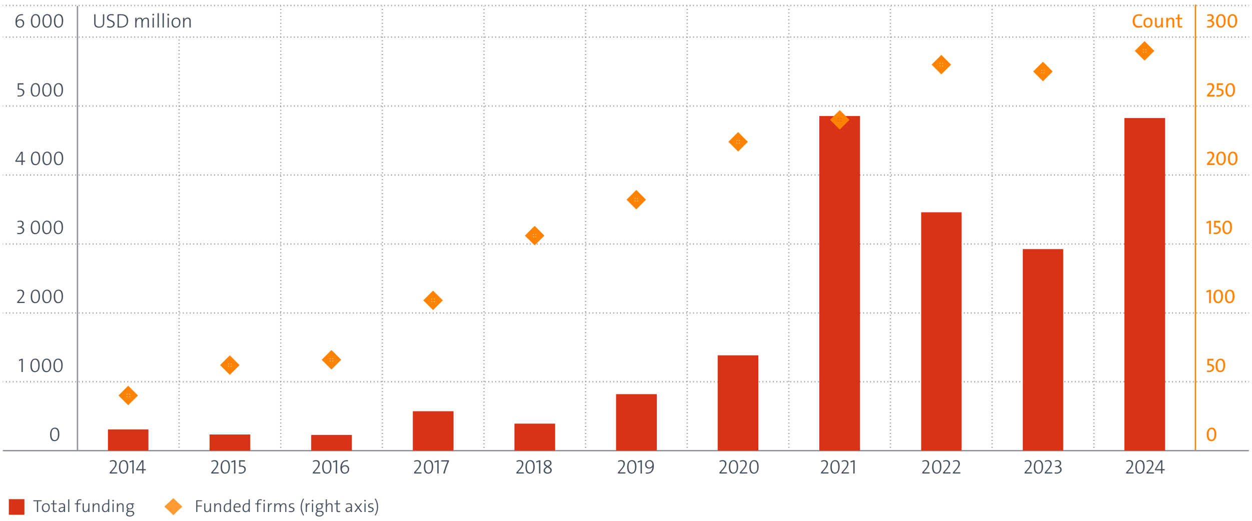
29 This is at least partially by design, as one of the selecting criteria for companies identified via keywords was to have received an investment.

On average, firms funded receive around USD 51 million in each deal, while the median firm receives USD 5 million. This notable difference between average and median points toward a long right tail in the funding distribution, i.e. a relatively small share of quantum firms received very large funding amounts, while most firms received small amounts. This is in line with general investment tendencies as recorded in in the OECD/STI Startup database as available from the OECD/STI Microdata Lab., even if the median is higher in quantum at around USD 5 million vs USD 2 million. Approximately 25% of firms received less or close to USD 1.1 million (this is higher than the general landscape investment, where the bottom 25% of the distribution received around USD 300 thousand), while the top 1% received more than USD 934 million (slightly lower than in the general sample, at close to USD 980 million). These larger rounds correspond to late-stage and growth investments and IPO-related funding.

Figure 4.4.2 indicates that the distribution of funding only partially mirrors the distribution of startups, with the United States playing a disproportionately prominent role. Around 60% of total funding in quantum over the entire sample went to US-based companies, even though the United States is home to only approximately 30% of all startups in the area. This discrepancy comes from larger average deals, as the United States also represents around 30% of the global number of deals recorded in quantum. Similarly, other countries, like Israel, appear to be particularly attractive in terms of funding compared to the number of startups they hold, while companies located in Canada, the United Kingdom, France and Germany are relatively less able to attract funding.

Figure 4.4.1

Total funding to and number of core quantum firms financed: 2014-2024

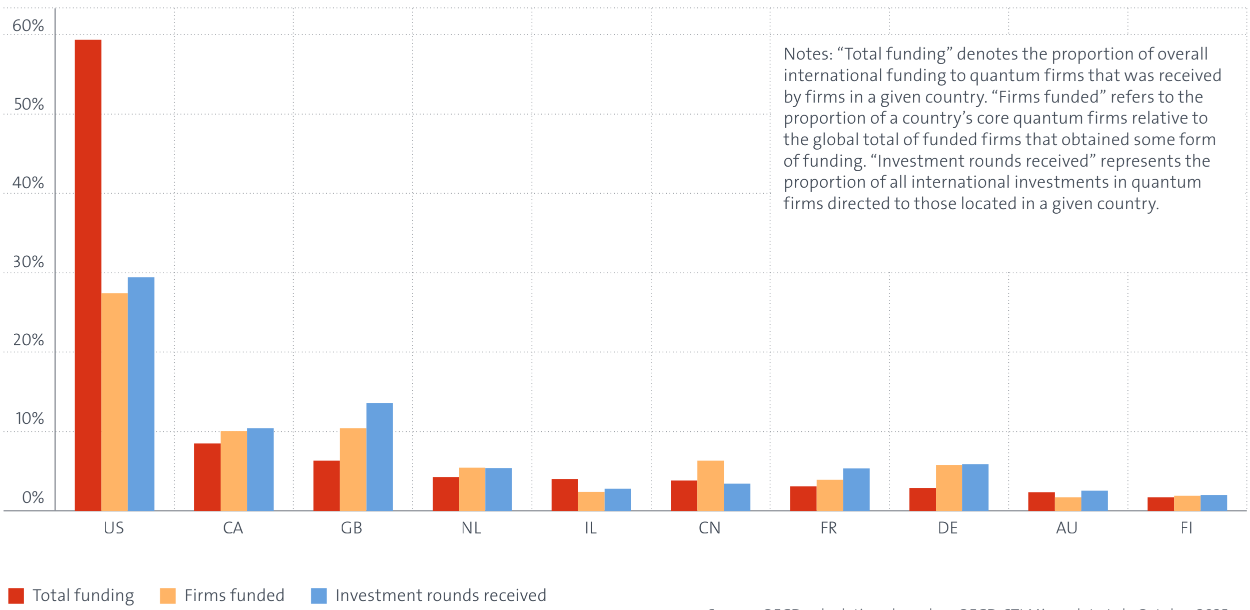


Notes: The figure portrays USD 20.01 billion, equivalent to 85% of total investment recorded.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 4.4.2

Country shares in global quantum funding, firms funded and investments rounds



Notes: "Total funding" denotes the proportion of overall international funding to quantum firms that was received by firms in a given country. "Firms funded" refers to the proportion of a country's core quantum firms relative to the global total of funded firms that obtained some form of funding. "Investment rounds received" represents the proportion of all international investments in quantum firms directed to those located in a given country.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

4.5 Conclusions

In conclusion, the quantum ecosystem is characterized by a mix of core technology developers and a broader set of organizations contributing to quantum advancement. While the number of quantum firms has grown rapidly in recent years, some signs of slow down – which should be cautiously interpreted, given data limitations – have started to emerge. Computing appears to be the most dynamic quantum technology in terms of entries, with sensing playing a less prominent role compared to both quantum computing and communication. Interestingly, patenting remains highly concentrated, and most patenting activity is carried out by non-core companies. The high educational attainment of founders underscores the sector's complexity, while data on both number of firms and investment highlights the leading role played by the United States in this area.

5. Investment in core quantum firms

The quantum ecosystem as described in Section 4 is not only in a very early stage of development, it also relies on extremely complex technologies with low technical readiness levels, high uncertainty regarding what platforms will emerge as winners, and a long development horizon (see Section 2). While the final part of Section 4 started to describe the investment received by core quantum companies, this section delves deeper into these investments and the most active investors (firms, rather than individuals) in the area.[30] The role of finance providers is paramount in ensuring that the firms operating in the ecosystem can keep innovating in a phase which is still exploratory and unlikely to generate reliable streams of revenues. While the ecosystem's future growth potential can provide the economic rationale for investment, the risks remain high. It is thus crucial to understand the prevailing types of funding and investment (grants, seed investments, early-stage venture capital funding, etc.), the geographies most active in quantum funding, and how these have evolved recently.

The wide implications of quantum technologies for numerous downstream industries such as defence, chemistry, finance and telecommunications (OECD, 2025a) can make investing in quantum firms appealing for a broader set of stakeholders than just professional investors like venture capitalists. Therefore, firms operating in downstream industries (which are explored in the second subsection below) may seek to support or acquire promising quantum firms to gain access to potentially valuable technologies. Similarly, governments looking to enhance capabilities in sensitive areas such as encrypted communication or foster a growing high-tech sector can benefit from backing quantum companies. Government investment is explored in the third and final part of this section.

This section draws mostly on the OECD/STI Startup database (building on Crunchbase and Dealroom data) as available from the OECD/STI Microdata Lab. It focuses on investments made in what was defined in Section 4 as core companies. Restricting the analysis to this component of the quantum ecosystem allows us to focus on companies whose primary activity is the development of quantum and quantum-enabling technologies (additional information on this sample is available in Annex A.2). Many firms involved in quantum technology are highly diversified (e.g. IBM, Intel and Google) and information on the proportion of each firm's investment specifically targeted at quantum is not available. Counting all investments made by these firms as quantum investment would grossly inflate the genuine figure.

5.1 Origin, type and size of investment in quantum

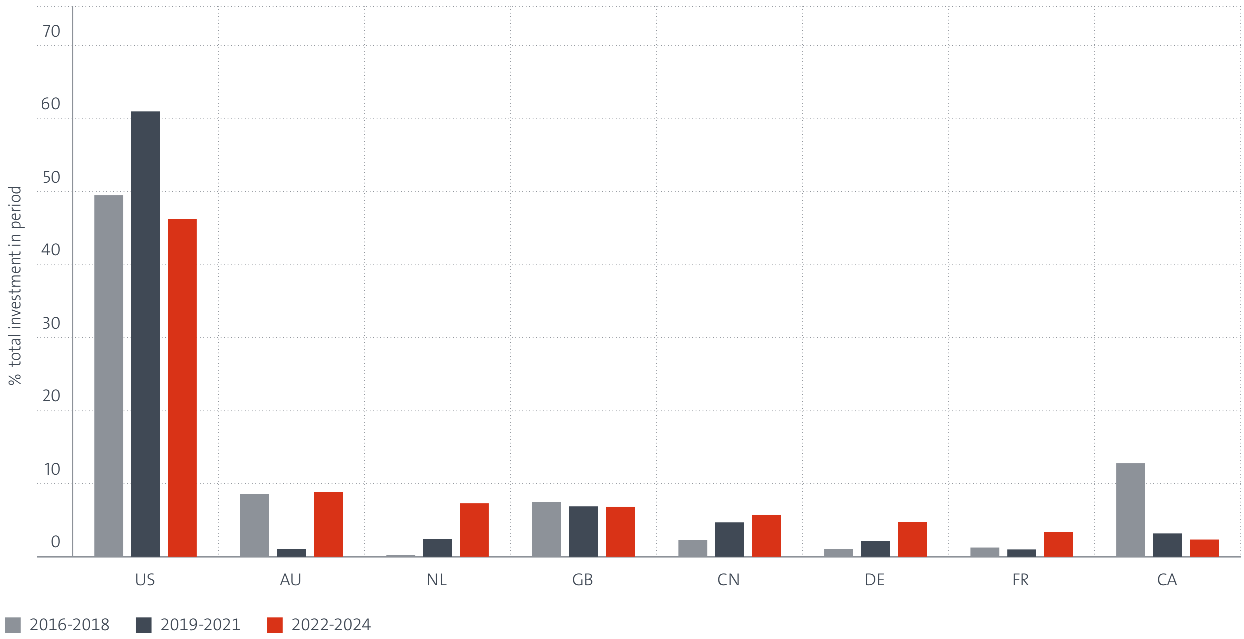
Section 4 already provided an overview of investment in the quantum ecosystem from the perspective of quantum companies Figure 5.1.1 shows the breakdown of quantum investment across investing countries over time (2016-2018, 2019-2021 and 2022-2024). The predominant role of the US is apparent: on average, US-based investors represented 52% of global investment in quantum companies over the period 2016-2024. Despite a decrease more recently, they still account for approximately 45% of core investment. European countries (France, Germany, the Netherlands and the United Kingdom) have significantly increased their share in total quantum investment over time. China-based investment is sizeable and fairly stable, while Canada's share has decreased considerably. Australia's remarkable increase in the recent period stems from large investments in Psiquantum by investors based in that country (Australia Government DISR, 2024).

Collectively, the countries mentioned so far account for more than 84% of all investment made in the quantum ecosystem in the period 2016-2024, and this share has increased over time – most recently from 73% to 87%. Smaller investors include Belgium, Japan, Korea and Israel.

30 As with the investment part of Section 4, this section will focus exclusively on the financing of core quantum firms as defined previously.

Figure 5.1.1

Location of quantum investors: 2016-2024



Notes: The figure shows the top eight investing countries in the core firms in the overall sample.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 5.1.2

Total quantum investment flows by investing and receiving country: 2016-2024

Investing country	Receiving country							
	AU	CA	CN	DE	FR	GB	NL	US
AU	306							1 018
CA	3	457	0	0	0	1		60
CN	2	0	739					50
DE	0	16	0	433	10	16	21	38
FR	7	7		5	347	9	7	15
GB	4	45	0	4	3	658		338
NL		7		6	1	18	838	5
US	83	687	31	34	22	141	1	7 859

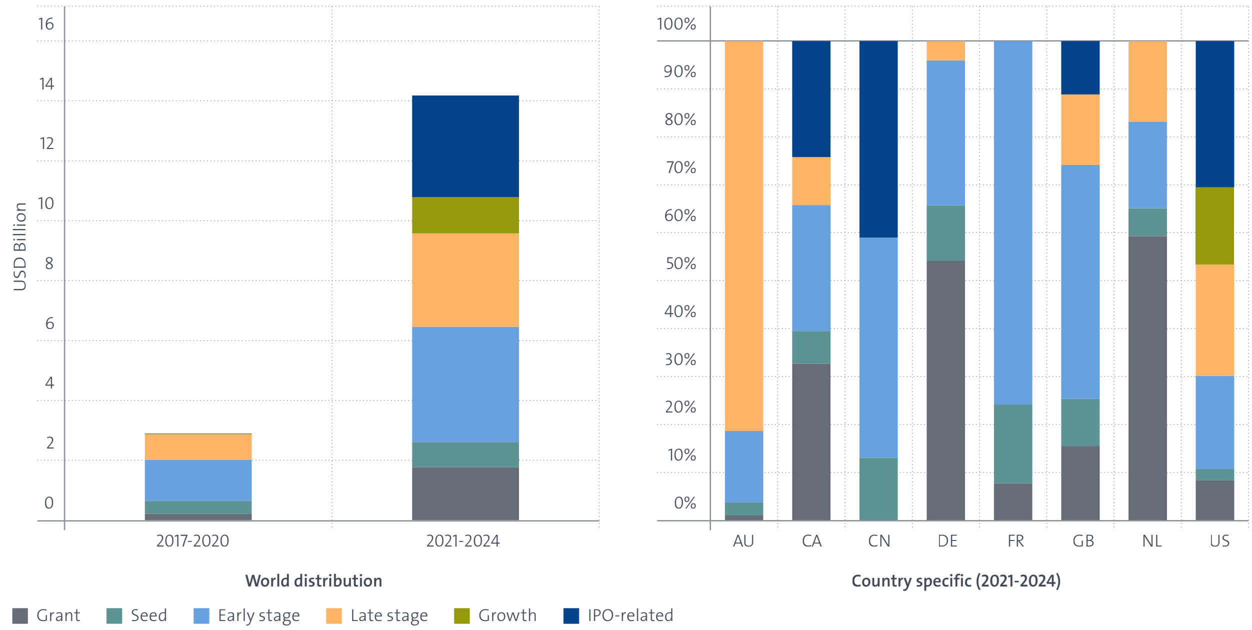
Notes: The figure shows the top eight investing countries in the core firms in the overall sample. The total amount of investment portrayed is USD 14.35 billion, namely 81% of total investment in quantum firms in the period 2016-2024 for which investor information is available.

0 | 2 000 | 4 000 | 6 000 | 8 000

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 5.1.3

Total quantum investment by country and type: 2017-2020 and 2021-2024



Notes: The left-hand panel shows the overall amount invested globally by type of investment. The right-hand panel shows the top eight investing countries in the core firms in the overall sample. The figure does not include deals with undisclosed or unknown amounts, unknown or undisclosed types or residual categories, namely spinout, alternative debt and other. The amount invested for each investment is split equally among investors.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 5.1.2 provides a breakdown of investment in core firms by investing and recipient country. US-to-US investment represents by far the biggest flow, in line with the previous evidence above showing US leadership both as a recipient and a provider of funding in the quantum ecosystem. In general, within-country investments (shown on the diagonal) are much higher than cross-country investments. The only exception to this pattern is Australian investment in US companies (linked to Psiquantum).[31] US-based quantum firms are the recipients of significant sums from UK-based investors. US investors are also considerably active in Canada (where they surpass domestic investors), and to a lesser extent in the United Kingdom.

Figure 5.1.3 breaks down investment in quantum companies by type of investment and funding stage. The categories included are grant, seed, early-stage, late-stage, growth and IPO (see Annex A.3 for additional information). The left-hand panel shows that globally, quantum investment increased considerably between 2017-2020 and 2021-2024. The pattern holds true across all major investing countries, suggesting that investor confidence in quantum technologies is increasing. This rise is observed across the various investment categories, but later-stage forms of investment like growth and IPO have seen the largest increases. While a direct causal link is hard to establish, these shifts may nonetheless reflect a broader trend toward ecosystem maturity.

When looking at investment by both country and type between 2021 and 2024 (the right-hand panel), US-based investors (the leading investors in quantum companies, as shown in Figure 5.1.1) engage in a diversified mix of investments at all stages. The limited share of grant and seed stage investment compared to other countries suggests greater maturity in the US ecosystem. In most other countries a higher share of funding comes from early-stage forms of investments (including grant, seed and early-stage funding). In the period 2021-2024 early-stage shares above 50% are observed in all countries except the United States and Australia. Over that same period early-stage VC was the most prevalent type of investment in China, France and the United Kingdom.

31 The Australian Government directly invested USD 125 million in convertible notes in PsiQuantum's U.S. parent company, with around USD 180 million in loans provided to the Australian entity. the Queensland Government provided USD 25 million in convertible notes to the U.S. parent company, with approximately USD 180 million provided to the Australian entity.

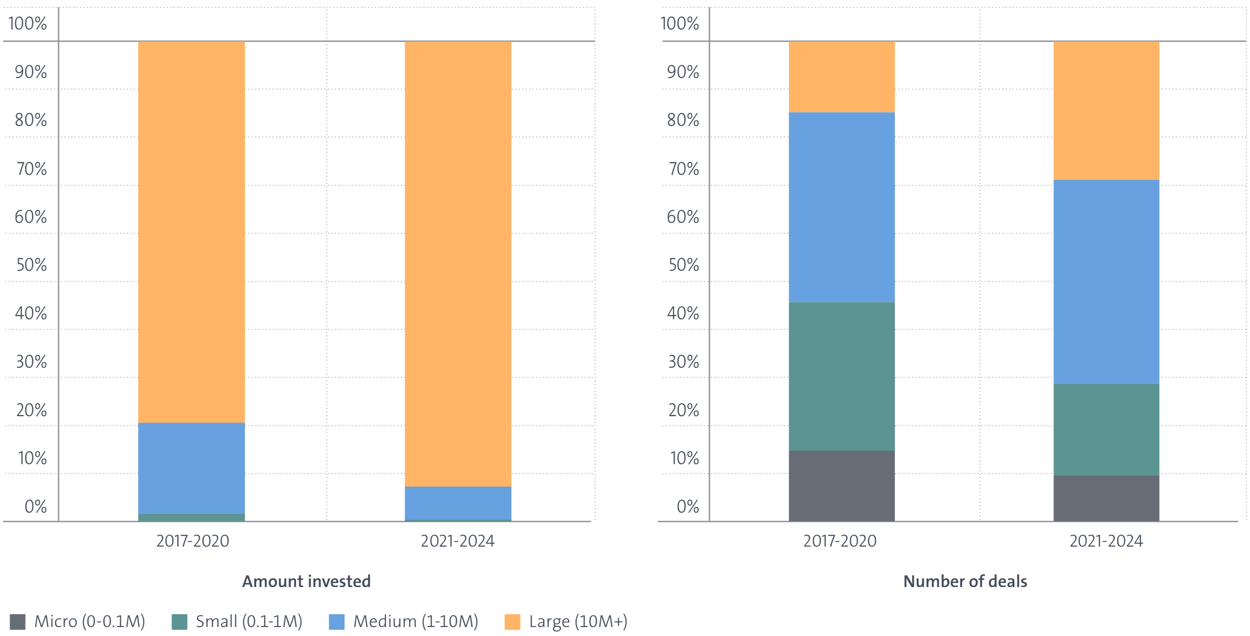
Grants play a significant role in Canada, Germany and the Netherlands, even if the relevance of IPO funding increased sharply thanks to the notable cases of Rigetti, IonQ and Arqit. In some countries, other types of investment play a very noticeable role: as hinted above, in the case of the United States this may be linked to the presence of many of the most mature companies in the quantum ecosystem, for which investment has moved beyond early-stage equity injections. The fact that early-stage investments provide the largest amount of resources to quantum firms does not imply that this is the most common form of investment: in fact, VC seed and grant investments are more common, accounting for around 29% and 25% of total deals respectively.

In terms of deal size, Figure 5.1.4 shows that, in the period 2021-2024 large deals (exceeding USD 10 million) represented most investment in quantum firms, although medium investments (in the USD 1-10 million) range also play a relevant role in most of the countries taken into consideration. Large investments are growing in importance compared to medium ones, as larger shares of resources are being allocated via very large investments. Smaller types of investment, either in the micro (USD 0-100 000) or small (USD 100 000 to 1 million) ranges, represent a minor share of the total resources accruing to the quantum ecosystem despite constituting a sizeable portion of the number of deals (close to 40% in 2017-2020 and 30% in 2021-2024, as can be seen in the right-hand panel). The right-hand panel also highlights how the share of these types of deals decreased between the two periods in absolute numbers.

Some countries appear to host investors more willing to commit substantial resources to quantum companies: Australia, China and the US, in the period 2021-2024, have a notably higher share of very large investments going into quantum companies, possibly signalling the more mature state of their national ecosystems; or maybe they are targeting more established companies. Large investments accounted for close to 97% of all investments in the US, more than the other countries under analysis. European countries, by contrast, participated in fewer deals above USD 10 million, but this share increased from the period 2017-2020, hinting at the growing maturity of these countries' quantum ecosystems. The right-hand panel shows that in terms of number of deals rather than total amount invested, smaller rounds are much more common, even in a country like the United States, where the overwhelming number of resources is provided via large deals. Larger deals remain widespread, however, suggesting that the quantum industry requires sizeable resources.

Figure 5.1.4

Amount and number of investments in quantum firms by size: 2017-2020 and 2021-2024

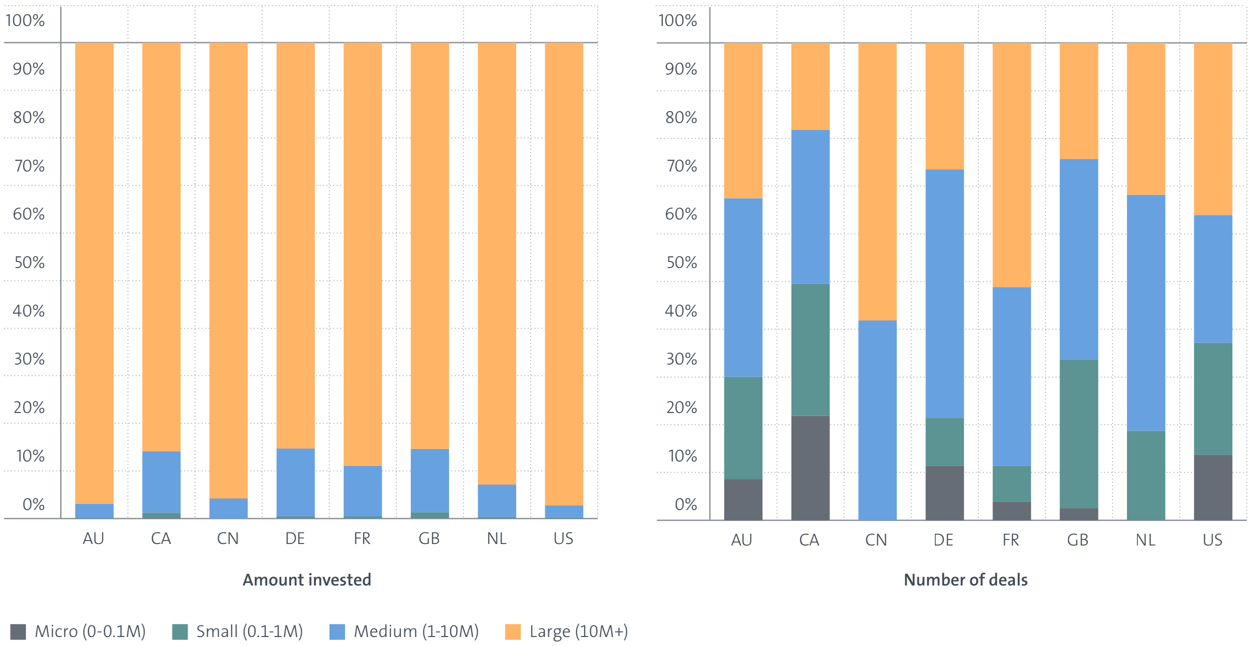


Notes: The figure refers to amount invested at the deal level, and to the number of deals.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 5.1.5

Total quantum investment by country and size: 2021-2024



Notes: The figure shows the top eight investing countries in the core firms in the overall sample. The amount invested for each investment is split equally among investors. The figure refers to the amount invested at the deal level, and to the number of deals, split among investors using fractional counts.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

5.2 Corporate investment in the quantum ecosystem: CVC and M&A

Quantum technologies have the potential to reshape technologies that are critical for a wide array of industries. This might provide an incentive for many firms to explore applications from quantum technologies and ensure that they will later be able to reap the benefits of enhanced computing power, more precise calculations and quicker, more secure communication. The breadth of these improvements implies that companies across a variety of fields beyond the ICT industry may have an interest in investing in the quantum ecosystem.

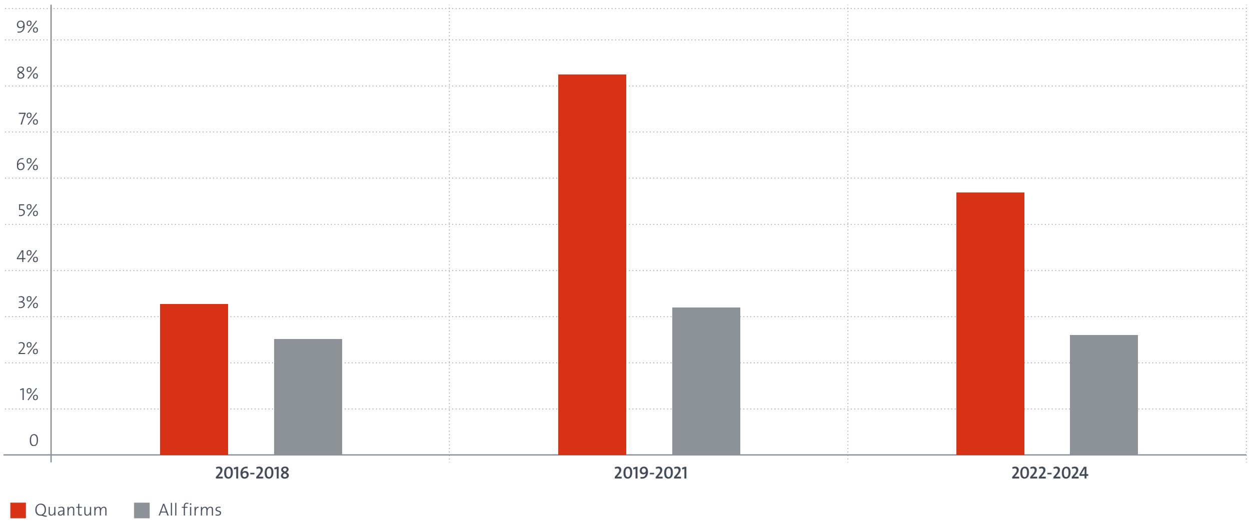
To study this phenomenon, two types of data are used: corporate venture capital (CVC) investment and merger and acquisitions (M&A). CVC investment can be used by established companies to improve their understanding of quantum technologies by accessing information held by quantum firms and can be a first step towards an acquisition (Dushnitsky & Lenox, 2006).

Figure 5.2.1 shows the trend in CVC over time as a proportion over total investment in quantum companies. As a point of comparison, the figure also displays the share of CVC in all investments in startups across all sectors as recorded in Crunchbase. The share of CVC in quantum investment is significant, reaching as high as 8% on average in the period 2019-2021. This is more than double the share of CVC in all investment in the periods 2019-2021 and 2022-2024 periods. This high share of CVC investment in quantum is in line with the transformative potential of quantum technologies for several industries; investment is primarily directed towards two of the three quantum technology areas (computing and communication); there is virtually no CVC investment in sensing and metrology.[32]

32 This is based on the subsample of core firms for which quantum patents are recorded. As noted in Section 4, sensing and metrology firms represent a minority of this sample.

Figure 5.2.1

Share of CVC in quantum investment compared with share of CVC in overall investment: 2016-2024



Notes: The figure includes data on investors classified as corporate VCs (these can also include other labels in their classification), namely tagged as “corporate venture capital” in CB and “corporate venture fund” in DR.

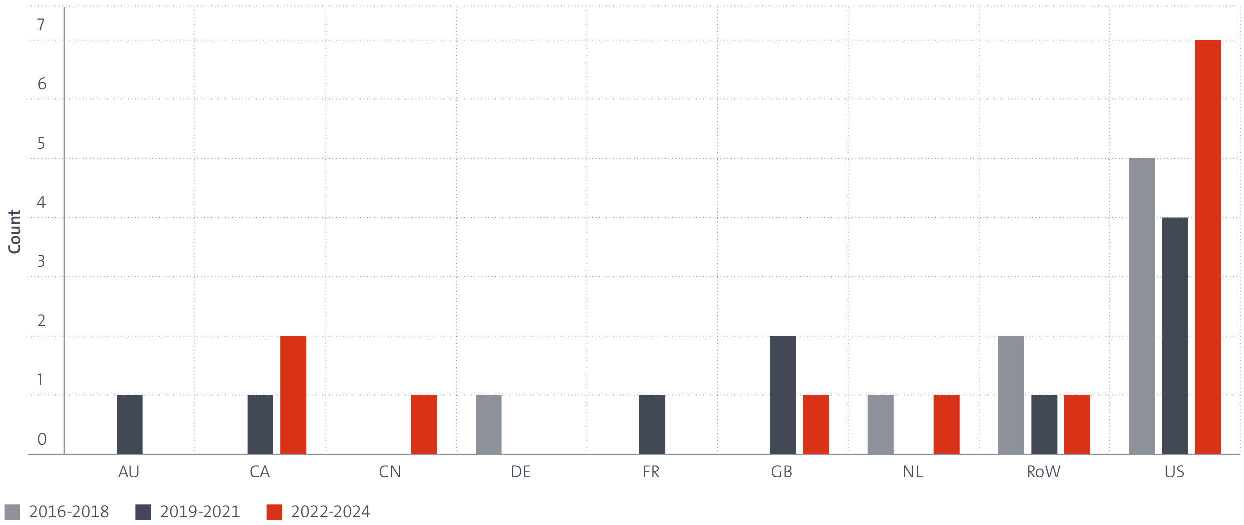
Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Figure 5.2.2 shows the number of acquisitions within the quantum ecosystem over time broken down by country where the acquired firm is located. While acquisitions are not numerous in absolute terms, they account for a significant share of the core sample, with approximately 5% of the companies having undergone an acquisition.

Most M&A activity in the quantum ecosystem concerned US-based companies (around 9% of all US core firms were targeted). Firms from other countries were also the target of M&A activity, but such cases are considerably less common, Canada being the only other country emerging from this picture.

Figure 5.2.2

Total M&A activity by country of acquired firm: 2016-2024



Notes: The figure shows the number of deals (32), which is equal to the number of companies. M&A deals are identified in the OECD/STI Startup database but were integrated with data from Orbis M&A used in previous OECD work (Berger, Calligaris, Greppi, & Kirpichev, 2025).

Source: OECD calculations based on OECD, STI Micro-data Lab, and Orbis M&A, Bureau van Dijk, October 2025..

Figure 5.2.3

Total M&A activity by country of acquiring and acquired firms: 2016-2024

Acquired country \ Acquiring country	AU	CA	CN	DE	FR	GB	NL	US	RoW
AU	1								
CA								3	
CN		1							
DE								1	
FR					1				
GB		1						2	
NL					1				1
US								12	4
RoW		1		1					2

Notes: The figure shows the number of deals (32), which is equal to the number of acquired companies. M&A deals are identified in the OECD/STI Startup database but were integrated with data from Orbis M&A used in previous OECD work (Berger, Calligaris, Greppi, & Kirpichev, 2025).

Colour scale: 0 3 6 9 12

Source: OECD calculations based on OECD, STI Micro-data Lab, and Orbis M&A, Bureau van Dijk, October 2025.

Figure 5.2.3 further breaks down M&A by acquiring and acquired country of the companies involved. 38% of M&A deals concern US-based companies acquiring other US-based firms. More generally, US companies appear to be the most active in M&A, including acquisitions by US companies of Canadian and United Kingdom-based firms, while companies from other countries (Finland, Korea and Sweden) also targeted US companies. Overall, 17 cross-border deals were recorded.

5.3 What role for direct public support?

Two factors can justify potential interest by governments in directly supporting the quantum ecosystem. First, quantum technologies generate significant externalities for numerous downstream industries, including chemicals, telecommunications and defence. Second, the long development timelines and high risks associated with largely unproven technologies can reduce incentives for private investors, leading to investment levels below what would be socially optimal. Both of these factors have been identified as key rationales for implementing active industrial policies (Criscuolo, Gonne, Kitazawa, & Lalanne, 2022) and may incentivise government to invest in this area (Berger, Dechezleprêtre, & Fadic, 2024).

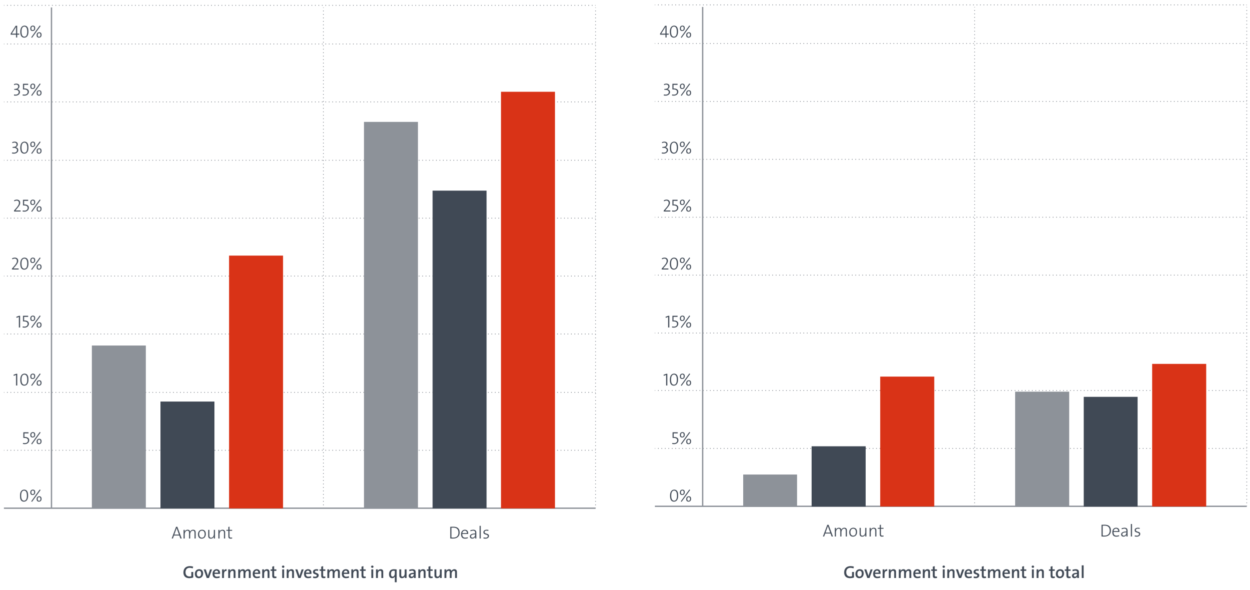
Figure 5.3.1 shows government investment in the quantum ecosystem as a share of total investment and of deals. The share of deals with government involvement is very high, between 25% and 35% across periods, suggesting the ecosystem is at an early stage where profitability alone may not justify private investment. This also suggests that the average size of government-backed deals is smaller than that of private investment.

The share of government funding is also higher for the quantum sector than for startups in general, indicating particularly high government involvement in this industry compared to others.

The share of government funding has increased over time, reaching over 20% in recent years, although this was mostly driven by 2024, when government investment represented around 40% of all quantum investment, because of the Australian and Queensland governments' investments in Psiquantum for a cumulative total of more than USD 700 million and the Dutch government's investment of close to USD 300 million in Quantum Delta. One might expect private investment to gain in importance as the quantum ecosystem matures. The persistence of a high public share may indicate limited progress in developing

Figure 5.3.1

Government quantum and general investment by share of invested amounts and deals: 2016-2024



Notes: Government investment is defined based on the type of investor (using tags available in both CB and DR), integrated with manual identification of government venture capital specifically (Berger, Criscuolo, & Dechezleprêtre, 2025). Overall, 183 government investors are identified out of 2 114 quantum investors. The percentage of deals refers to the share of deals where at least one investor is tagged as government. Some deals have both private and government investors.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

quantum technology in some countries, or it could reflect that private investment is being diverted towards more mature or high-profile sectors, such as artificial intelligence.

Figure 5.3.2 breaks down total investment in quantum firms into government and private investment across countries. The left panel shows significant cross-country differences and a widespread increase in government support between 2017-2020 and 2021-2024 visible for all countries sampled.

Government involvement in quantum investment has been highest in Australia and the Netherlands, with over 70% of quantum investment in the period 2021-2024. Australia, Germany and the Netherlands saw the largest increases in government funding over the two periods. By comparison, France, Germany and the United Kingdom have lower shares of government funding, even though all three countries increased the government support.

The right panel focuses on investment levels rather than shares of total country investment, confirming the insights discussed above. It also highlights the substantial scale of US government investment, which (although relatively small as a percentage) is significant in absolute terms. Unsurprisingly, Australia and the Netherlands follow as the other countries with the largest total government investments over the period 2021-2024.

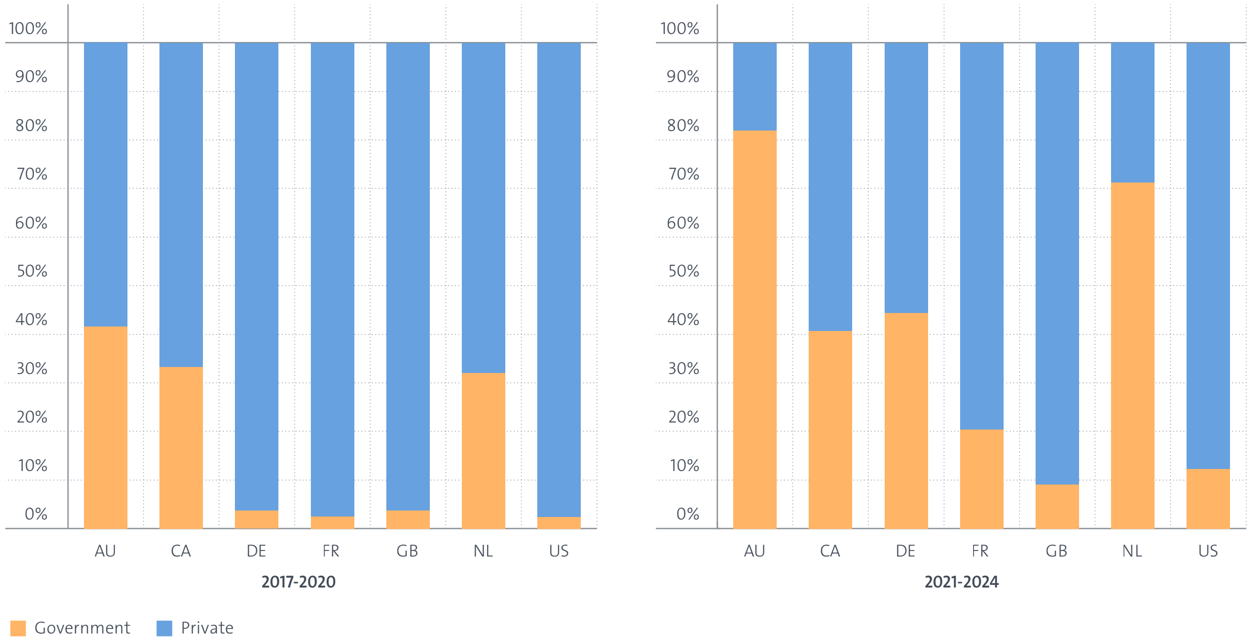
5.4 Conclusions

Investment in the quantum ecosystem has expanded significantly, driven by both private and public actors. The United States leads in both the volume and diversity of investments, while other countries are increasing their participation. The increasing number of large investment rounds reflect the sector's maturation, while the sizeable role of corporate venture capital points to its potential wide implications for established players. Nevertheless, government support remains crucial: given the high risks and long development timelines of quantum technologies, this may not come as a surprise. Supporting the transition from research to commercial applications will be essential for the continued development of the quantum industry.

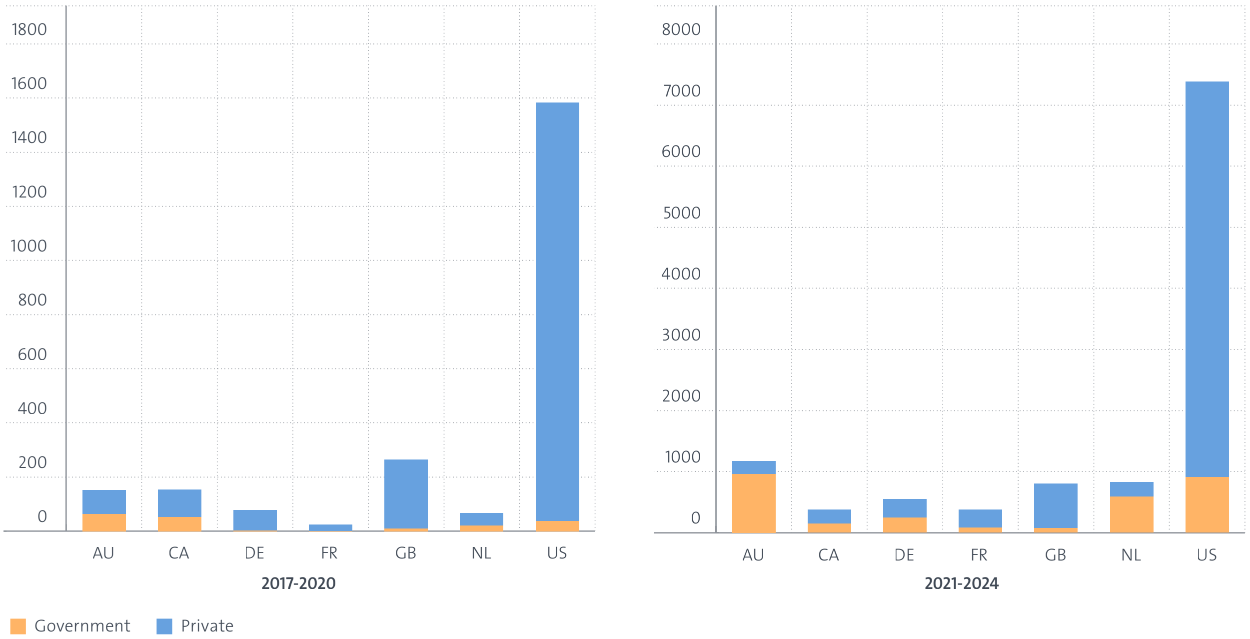
Figure 5.3.2

Government quantum investment by share of invested amounts and total investment, by country: 2017-2024

PANEL A – Investment shares



PANEL B – Investment amounts



Notes: Government investment is defined based on the type of investor (using tags available in both CB and DR), integrated with manual identification of government venture capital specifically (Berger, Criscuolo, & Dechezleprêtre, 2025). Overall, 183 government investors are identified out over 2 114 quantum investors.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

6. Mapping skill needs in the quantum ecosystem: evidence from online job vacancies in Canada, the United Kingdom and the United States

Mapping skill needs for the quantum industry is essential as the field transitions from a primarily research-driven domain to one of industrial relevance. Section 2 highlighted the early stage of the industrial ecosystem, and the need for quantum technologies to converge on dominant designs on which commercial applications can be more easily built. Section 3 points out that quantum patents rely heavily on science, as indicated by the high percentage of citations to non-patent prior art. Section 4 pointed out the remarkable scientific expertise of quantum company founders, characterised by a high proportion of PhDs. However, founders alone cannot possess all the skills needed to help quantum firms evolve into profitable businesses. This has created a growing gap between the demand for and supply of talent, highlighting the need for a well-prepared quantum workforce with specialised qualifications (Greinert, Ubben, Dogan, Hilfert-Rüppell, & Müller, 2024).[33] At the same time, it underscores the importance of integrating professionals with business backgrounds capable of supporting the development of commercial applications. Understanding emerging skill trends can help identify critical capabilities and roles, and guide education, training and workforce strategies. Such insights can enable firms, governments and academia to support the development of expertise required to advance quantum hardware, software and applications. Without this understanding, innovation and market growth could risk facing significant bottlenecks.

The objective of this section is to map the demand for quantum-related jobs and skills using job posting data for three selected countries from Lightcast, providing a data-driven perspective on the sector's labour market dynamics.[34] By analysing the skills and roles firms seek, the section complements the broader description of the industrial quantum ecosystem presented in Section 4, revealing competencies central to the quantum technology development discussed in Section 2 and how they are applied across different types of firms. This section covers Canada, the United Kingdom and the United States, which together account for half of the core quantum firms included in the analysis. The data span from January 2021 to July 2025 and capture job vacancies posted online during this period, reflecting positions advertised rather than the existing workforce stock. Details on the data construction and processing methodology are provided in Annex A.5.

To explore the quantum labour market from multiple angles, online job postings are analysed according to three different search strategies and fall into different groups. The first includes all vacancies from any employer that mention **quantum skills,** often posted by large firms with R&D projects or corporate ventures exploring quantum applications as part of broader innovation strategies. The list of quantum-related skills used to extract relevant job postings was developed based on keyword searches and is available in Annex A.6.

The second group includes all vacancies from any employer that mention **quantum-enabling skills,** such as photonics and cryogenics, but explicitly excluding quantum-specific skills from the first group. While not exclusively focused on quantum, these skills support quantum development and have broader applications for fields like optical technologies, biotechnology and advanced materials. They form a talent pool that can transition into quantum-focused roles. Considering these skills in the analysis makes it possible to distinguish between quantum-specific skills and the broader set of technologies that sustain them. The list of quantum-enabling skills is presented in Annex A.7.

The third group includes all vacancies from **core quantum firms** as identified in Section 4, where the core business activity relates to the development of quantum and enabling technologies, and which are located in Canada, the United Kingdom and the United States. Job postings are matched to the corresponding firms using Lightcast data applying name-matching algorithms based on Squicciarini and Dernis (2013) and followed by extensive

33 Data on the supply of skills are not available for the current analysis, but would represent a natural extension of this research. For example, one could examine indicators like the number of graduates in quantum-relevant fields, such as physics and computer science as a proxy for the supply of quantum-relevant skills, and then compare these findings with the demand data presented in this chapter.

34 Lightcast collects online vacancy data (e.g. employer name, location, occupation, industry, skills, education and experience levels) by web-scraping over 40 000 distinct job boards and company websites in many English-speaking and European countries. The methodology of Lightcast data collection is available at: kb.lightcast.io/en/collections/3904183-data-methodology.

manual revision, with the sequential steps involved provided in Figure A5.1 in Annex A.5. Although the groups are conceptually distinct, some core quantum firms also operate in enabling domains such as photonics. These are nevertheless classified as core quantum because of their direct contribution to quantum technology developments. This group provides insights into the skills demanded by firms operating at the technological frontier.

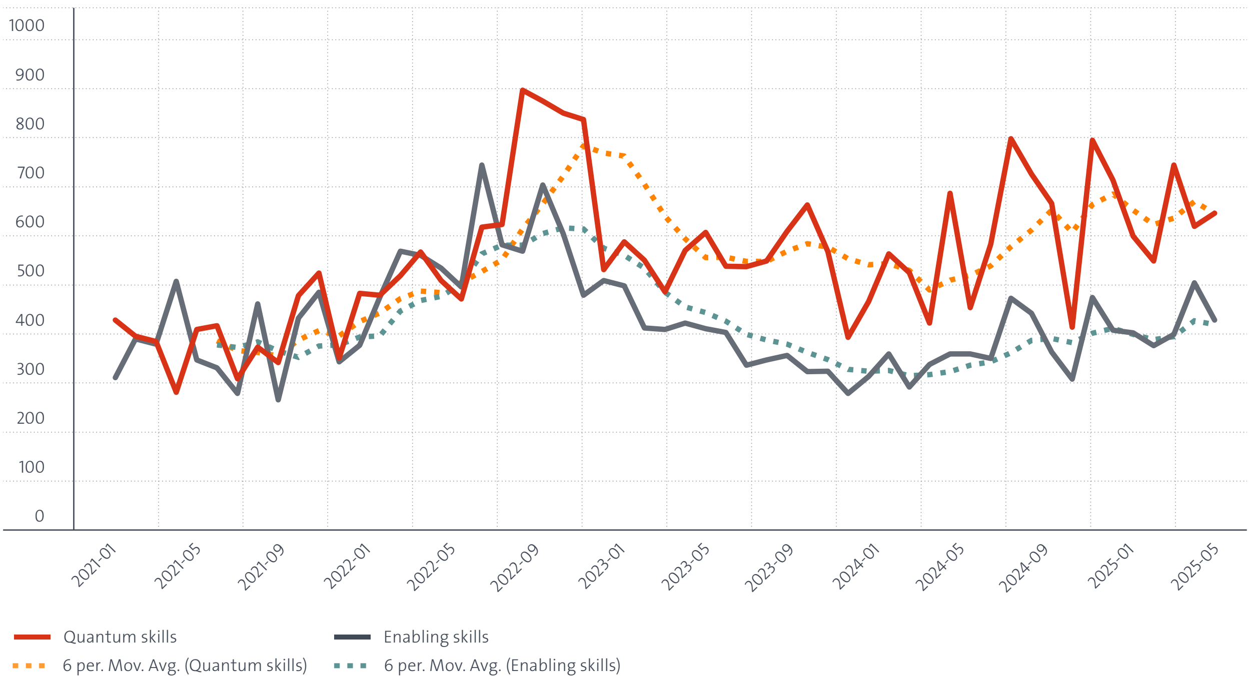
6.1 Trends in quantum-related online job postings in the three selected countries

Job postings requiring quantum skills in Canada, the United Kingdom and the United States increased steadily through 2021 and 2022, peaking toward late 2022 before declining in 2023 (similarly to the 2023 decline observed in Section 4 regarding core quantum firms' entry) and stabilising since (Figure 6.1.1). A similar trajectory is observed for postings requiring quantum-enabling skills, which rose from around 300 in early 2021 to a high of 744 in mid-2022 before declining thereafter. The majority of the observed increase through 2022 was driven by the United States (Figure A8.1 in Annex A.8). Since mid-2023 both series have remained relatively stable, averaging around 620 monthly postings for quantum-related skills and 400 for quantum-enabling skills. This pattern may suggest that, following an expansion phase and subsequent adjustment, demand for quantum talent has entered a period of consolidation. Most demand originates from firms where quantum technologies represent a side activity rather than the core business, particularly large firms such as Pacific Northwest National Laboratory (PNNL, one of the United States Department of Energy's national laboratories), Blue Origin and IBM.

Figure 6.1.1

Quantum-related and enabling skill-related job postings peaked in late 2022

Number of job postings per month, January 2021-July 2025, with 6-month moving average included



Notes: Online job postings data for January 2021 to July 2025. The dashed lines correspond to six-month moving averages. Trends reflect the share of quantum-related postings within the subset of job postings matching the defined quantum and enabling skill criteria. The list of quantum-related skills is in Annex A.6, and the list of quantum-enabling skills is in Annex A.7.

Source: OECD calculations based on Lightcast, October 2025.

6.1.1 Occupational composition of quantum-related job postings

The composition shows that quantum-related online job postings are concentrated in a small number of occupations. As Figure 6.1.2 shows, information technology and computer science occupations accounted for about a third of quantum vacancies in 2021 (31%), before declining to a quarter by 2024 (26%). Science and research represented more than a quarter of vacancies in 2021 (26%) and 2024 (25%). Education and training represent around 10% of occupations, confirming the importance of academia in supporting the development of quantum technologies, as noted in Section 4. Engineering increased slightly from 9% to 10%. Finance, which was highlighted in Section 4 as one of the main industries with quantum application in the ecosystem, grew from 4% to 5%, illustrating a gradual broadening of demand beyond core scientific positions to include those such as financial quantitative analysts and risk managers (Figure A8.2 in Annex A.8).

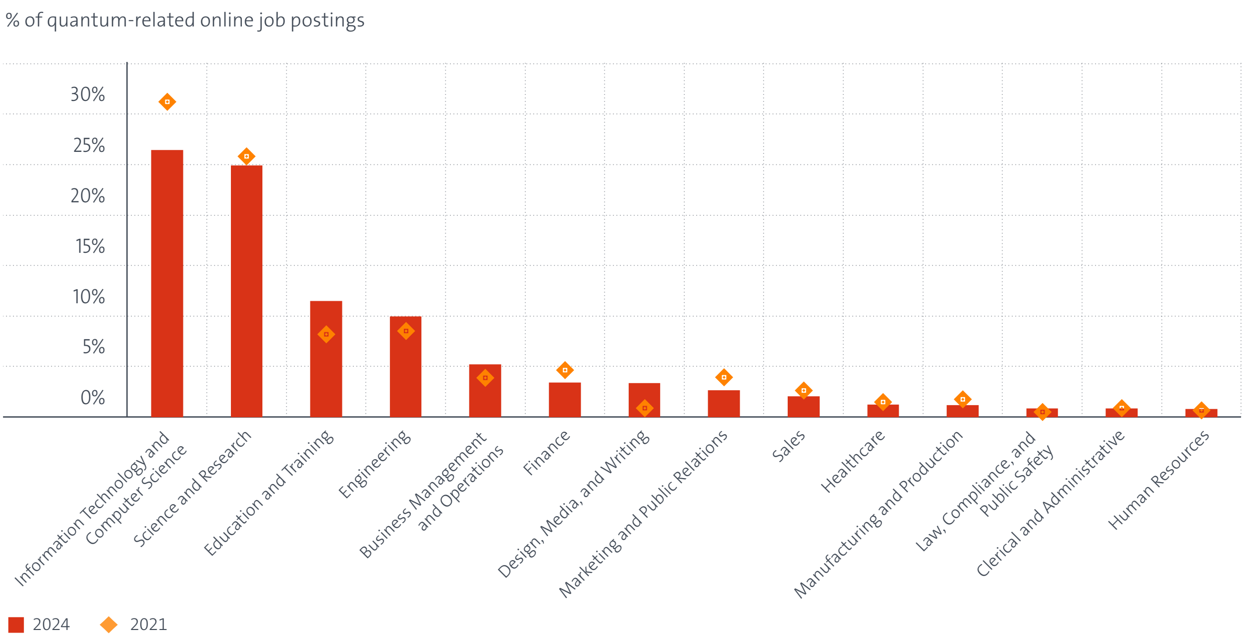
Other occupations represent a relatively small proportion of quantum-related vacancies. Business management, marketing and sales together accounted for less than 10% of online job postings requiring quantum-related skills in both 2021 and 2024, while manufacturing, healthcare and law remained below 2%. This may indicate that demand for quantum talent continues to be concentrated in technical and research-oriented roles. Annex A.8 provides a more detailed view of the occupational patterns, with Figure A8.2 showing data at the occupation level and Figure A8.3 at the job title level.

6.1.2 Overview of skill patterns

Firms demanding quantum-related skills require advanced technical expertise with broader competencies, supporting the integration and application of quantum knowledge across diverse industries. Quantum job postings show a strong emphasis on both core quantum skills and technical foundations for applying quantum knowledge. Research remains the skill most in demand, appearing in 72% of job postings in 2021-2022 and rising to 78% in 2023-2024 (Figure 6.1.3). Quantum computing and physics follow closely, with quantum computing increasing from 58% to 65% and physics from 48% to 56%, reflecting the technical foundation required for firms integrating quantum technologies.

Figure 6.1.2

Demand for quantum skills is concentrated in very few occupational categories



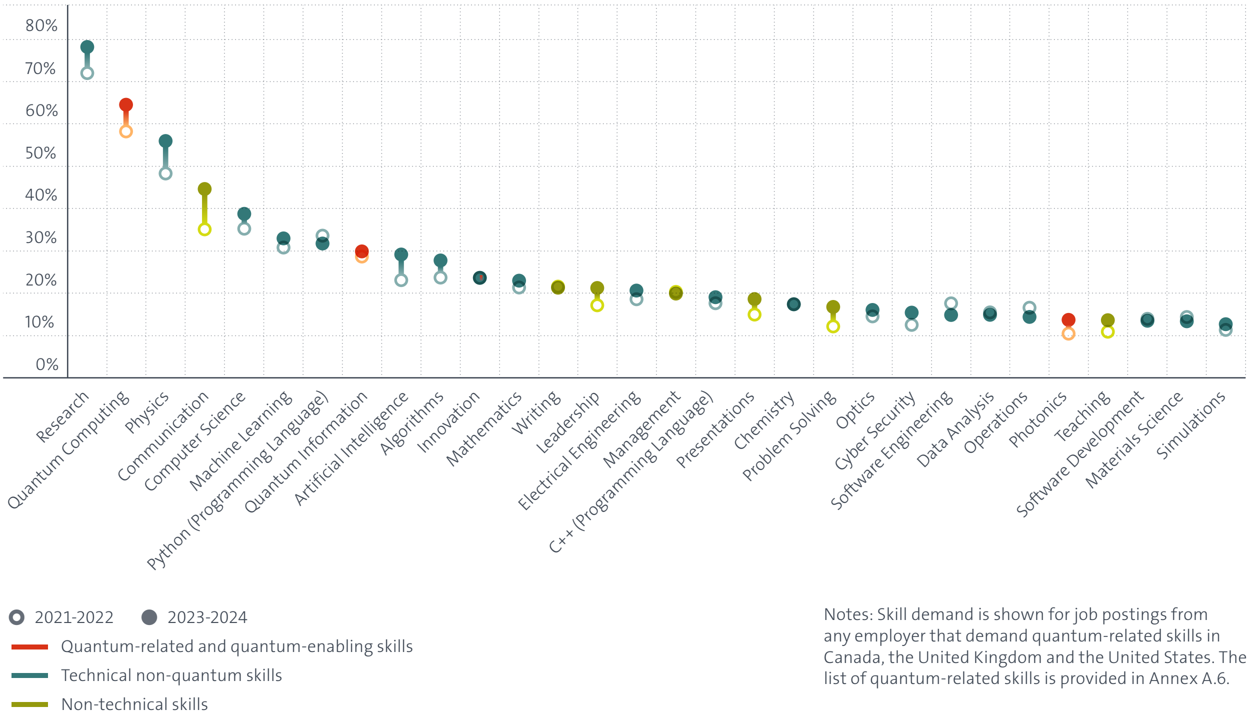
Notes: The figure uses the Lightcast Occupation Taxonomy (LOT) at the career area level, the most aggregated level of the taxonomy. The occupational composition is presented for job postings from any employer that demands quantum-related skills in Canada, the United Kingdom and the United States. The list of quantum-related skills is provided in Annex A.6. The more detailed level (specialised occupation) is available in Figure A8.2 in Annex A.8.

Source: OECD calculations based on Lightcast, October 2025.

Figure 6.1.3

Quantum skills span core scientific and technical areas

% of quantum-related online job postings that require each skill, by period



Notes: Skill demand is shown for job postings from any employer that demand quantum-related skills in Canada, the United Kingdom and the United States. The list of quantum-related skills is provided in Annex A.6.

Source: OECD calculations based on Lightcast, October 2025.

Programming languages and computer science skills also remain prominent, with Python mentioned in roughly one-third of quantum-related online job postings in 2021-2024, while expertise in computer science grew from 32% to 39%, reflecting increasing demand. Other specialised technical skills such as machine learning (31% to 33%), and quantum information (29% to 30%) highlight the computational and analytical expertise sought by these firms. Algorithms and artificial intelligence have seen a large increase over time, from 24% to 28% and 23% to 29% respectively, while mathematics and electrical engineering grew more moderately.

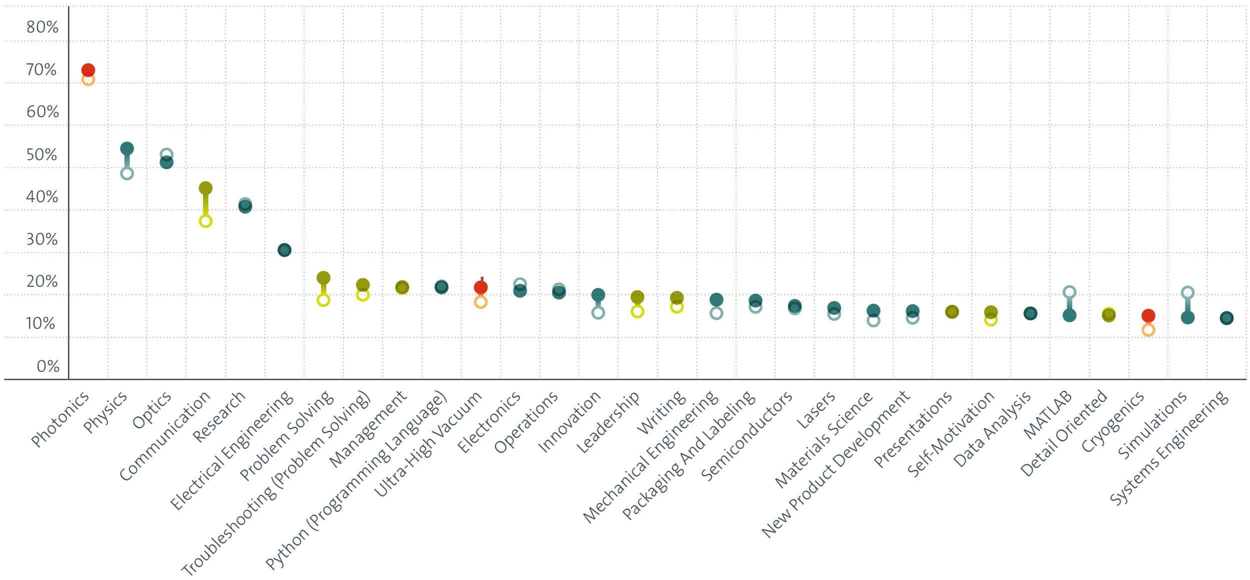
Socio-emotional and functional skills remain consistently relevant. Communication increased from 35% to 45% and leadership from 17% to 21%, while writing and management remained stable at 21% and 20% respectively. These patterns highlight that organisational and coordination capabilities continue to complement technical expertise in quantum-oriented positions.

While quantum-oriented positions prioritise computational and analytical expertise, including Python, machine learning and quantum information, quantum-enabling job postings place greater emphasis on foundational technical support, such as photonics, optics and physics, which facilitate the practical implementation of quantum technologies. As Figure 6.1.4 shows, photonics is the most frequently mentioned skill, increasing slightly from 71% in 2021-2022 to 73% in 2023-2024, followed by physics (49% to 55%) and optics (53% to 52%). Socio-emotional and functional skills also play an important role, with communication growing from 37% to 45% and management remaining stable at 21%. Technical competencies such as electrical engineering (30% to 31%), troubleshooting (20% to 22%) and the programming language Python (22% in both periods) are also consistently sought. Other notable skills include ultra-high vacuum techniques (18% to 22%), which are essential for hardware development, innovation (16% to 20%), reflecting the experimental nature of the field, and laser technologies (15% to 16%), a key component of photonic systems.

Figure 6.1.4

Quantum-enabling skills range from technical to socio-emotional and functional skills

% of quantum-enabling online job postings that require each skill, by period



2021-2022 2023-2024

Quantum-related and quantum-enabling skills

Technical non-quantum skills

Non-technical skills

Notes: Skill demand is shown for job postings from any employer that demand quantum-enabling skills in Canada, the United Kingdom and the United States. The list of enabling skills is available in Annex A.7.

Source: OECD calculations based on Lightcast, October 2025.

6.1.3 Trends in quantum-related skills demand

As mentioned previously, two quantum-specific skills (quantum computing and quantum information) are among the most frequently cited overall in quantum-related job postings. However, by zooming in on quantum-specific skills only, it is possible to examine the trends more clearly (Figure 6.1.5). While these skills represent smaller shares overall, narrowing the analysis provides a more granular view of the technical competencies that underpin quantum-related roles. It sheds light on how demand has evolved from foundational theory to specialised applications and complements the earlier findings on the prominence of socio-emotional and functional skills.

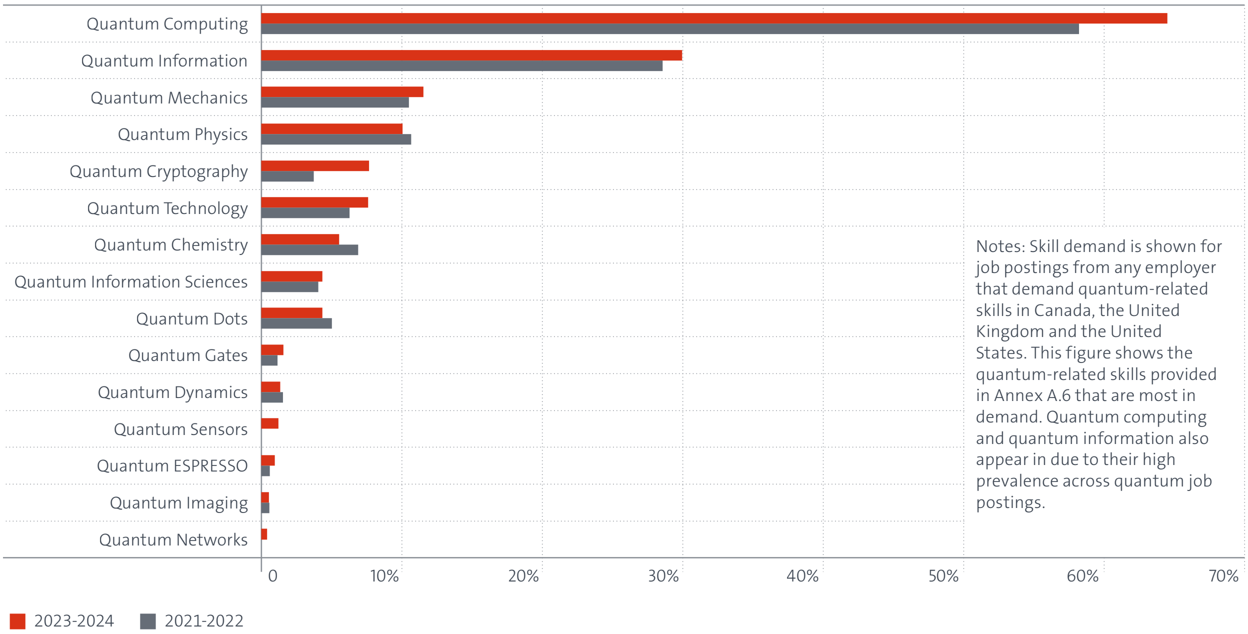
Beyond these core skills, foundational theoretical competencies such as quantum mechanics (11% to 12%) and quantum physics (11% to 10%) show stable demand. Quantum cryptography, which uses principles of quantum mechanics to enable secure communication, doubled from 4% to 8%, quantum technology increased from 6% to 8% and other relevant skills, such as quantum chemistry, quantum information sciences and quantum dots, appear in more than 4% of quantum-related online job postings.

Several quantum skills were captured in Lightcast for the first time in 2025. These include quantum walks (analogous to classical random walks), Silq programming (a high-level programming language for quantum computing), Microsoft Azure Quantum (a cloud-based platform providing access to quantum hardware and software), neutral atom quantum computing (an approach using arrays of neutral atoms manipulated by lasers) and various specialised quantum computing platforms, reflecting the adoption of cutting-edge tools and methods.

Figure 6.1.5

Quantum computing and information are the quantum skills most in demand

% of quantum-related online job postings that require each skill, by period



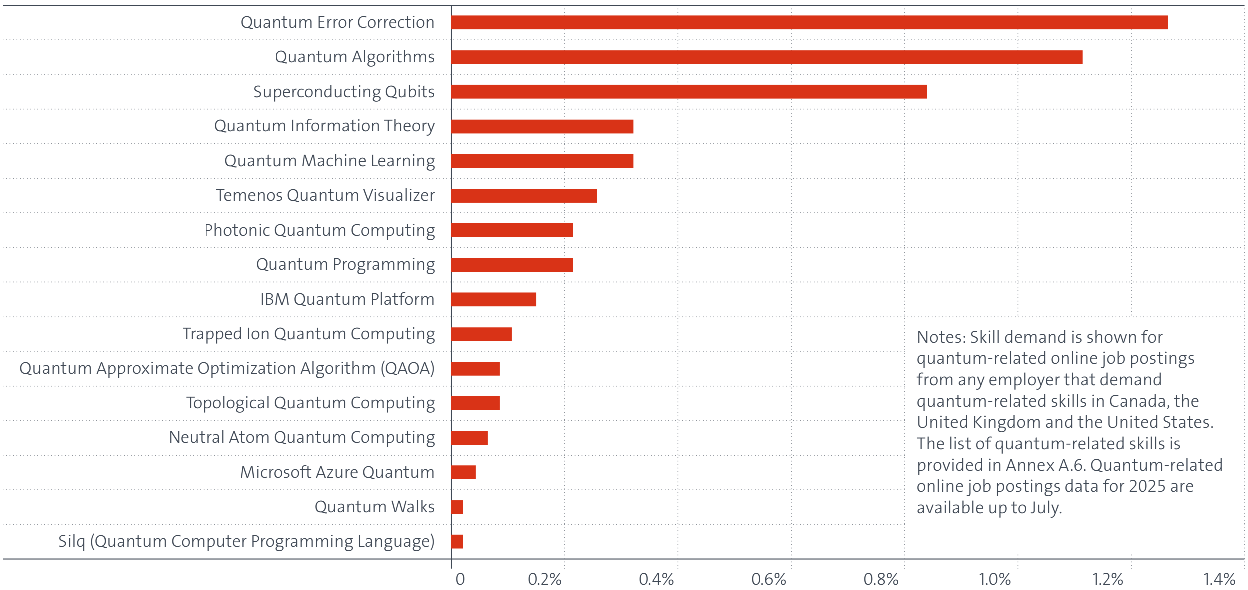
Notes: Skill demand is shown for job postings from any employer that demand quantum-related skills in Canada, the United Kingdom and the United States. This figure shows the quantum-related skills provided in Annex A.6 that are most in demand. Quantum computing and quantum information also appear in due to their high prevalence across quantum job postings.

Source: OECD calculations based on Lightcast, October 2025.

Figure 6.1.6

New quantum skills in 2025 job postings show emerging needs

% of quantum-related online job postings that require each skill



Notes: Skill demand is shown for quantum-related online job postings from any employer that demand quantum-related skills in Canada, the United Kingdom and the United States. The list of quantum-related skills is provided in Annex A.6. Quantum-related online job postings data for 2025 are available up to July.

Source: OECD calculations based on Lightcast, October 2025.

Skills related to quantum error correction, quantum algorithms and superconducting qubits (whose quantum states are controlled by electron charge using semiconductor materials) are particularly prominent, with 1.3%, 1.1% and 0.4% of quantum-related online job postings respectively (Figure 6.1.6). The inclusion of these high-value technical skills is significant. For instance, quantum error correction plays a central role in the realisation of functional quantum computing, acting as a cross-cutting and reliable skill with implications across software, hardware and systems engineering (Roffe, 2019). Other newly tracked skills include photonic quantum computing, quantum machine learning and quantum information theory, indicating that a broader range of quantum knowledge is now being monitored in labour demand.

6.1.4 Trends in quantum-enabling skills demand

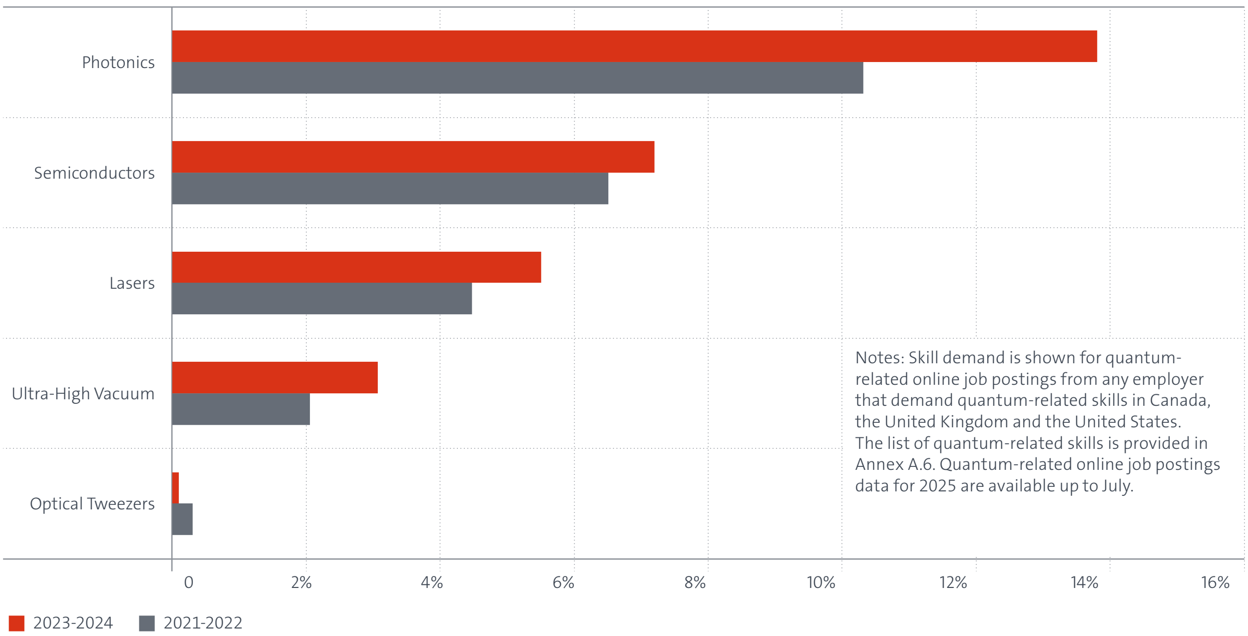
Understanding quantum-enabling skills is crucial for mapping the capabilities that support the rapidly evolving quantum industry. They too are showing steady growth and continue to play an important role in supporting quantum applications. Photonics remained the skill most in demand, increasing from 10% of total quantum-related online job postings in 2021-2022 to 14% in 2023-2024, reflecting its broad applicability across quantum and related technologies (Figure 6.1.7). Photonic quantum computing supports high-speed quantum operations using modular and networked architectures, paving the way for practical and efficient quantum processors (AbuGhanem, 2024). Semiconductors, which can be used to control quantum states, increased slightly to 7%, while lasers rose from 4% to 6%. Demand for ultra-high vacuum also increased from 2% to 3%, whereas optical tweezers (focused lasers that trap and manipulate atoms for quantum experiments) remained rare, appearing in less than 1% of quantum-related online job postings.

To better understand the computational capabilities sought by firms integrating quantum knowledge, the analysis also considers programming language requirements in quantum-related online job postings. Mentions of software skills show that quantum-specific frameworks such as Qiskit and Q# remain limited compared to general-purpose languages. Qiskit remained stable at 5% in both 2021-2022 and 2023-2024, while Q# grew from 0.48% to 0.99% over the same period (Figure 6.1.8). By contrast, widely used programming

Figure 6.1.7

Demand for photonics outpaces other quantum-enabling

% of quantum-related online job postings that require each enabling skill, by period



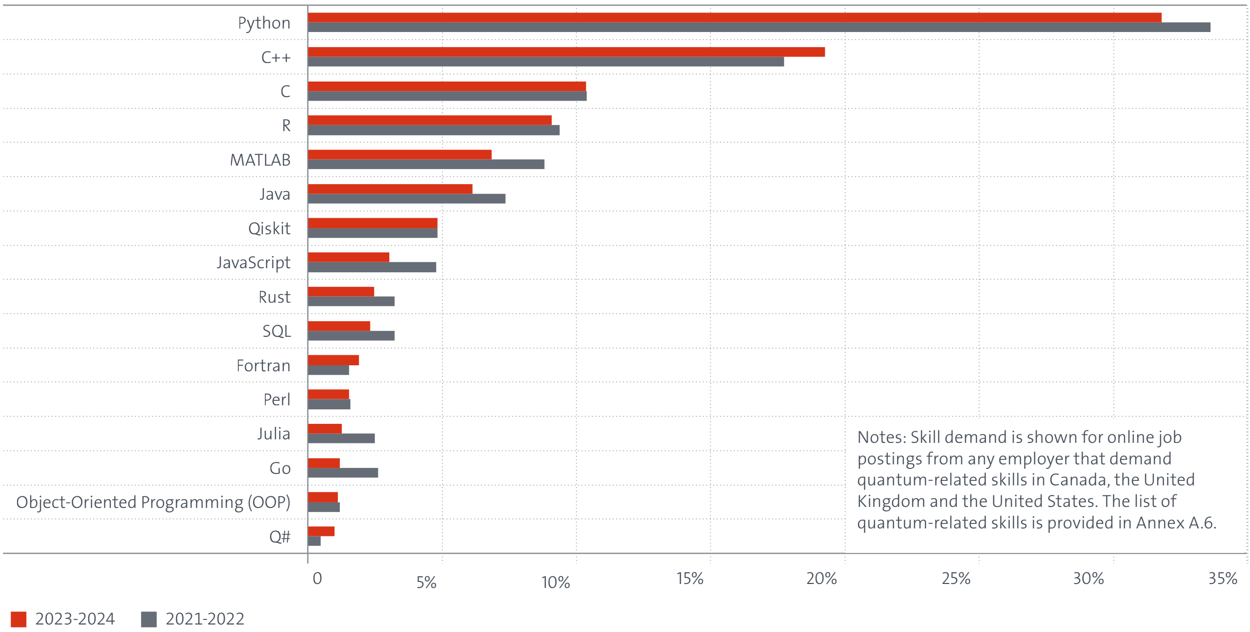
Notes: Skill demand is shown for quantum-related online job postings from any employer that demand quantum-related skills in Canada, the United Kingdom and the United States. The list of quantum-related skills is provided in Annex A.6. Quantum-related online job postings data for 2025 are available up to July.

Source: OECD calculations based on Lightcast, October 2025.

Figure 6.1.8

General programming skills remain central for quantum-specific applications

% of quantum-related online job postings that require each skill, by period



Source: OECD calculations based on Lightcast, October 2025..

languages such as Python (34% to 32%) and C++ (18% to 19%) continue to be more in demand, reflecting the ongoing reliance on general-purpose programming skills alongside emerging quantum tools. Other common languages include C (10%), R (9%) and MATLAB (9% to 7%), highlighting the diverse computational skill set required in applied quantum projects.

6.1.5 Skills required across education levels

The quantum talent ecosystem attracts candidates across a range of educational backgrounds. Among quantum-related online job postings analysed from the United States, 39% list a bachelor's degree as the minimum requirement, 29% require a PhD, 12% a master's degree, 3% an associate degree, 3% a high school diploma or GED and 13% do not specify any minimum educational requirement.

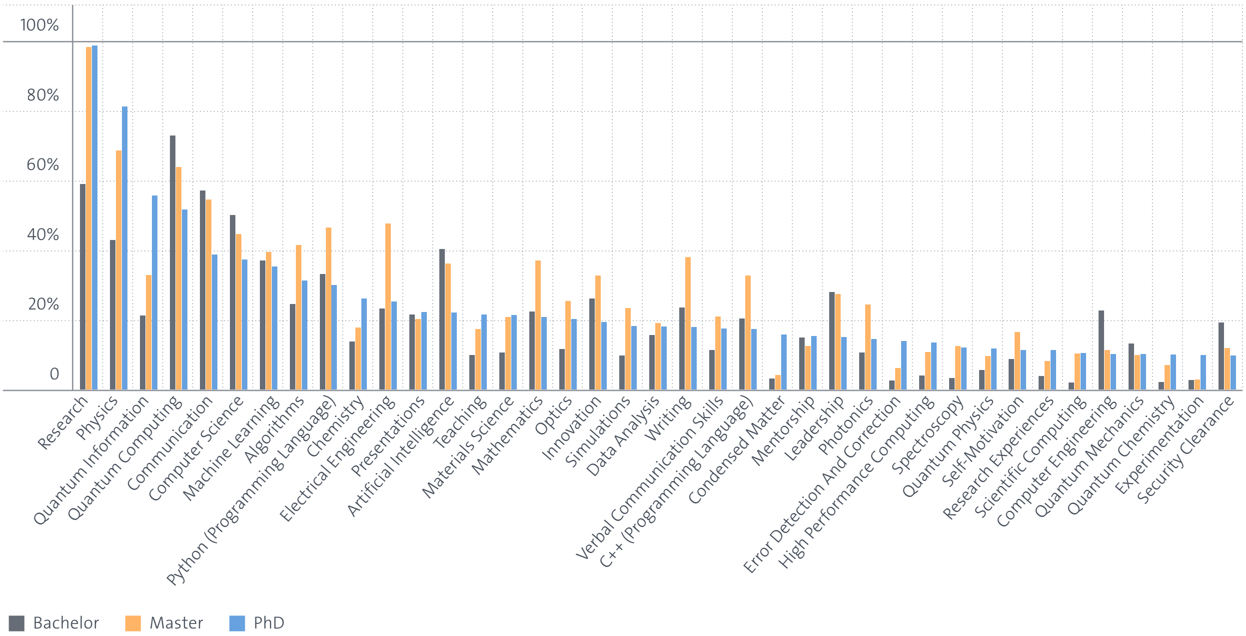
Differences in skill requirements by education level shed light on the structure of talent demand in the quantum ecosystem. The data show that postings requiring a PhD place a much stronger emphasis on research-oriented and theoretical skills such as physics (+39 percentage points compared to bachelor-level jobs), quantum information (+35 p.p.) and research (+40 p.p.), as Figure 6.1.9 shows. By contrast, master-level postings are more likely to request applied or engineering-related skills, including electrical engineering (+25 p.p.), applied physics (+15 p.p.), optics (+14 p.p.) and programming languages such as Python (+13 p.p.) and C++ (+12 p.p.). Bachelor-level positions more frequently refer to socio-emotional and functional skills such as communication (+18 p.p.), leadership (+13 p.p.) and security clearance (10 p.p.), all of which appear less often in quantum-related online job postings.

This composition reveals a clear segmentation in the quantum labour market, as PhD-level positions remain concentrated in research and theory development, while master-level roles link scientific knowledge to engineering applications (e.g. electrical engineering, +22 p.p. over PhDs), and bachelor-level jobs focus on operational, programming and coordination functions.

Figure 6.1.9

Education levels shape quantum skill demand

% of quantum-related online job postings that require each skill, educational segment: 2023-2024



Notes: Skill demand is presented for online job postings from any employer that demand quantum-related skills in the United States only. The list of quantum-related skills is provided in Annex A.6.

Source: OECD calculations based on Lightcast, October 2025.

6.2 Overview of skill demand by core quantum firms

Having characterised the broader demand for quantum and quantum-enabling skills, our analysis now turns to core quantum firms. These typically require a diverse combination of skills, reflecting the technical complexity and experimental nature of their operations. Examining the skill requirements of core quantum firms allows for a clearer understanding of the broader set of skills that support the development of quantum technologies, complementing the insights from job postings specifically requiring quantum-specific skills.

Of the 934 core quantum firms identified in section 4, 139 were successfully matched to Lightcast for the three countries analysed (Table 6.2.1). The table also shows that online vacancies requiring quantum-related skills were posted by 2 658 firms, whereas online vacancies requiring quantum-enabling skills were posted by 2 336. These figures suggest the quantum ecosystem extends well beyond the core set of firms focused primarily on quantum activities. Although core quantum firms remain central to technology development, the broader set of firms posting vacancies requiring quantum-related and quantum-enabling skills accounts for a much larger number of job postings over the period of this study, demonstrating that labour demand is being actively driven across the wider ecosystem.

Of the 139 core quantum firms identified in section 4 and successfully matched to Lightcast, 65% posted at least one vacancy online requiring a quantum-specific or a quantum-enabling skill. These firms account for 87% of all job postings in this group, highlighting that most hiring activity comes from firms engaging with quantum-related skills.

Table 6.2.1

Distribution of firms across quantum-related groups

	Job postings requiring quantum skills	Job postings requiring quantum-enabling skills	Core quantum firms
Number of firms*	2 658	2 336	139
Number of job postings	30 575	28 714	10 937

Notes: *The number of firms in quantum-related and quantum-enabling job postings should be considered a lower bound, as some company names in each group were not fully cleaned or matched by Lightcast (7% and 8%, respectively). By contrast, core quantum firms were thoroughly cleaned and verified during data construction. Job postings from core quantum firms include all online job postings from this group, whereas the quantum-specific and quantum-enabling groups include job postings explicitly listing quantum-specific or quantum-enabling skills, not all online job postings published by these firms.

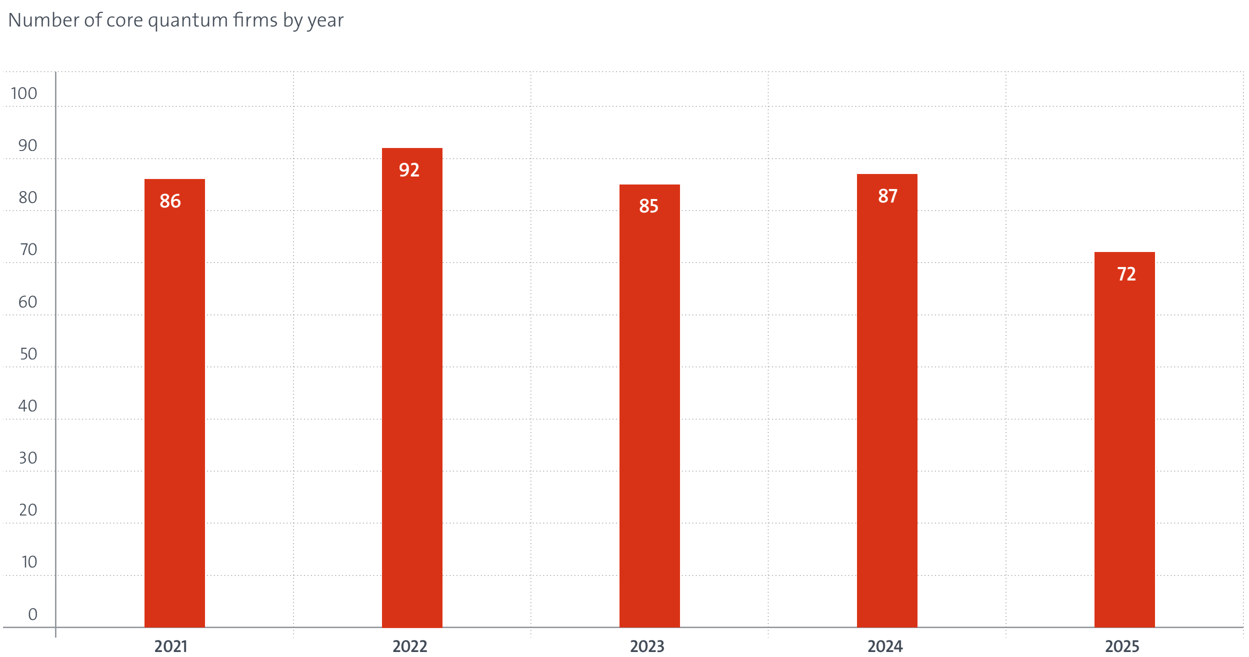
Source: OECD calculations based on Lightcast, October 2025.

Figure 6.2.1 presents the number of core quantum firms with at least one online job posting each year, based on Lightcast. The number of firms varies slightly over time, reflecting fluctuations in labour demand flows rather than firm entry or exit, with around 90 firms between 2021 and 2024, and 72 in the first seven months of 2025. Core quantum firms are concentrated in the United States (109), followed by the United Kingdom (54) and Canada (18).

Labour demand in core quantum firms highlights the evolving emphasis on quantum-related and enabling skills. In total these firms advertised 2 280 job postings in 2021, 2 937 in 2022 and 2 259 in 2024. Figure 6.2.2 shows that 8% of online vacancies posted by these firms required quantum skills in 2021, rising to 16% in 2024 and 29% in the first seven months of 2025. The share of online job postings requiring quantum-enabling skills rose from 6% in 2021 to 9% in 2024, and the share of online job postings requiring both quantum skills and quantum-enabling skills rose from 1% to 4% over the same period. Job postings from core quantum companies that do not list quantum-related or enabling skills typically target other profiles, including roles in sales, marketing or human resources roles. The core quantum firms that posted most vacancies online in the data across Canada, the United Kingdom and the United States were Davidson Technologies (690), Lightmatter (641) and Psiquantum (430).

Figure 6.2.1

Active core quantum firms identified using job postings



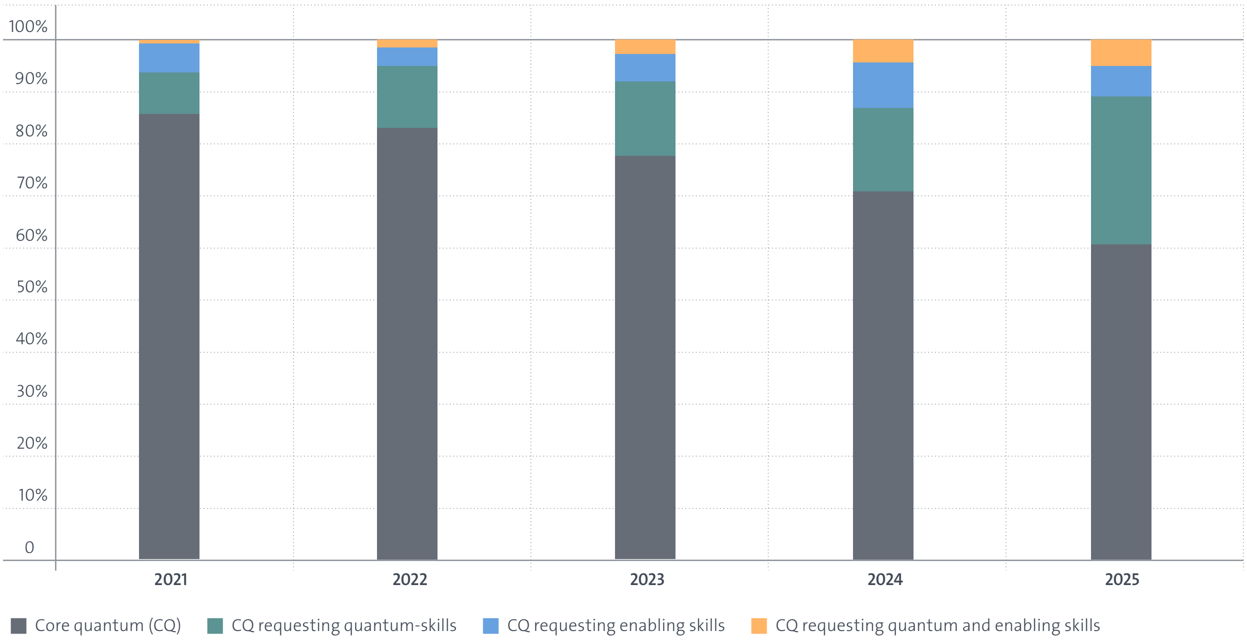
Notes: Annual counts are shown for all online job postings from core quantum firms in Canada, the United Kingdom and the United States. Online job postings data for 2025 are available up to July. Firms can post job vacancies in multiple countries.

Source: OECD calculations based on Lightcast, October 202

Figure 6.2.2

Core quantum firms require more quantum-specific and quantum-enabling skills over time

% of core quantum online job postings, 2021-July 2025



Notes: The figure shows the composition of all online job postings from core quantum firms in Canada, the United Kingdom and the United States, distinguishing job postings that require quantum skills, enabling skills or both. The dark blue bar (core quantum or CQ) represents all job postings from core quantum firms, including those that do not explicitly mention quantum or enabling skills. Job postings data for 2025 are available up to July. Lightcast periodically improves how it extracts and classifies skills from job descriptions. Therefore, part of the observed increase in the share of job postings requiring quantum and enabling skills may reflect improved skill recognition rather than an actual rise in skill demand.

Source: OECD calculations based on Lightcast, October 2025

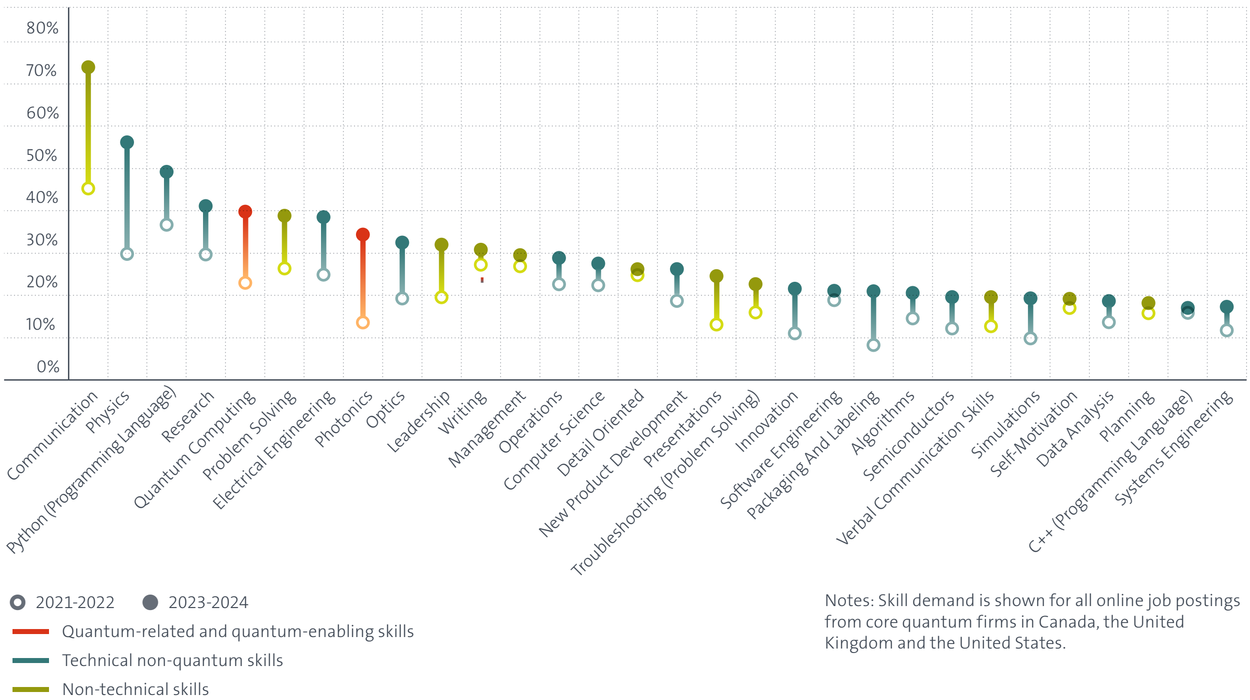
Online job postings from core quantum firms reveal an ecosystem deepening its technical base. By examining all online vacancies, as opposed to only those requiring quantum-related or quantum-enabling skills, this analysis also captures a broader set of competencies, explaining the increasing prominence of organisational, socio-emotional and functional skills. It possibly reflects the diverse roles needed to support R&D, scale-up and commercialisation within the quantum ecosystem.

Between 2021-2022 and 2023-2024 demand grew strongly for communication (45% to 74%) and problem-solving skills (26% to 39%) (Figure 6.2.3). On the technical side, the demand for expertise in physics increased from 30% to 56%, and in Python from 36% to 49%. Quantum computing saw one of the sharpest increases, from 23% to 40%. Electrical engineering, photonics and optics also grew significantly, with photonics rising from 13% to 35%, reflecting greater emphasis on the physical implementation and experimental infrastructure of quantum systems. The prominence of socio-emotional and functional skills like communication, problem-solving, leadership and management indicates that firms are also investing in capabilities needed to grow, organise and engage with new applications.

Figure 6.2.3

Core quantum firms need to combine technical expertise with transversal skills

% of core quantum online job postings that require each skill, by period



Notes: Skill demand is shown for all online job postings from core quantum firms in Canada, the United Kingdom and the United States.

Source: OECD calculations based on Lightcast, October 2025.

6.3 Conclusions

The quantum ecosystem's demand for skills remains heavily focused on advanced scientific and technical expertise, particularly in physics, computer science, and engineering. At the same time, required skills set are gradually broadening, particularly within core quantum firms, where interest in transversal skills such as business and managerial capabilities reflects the sector's gradual shift from research activities to industrial deployment. Quantum-related and enabling skills are sought across a broad range of firms, with non-core quantum firms accounting for most job postings requiring quantum-related skills over the 2021-2025 period. Strengthening talent pipelines across these skill domains will remain essential to support innovation and sustain long-term growth and competitiveness of the quantum ecosystem.

7. International trade in quantum

This section analyses the international trade in goods that underpin the quantum ecosystem, referred to as "quantum-relevant goods", distinguishing between raw materials and equipment. The analysis is based on UN Comtrade (BACI) data, which includes information on more than 5 000 products from more than 200 countries.

As the quantum ecosystem is still in its infancy the insights presented in what follows should be interpreted with caution, as they are likely capturing flows of goods which, despite their relevance for the quantum ecosystem, are mostly aimed at more established industries such as semiconductors, whose value chains partially overlap with that of the quantum ecosystem, as shown by OECD (2025b) and UK DSIT (2024). Consequently (given their larger size), these industries are likely to account for a higher share of the traded quantum-relevant goods than the quantum ecosystem itself. Despite this important caveat, the insights provided in this section can shed light on potential advantages, resources and dependencies within this value chain.

Quantum-relevant goods (including raw materials and equipment goods) were identified based on multiple sources described in detail in Annex A.9. The identification of the HS codes used for the analysis presented here took place in two main steps. First, a list of products relevant for the quantum ecosystem (both raw materials and equipment) was identified. Second, this list was matched to harmonized system (HS) codes at the six-digit level (2022 edition).[35]

Among equipment goods identified, only the most high-tech were included in the analysis, as they are the most critical for the development of quantum technologies. Only equipment goods with a Product Complexity Index (PCI) greater than 1 as defined by the Observatory of Economic Complexity (OEC) were included (OEC, 2025). This roughly corresponds to the top 15% of the global product complexity distribution. For example, goods such as cables (HS code 854442) and vacuum chambers/pumps (HS code 841410) were excluded. While these are used in quantum for signal transmission and to create ultra-high-vacuum environments, they are not predominantly used in quantum technologies compared to other industries such as telecommunications or semiconductor manufacturing, and are also less likely to constitute choke points due to their low technological content.

Table 7.1 shows the final set of goods used in the analysis categorised into raw materials and equipment. This correspondes to 29 HS codes at the six-digit level (2017 edition).

35 Current data limitations prevent the current analysis from exploring more granular goods by looking at 8-digits codes.

Table 7.1

List of quantum-relevant goods and HS codes used in the analysis

Raw material – quantum	HS code label	HS code (2017)
Aluminium	Aluminium	760110
Aluminium Oxide	Aluminium Oxide	281820
Arsenic	Arsenic	280480
Barium Titanate	Oxometallic salts (nes)	284190
Barium, Caesium, Rubidium, Strontium	Alkali metals (nes)	280519
Bismuth	Bismuth	810600
Diamond	Industrial diamonds	710221
Rare earths (Erbium, Europium, Ytterbium)	Rare-earth metals	280530
Gallium Arsenide	Doped chemical compounds	381800
Gallium, Germanium, Indium, Niobium	Non-ferrous metals (other)	811292
Helium-3, Silicon-28	Isotopes (nes)	284590
Indium Phosphide	Phosphides (nes)	285390
Lithium Niobate	Foundry binders and chemicals (nes)	382499
Nitrogen	Nitrogen	280430
Silicon Carbide (SiC)	Silicon carbide	284920
Tantalum	Tantalum	810320
Titanium	Titanium	810820

Equipment – quantum	HS code label	HS code (2017)
Fab. Equipment (Clean, Deposition, Etch, Lithography)	Fab. Equipment	848620
Connectors	Electrical connectors	853669
Cryostats	Heat exchange units	841950
Power Supplies	Static converters	850440
HEMT Devices	Other transistors	854129
Laser Systems	Lasers	901320
Microscopes & Spectrometers	Spectrometers	902730
Optical frequency equipment	Optical radiation measurement (nes)	902750
Quantum Electronics (Other)	Other integrated circuits	854239
Quantum Processors	Processors	854231
Photon Detectors	Electrical and radiation measurement (nes)	903089
Time & Frequency Recording	Time recording apparatus (nes)	910690

Notes: The table refers to the 2017 edition of HS codes as used in the analysis. The table includes both the quantum-relevant product within each HS code (under "Raw material – quantum" and "Equipment – quantum") and the label of the HS code ("HS code label"), which covers all the goods included under the relevant HS codes. "Time & Frequency Recording" are included even if the PCI value was not available. nes = not elsewhere specified.

Source: OECD.

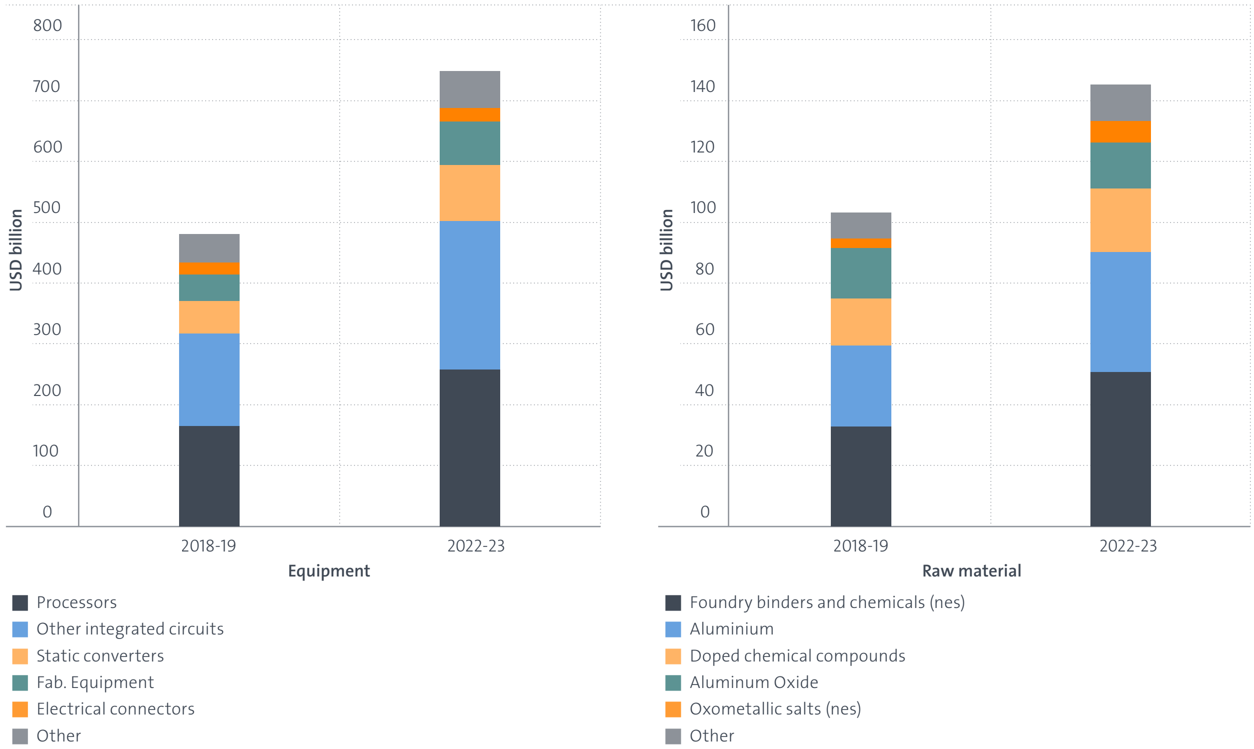
7.1 Main exporters and importers of quantum-relevant goods

Figure 7.1.1 shows global quantum-relevant exports by product. Among quantum-relevant equipment goods (left-hand panel), electrical machinery appears to play an outsized role in terms of export value, irrespective of the period observed (2018-2019 or 2022-2023). At the global level, the largest exported items are processors and other integrated circuits (both representing different types of integrated circuits), plus static converters (all classified under electrical machinery). Fab. equipment is the most exported good outside the electrical machinery category.

The value of exports has been increasing across products: the total value surged from close to USD 500 billion in 2018-2019 to more than USD 700 billion in 2022-2023. The four goods mentioned above account for approximately 90% of the value of quantum-relevant equipment exports in 2022-2023, implying that broad patterns in terms of exports should be interpreted with cautions, as they are mostly driven by a limited set of products. It is important to keep in mind that the quantum ecosystem is still in its infancy and it is challenging to identify products entirely specific to this value chain. The size of the trade flows shown should therefore be interpreted with caution, as the goods considered are mostly used in industries other than quantum.

Figure 7.1.1

Global quantum exports, by type and product: 2018-2019 and 2022-2023



Notes: The figure shows the five most exported goods by category in 2022-2023, on average. Remaining goods are summed under the "Other" label. Trade flows involving Hong Kong (China) are excluded.

Source: OECD calculations based on UN BACI database, August 2025.

For raw materials (right-hand panel), five goods account for more than 90% of the export value. *Foundry binders and chemicals (nes)* and aluminium are the most exported items by value, followed by *Doped chemical compounds, Aluminium oxide* and *Oxometallic salts (nes).* Global exports of quantum-relevant raw materials also increased across the two periods; the value of exports increased from around USD 100 billion to around USD 140 billion. The caveat mentioned above applies: due its early stage of development, the quantum ecosystem is very likely not the main recipient of these raw materials.

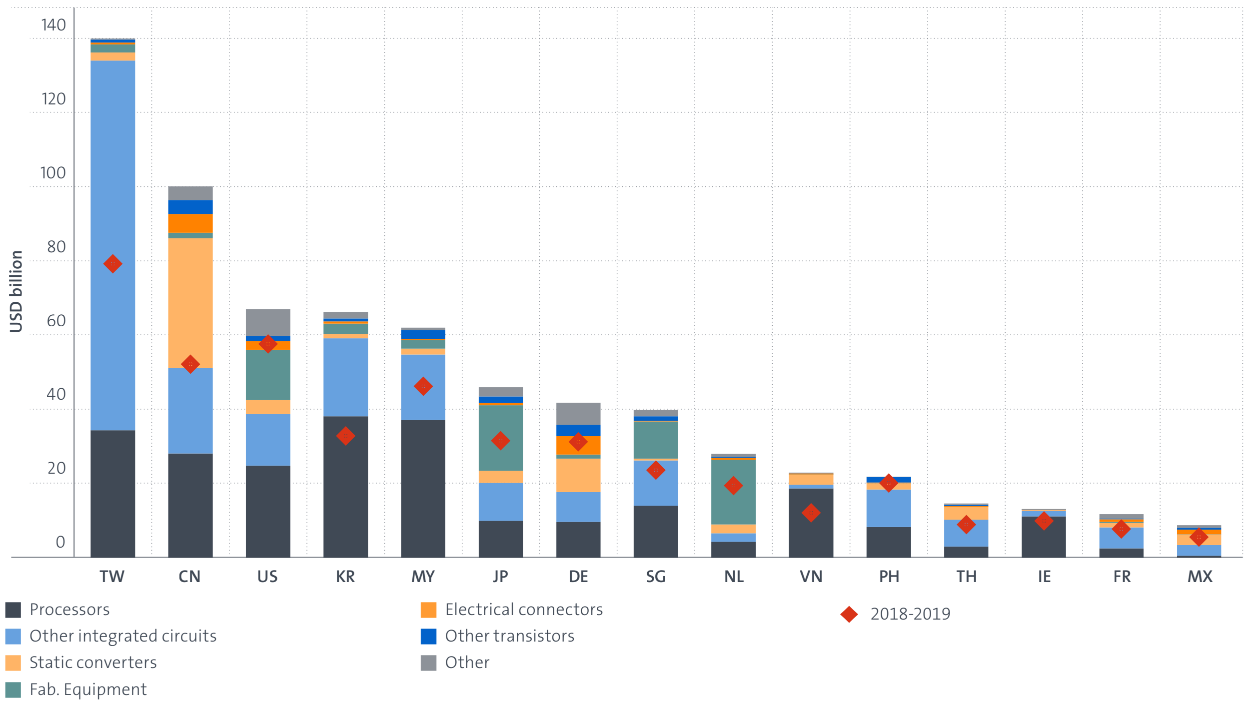
Figure 7.1.2 shows key exporters of quantum-relevant goods for equipment (upper panel) and raw materials (lower panel). In terms of equipment, economies like Taiwan, Province of China, China, Korea, the United States and Malaysia played a leading role in 2022-2023, with total average annual exports of USD 140 billion, USD 100 billion, USD 67 billion, USD 66 billion and USD 61 billion respectively in the period 2022-2023. Some of these economies, particularly Taiwan, Province of China, (and to a lesser extent Korea and Malaysia) have notable portions of their quantum-relevant exports attributable to integrated circuit devices, specifically *Processors and Other integrated circuits.*[36] Excluding this type of product, the role of China, the United States, Germany, Japan and the Netherlands appears far more prominent. Across economies, electrical machinery (which includes *integrated circuits* as well as *static converters*) constitutes the bulk of exports. The Netherlands represents a notable exception in this respect, due to exports of *Fab. equipment* – specialised semiconductor manufacturing equipment. The United States, Japan and Singapore also have a higher share of *Fab. equipment* exports. In China, *Static converters* represent the leading export item, followed by both types of *integrated circuits*. *Electrical connectors* also contribute significantly (similarly to Germany), while other transistors feature more prominently than in global trends. Germany and the United States also have non-negligible shares of other goods exported, which may be linked to exports of precision instruments.

36 This category includes qubit control electronics, which are essential for the operation of quantum technologies.

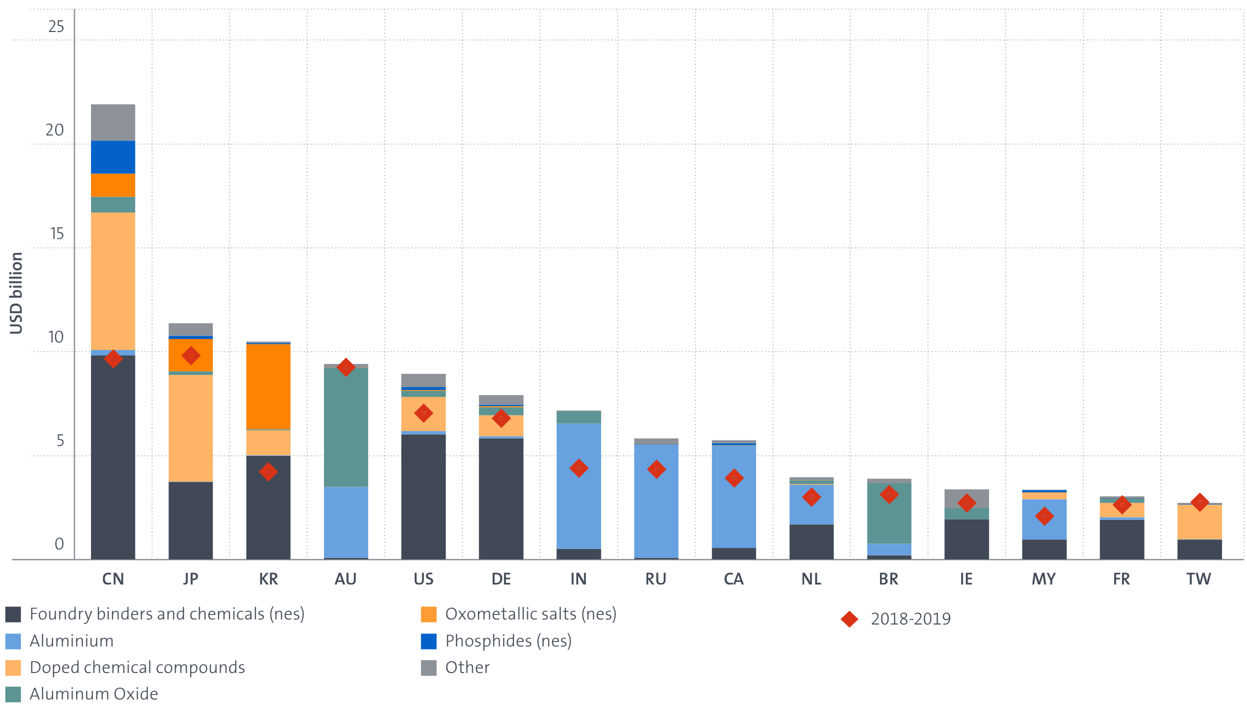
Figure 7.1.2

Global average quantum exports by economy and product: 2022-2023 and 2018-2019

Equipment



Raw material



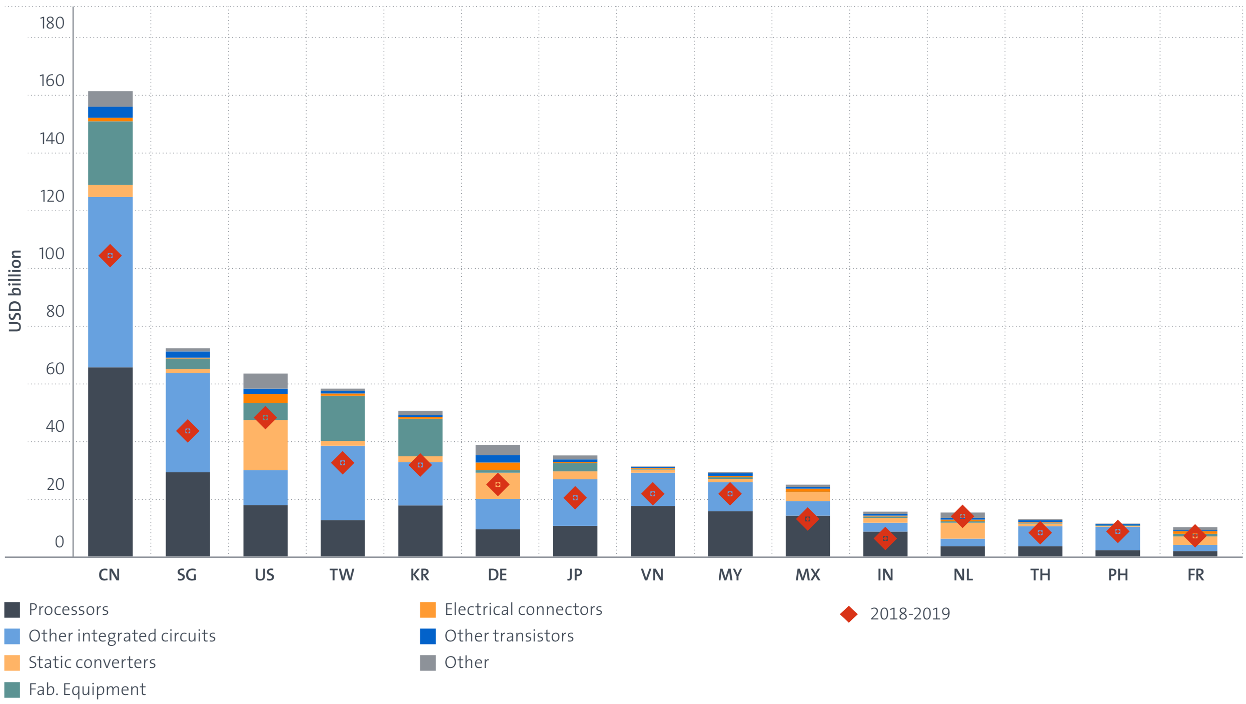
Notes: The figure shows the top 15 exporters of quantum-relevant equipment and raw material in the 2022-2023 period, by average. Trade flows involving Hong Kong (China) are excluded from this figure.

Source: OECD calculations based on UN BACI database, August 2025.

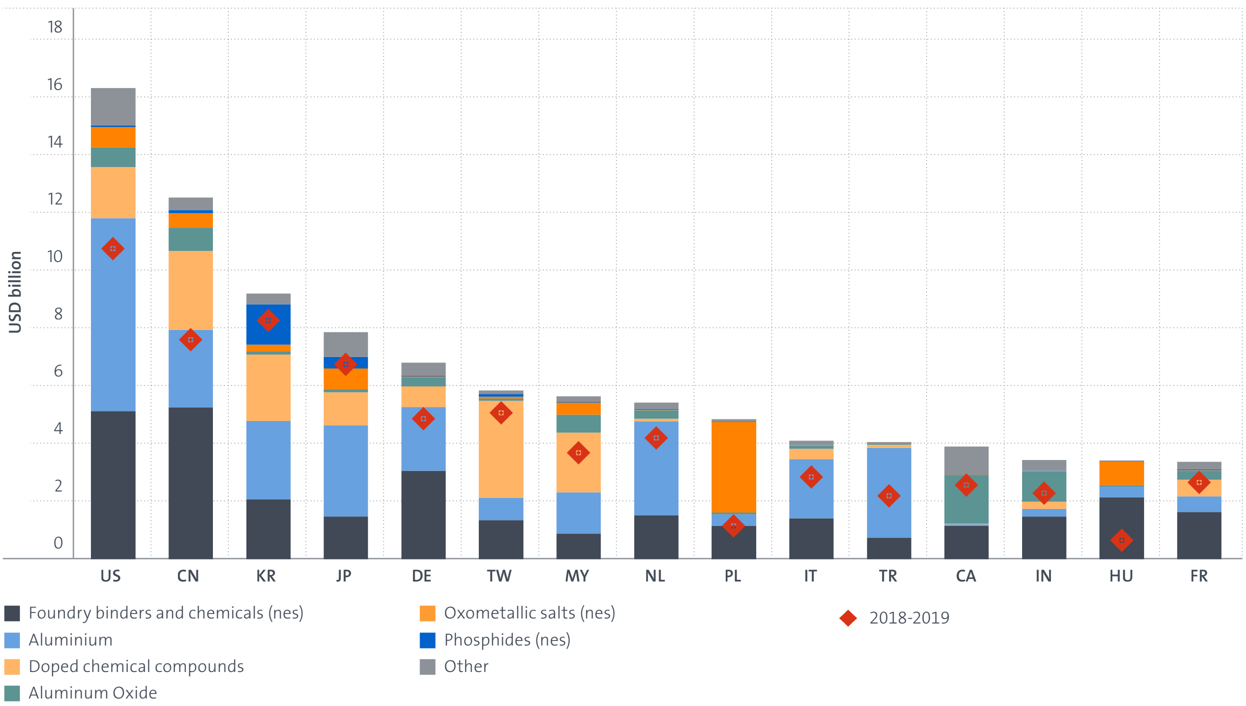
Figure 7.1.3

Global average quantum-relevant imports by economy and product: 2022-2023 and 2018-2019

Equipment



Raw material



Notes: The figure shows the top 15 importers of quantum-relevant equipment and raw material in the period 2022-2023, by average.
Trade flows involving Hong Kong (China) are excluded.

Source: OECD calculations based on UN BACI database, August 2025.

Over the period from 2018-2019 to 2022-2023, all economies in the sample experienced increasing equipment exports (see the diamond for average exports in 2018-2019), but this growth was particularly strong in China, Korea and Vietnam (which is heavily focused on integrated circuits, more specifically processors), all of which nearly doubled their exports.

Comparing the lower and upper panels of Figure 7.1.2 highlights how, across economies, exports of equipment for the quantum value chain tend to largely outweigh the value of raw materials exported. In 2022-2023, China was the lead exporter of quantum-relevant raw materials (with approximately USD 22 billion), followed by Japan and Korea, both with more than USD 10 billion. China's main exports, similar to Japan, are *Foundry binders and chemicals (nes)* and *Doped chemical compounds,* while Korea stands out for its exports of *Oxometallic salts (nes)*. For the United States and Germany, *Foundry binders and chemicals (nes)* constitute the bulk of exports. Finally, Australia (and to a lesser extent Brazil) plays a crucial role in *Aluminium oxide,* while Russia, India and Canada do so for *Aluminium*.

China and Korea experienced marked increases in quantum-relevant raw material exports between 2018-2019 and 2022-2023. Conversely, Australia's exports in this area remained largely stable, similar to Taiwan, Province of China.

Figure 7.1.3 shows the main importers of quantum-relevant goods separately for equipment (upper panel) and raw materials (lower panel). The upper panel highlights the considerable size of China's imports of equipment in 2022-2023. China is followed by Singapore, the United States, Taiwan, Province of China, and Korea. *Processors* and *Other integrated circuits* are the goods with the highest value of imports across most countries. Economies like Taiwan, Province of China, China and Korea have also notable imports of *Fab. equipment,* while for the United States and Germany imports of *Static converters* are more important. In all economies except the Netherlands, imports have grown considerably since the period 2018-2019 (the red diamond).

As for raw materials, the United States was the biggest importer in the period 2022-2023, with more than USD 16 billion, followed by China. Leading importers like China and the United States tend to import chiefly *Foundry binders and chemicals (nes)*. In the United States, similar to Japan, Italy and Türkiye, *Aluminium* is the biggest import. *Doped chemical compounds* is a particularly sizeable category in China, Korea, Taiwan, Province of China, and Malysia. Finally, Poland focuses on *Oxometallic salts (nes)*. Poland (together with Hungary) also shows the strongest increase in demand for quantum-relevant raw materials. Other economies have recorded increasing imports across the board.

7.2 Relative specialisation, market concentration and trade dependencies

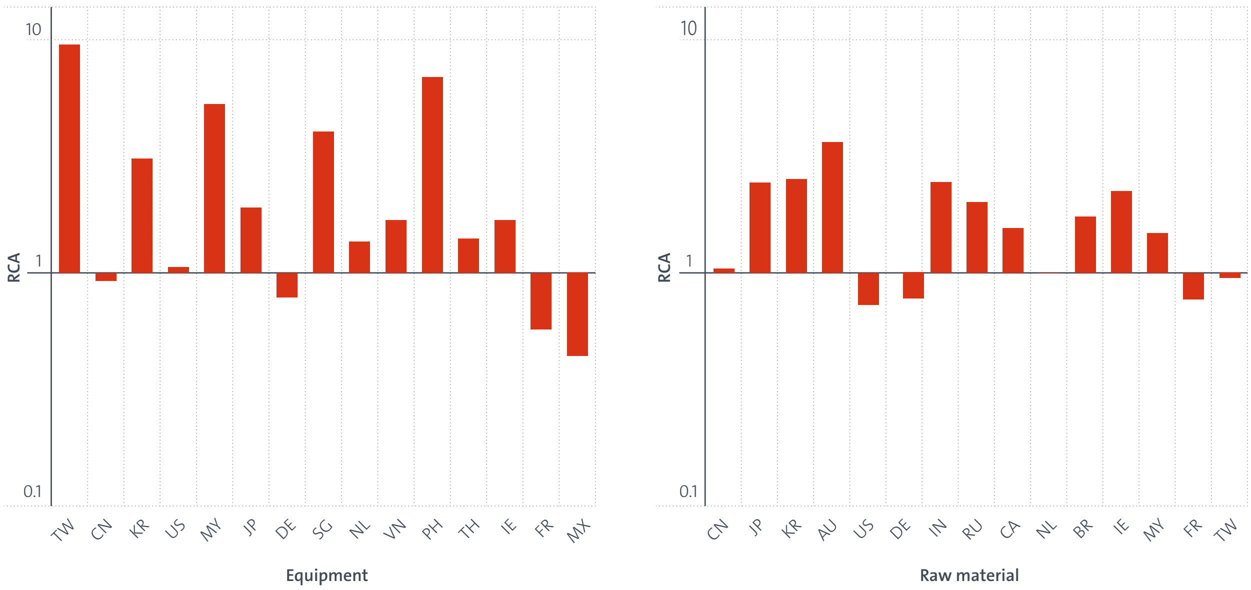
Revealed comparative advantage (RCA) can help assess countries' specialisation within the quantum value chain. RCA is a commonly used measure in trade analysis; it accounts for the size of an economy by comparing the global share of exports by country i of good j to the share of exports by country i in all goods.[37] For example, a country exporting 10% of all quantum-relevant goods, but 5% of all goods, would have an RCA value of 2, which would indicate relative specialisation in quantum-relevant goods. A value above 1 indicates relative specialisation; a value below 1 indicates that the country is not specialised in this particular good. Note that RCA values have an inherent limitation; they take values between 0 and +∞ and are asymmetric around the threshold value of 1. For example, an RCA of 2 is the specialisation equivalent of a value of 0.5 for non-specialisation. To address this issue, Figure 7.2.1 is represented on a logarithmic scale, which provides symmetry around the threshold and allows for a more intuitive interpretation.

Figure 7.2.1 shows the RCA values of the main exporters of quantum-relevant goods identified in Figure 7.1.2. Taiwan, Province of China, the Philippines, Singapore, Malaysia and Korea all show strong specialisation in equipment goods (left-hand panel), reflecting their well-established focus on integrated circuits. Interestingly, not all the main exporters of quantum-relevant goods figure prominently in this graph, and this is true for both quantum-relevant equipment, as well as raw materials. For equipment,

37 $RCA_{Ai} = (X_{Ai}/(\sum_{j \in P} X_{Aj})) / (X_{wi}/\sum_{j \in P} X_{wj}))$, where X_{Ai} represents the exports of economy *A* in industry *i*, $\sum_{j \in P} X_{Aj}$ represents the total exports of goods for economy *A*. X_{Wi} denotes the world's exports in industry *i*, and $\sum_{j \in P} X_{wj}$ accounts for the world's total exports of all goods.

Figure 7.2.1

Average RCA values for top exporters by type: 2022-2023



Notes: The figure shows the same top exporters identified in Figure 7.1.2, ordered according to the same ranking. Trade flows involving Hong Kong (China) are excluded. The figure is shown on a logarithmic scale.

Source: OECD calculations based on UN BACI database, August 2025.

economies like China, Germany, France and Mexico have RCA values lower than one in 2022-2023, suggesting their strong export performance in volume terms does not equate to a specialisation in the area, but is merely a reflection of their size. This highlights that exports and RCA provide distinct yet complementary information. The same can be said when looking at raw materials (right-hand panel), which show that Taiwan, Province of China, Germany, the Netherlands and the United States, while sizeable exporters of quantum-relevant raw materials, are not specialised in these products. By contrast, Australia, Japan, Korea and India appear more specialised in these.

The Herfindahl-Hirschman index (HHI) can be used as a measure of market concentration, making it possible to identify products where high concentration may raise concerns about dependency on a limited number of supplying countries. The HHI index is computed as the sum of the squared market shares of each economy for each good *j*.[38] For example, if a single economy is responsible for all global exports of good *j*, the HHI of this product would be equal to 1 (the maximum possible value). By contrast, if ten different economies each account for 10% (0.1) of exports of this good, the HHI would be equal to 0.1 (10*0.12). The lower the HHI index, the less concentrated a value chain.

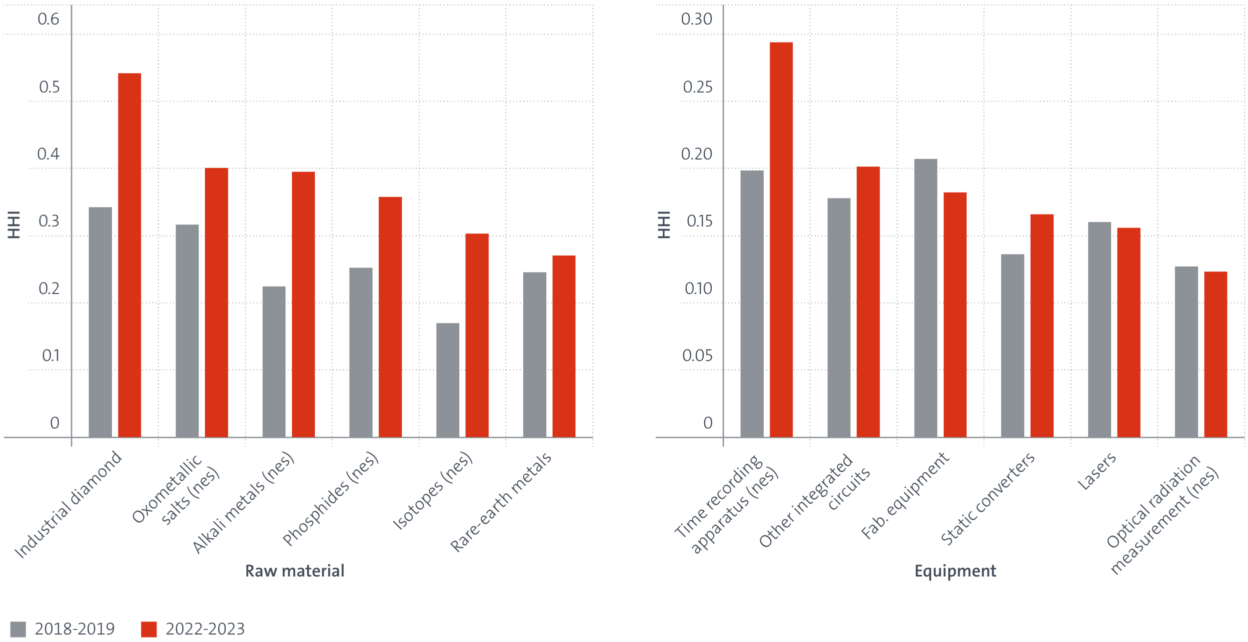
Previous studies (Kowalski & Legendre, 2023) have defined markets with an HHI between 0.15 and 0.25 as moderately concentrated, and markets with a HHI greater than 0.25 as highly concentrated. Figure 7.2.2 shows that several quantum-relevant products, especially raw materials, are highly concentrated. *Industrial diamonds, Oxometallic salts (nes), Alkali metals (nes), Phosphide (nes), Isotopes (nes)* and *Rare-earth metals* all stand out, not only due to their high concentration (with values above 0.25 on average in the period 20222023), but also due to their increasing HHI values across the two periods sampled, in line with a widespread trend across quantum raw materials.

For equipment products the concentration is lower on average, even if there are products that can be defined as moderately to highly concentrated, such as *Time recording apparatus (nes).* Interestingly some products, like *Fab. equipment, Lasers* and *Optical radiation measurement* have slightly decreasing rates of concentration.

38 $HHI_j = \sum_{i=1}^{N} s_{ij}^2$ where s_{ij} is the market share of economy *i* for a given product *j*.

Figure 7.2.2

Average HHI values by type and product: 2022-2023 and 2018-2019



Notes: This figure shows the six quantum-relevant goods, both equipment and raw materials, with the largest average HHI values in 2022-2023. Trade flows involving Hong Kong (China) are excluded.

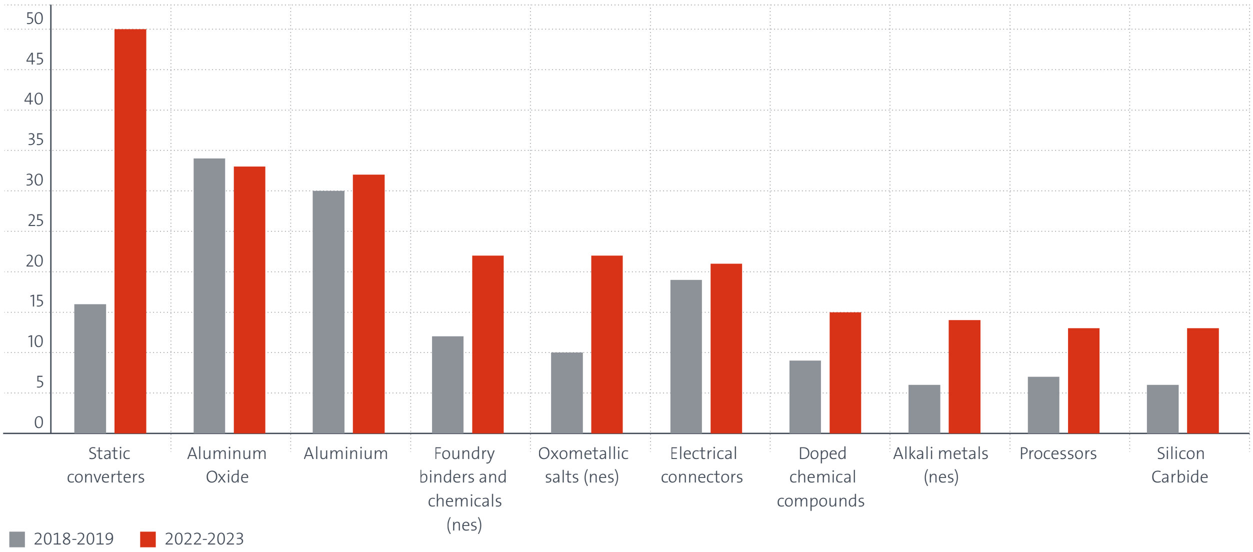
Source: OECD calculations based on UN BACI database, August 2025

By computing the HHI index for each importing country and each commodity, it is possible to identify whether a country's imports of a specific product are concentrated among a limited number of suppliers. Building on the methodology developed by (Kowalski & Legendre, 2023), several criteria are used to define a dependency. First, imports of product *k* by country *i* must be highly concentrated geographically (HHI > 0.40). Second, the ratio of exports to imports of product *k* in country *i* must be lower than the 90th percentile of the global distribution of the exports to imports ratio of product *k* across all countries, to avoid including economies with a large domestic production (and related exports) of product *k*. Third, imports by country *i* from (origin) country *j* of product *k* must account for more than 10% of the country's total imports of product *k*. Finally, imports of a product must have a value of more than USD 10 million.

Figure 7.2.3 highlights the products with the highest number of dependencies in 2022-2023. For all reported goods the number of dependencies is either stable or (in most cases) increasing compared to 2018-2019. This trend is particularly evident for Static converters, the product demonstrating the most dependencies in the latest period, with nearly 50 economies relying on a strategically important partner. (In almost 40 cases this strategic partner is China.) The next two products, *Aluminium oxide* and *Aluminium*, each with some 30 dependencies, show a different pattern: Australia occupies the most strategic position for *Aluminium oxide,* while Russia is the key supplier of *Aluminium*. Korea emerges as the most critical player for *Oxometallic salts (nes),* a product for which dependencies are rising. China is also a strategic supplier for *Foundry binders and chemicals (nes)* and *Electrical connectors*.

Figure 7.2.3

Total trade dependencies for quantum-relevant goods by type: 2018-2019 and 2022-2023

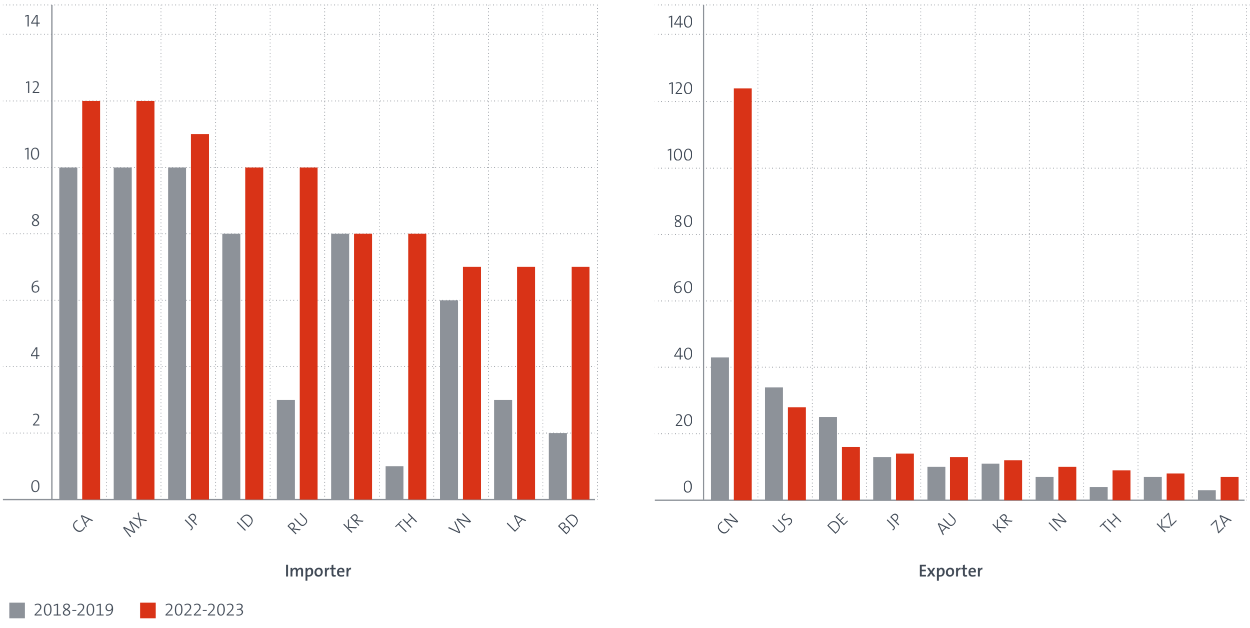


Notes: The figure shows the top ten quantum-relevant products by total number of dependencies in 2022-2023.

Source: OECD calculations based on UN BACI database, August 2025.

Figure 7.2.4

Trade dependencies for quantum-relevant goods, importers and exporters: 2018-2019 and 2022-2023



Notes: The figure shows the top economies by number of dependencies experienced, or by how many other economies were dependent on them, in 2022-2023, in total.

Source: OECD calculations based on UN BACI database, August 2025

The important role of China as a critical supplier for many importers is confirmed in Figure 7.2.4, which shows the importing economies with the highest number of dependencies (on the left) and the economies on which most others depend (on the right). On the left, the figure mirrors the pattern observed in Figure 7.2.3, showing an overall increase in dependencies (except for Korea), with Canada, Mexico and Japan being the economies with most dependencies in this area. On the right, China's role as a key supplier is particularly evident, with 124 of the 329 dependencies in the quantum ecosystem in 2022-2023 linked to this country. This number has approximately tripled compared to the previous period (2018-2019), when it was just over 40. The United States and Germany also occupy strategic positions in the value chain, although the number of economies dependent on them has slightly decreased over the two periods.

7.3 Conclusions

The identification of critical inputs for quantum remains challenging, due to data limitation and to the small size of this ecosystem, which partially overlaps more established value chains like that of the semiconductor industry. The analysis – which should consequently be cautiously interpreted – reveals increasing export and import volumes, with just a few products accounting for most of the identified trade flows. Market concentration and trade dependencies are rising for several critical inputs, highlighting potential vulnerabilities in global supply chains. As the quantum ecosystem matures, ensuring resilient access to key materials and technologies will be vital for supporting innovation and technology diffusion and mitigating strategic risks.

8. The role of government in shaping quantum ecosystems

Governments will play a leading role in shaping quantum ecosystems for the foreseeable future. Companies in several sectors are examining how they might use quantum technologies. However at present there is no broad commercial market for general-purpose quantum computers; the few operational devices are mostly used by academic and research institutions, often with public funding. This means public investment in R&D will likely be the foundation of quantum ecosystems for some time to come.

Despite some national differences, quantum ecosystems around the world possess a similar constellation of institutions. Leading countries all have a mix of universities and PROs, startups and large companies, and government agencies. These institutional arrangements typically reflect existing innovation systems and long-standing national research strengths. Governments can take steps now to help ensure that when quantum technologies become market-ready there is an ecosystem primed to use them.

This section presents an overview of the role of governments in shaping quantum ecosystems, with a focus on national strategies and the funding of R&D, commercialisation of research and technology diffusion that have emerged over the last decade to support the development of quantum technologies. Some of these elements are treated more extensively in the OECD Quantum Technologies Policy Primer (OECD, 2025a), and the OECD Overview of national strategies and policies for quantum technologies (OECD, 2025c).

8.1 National quantum strategies: features, governance and commitments

Early national quantum strategies, in the United Kingdom, the European Union and the United States, focused primarily on supporting research and development (OECD, 2025c). Since around 2021, newer strategies have increasingly stressed commercialisation, applications and industrial deployment, reflecting a stronger economic orientation. As the European Union moves towards a Quantum Act and the United States debates reauthorisation of its quantum legislation, emerging evaluations of these first-wave strategies reinforce this shift and point to the need for stronger support to translate research into market-ready solutions.

At the inception of these strategies, defence establishments have been pivotal in developing quantum technology policy. In the United States, following an initial report in 2009 (National Science and Technology Council, 2009), the National Security Agency began monitoring quantum computing developments, specifically for threats to classical cryptography. During the preparation of the American quantum strategy in 2018, the National Photonics Initiative prepared a report on *The Role of the Defense Department in the NQIA* (NPI, 2018). This document highlights the support of the Department of Defence (DoD) and affiliated labs such as the Army Research Laboratory (ARL), the Air Force Research Laboratory (AFRL), and the Naval Research Laboratory (NRL) to quantum technology research.

The United Kingdom's first quantum strategy (in 2014) was shaped significantly by the Ministry of Defence, while the first quantum technology impact assessment to appear in a high-level policy document in France was part of the country's 2013 defence white paper (Ministère des Armées, 2013). Academics note that quantum technologies "primarily emerged out of two institutions: academia and government", with defence agencies serving as primary funders drivers through organisations like DARPA in the United States and similar bodies elsewhere (Perrier, 2022).

Pandemic-related strategic concerns and large stimulus packages played a part in formalising quantum strategies in many countries (OECD, 2025c). In this context, initial quantum policy agendas, shaped mainly by defence, industry and scientific actors, have evolved into broader policy frameworks. The expanding scope of objectives listed by these documents have embraces wider economic and societal goals and typically include:

— **Ensuring strategic autonomy and technological sovereignty:** Apprehensions about dependency on external actors for critical components have led to explicit mandates to develop domestic supply chains, protect intellectual property (IP) and cultivate in-house expertise.

— **Driving economic and industrial activity:** The aspiration to capture the transformational potential of quantum technologies underpins strategic efforts to foster diverse innovation ecosystems. These efforts blend top-down leadership (such as national-level funding initiatives and roadmaps) with initiatives to build ecosystems from the bottom up (through incubators, consortia and testbeds).

— **Sustaining scientific leadership:** Strategies are often accompanied by substantial investments in research institutes, infrastructure and interdisciplinary hubs.

— **Building and retaining a skilled workforce:** Recognising the crucial role of talent, strategies embed comprehensive educational initiatives to ensure a steady flow of quantum specialists.

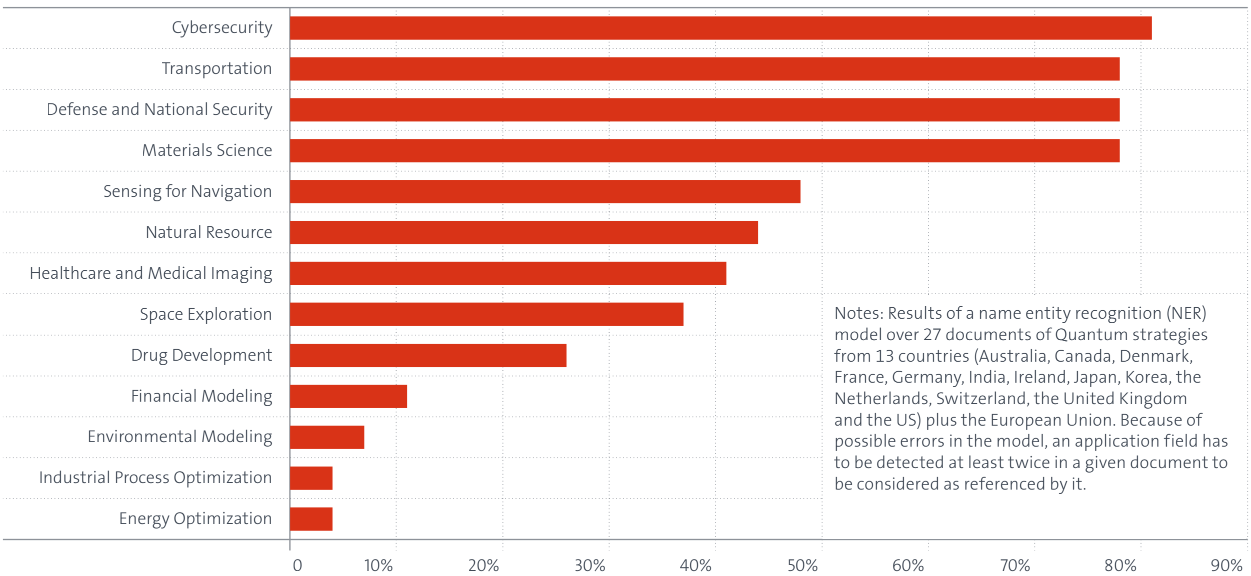
Strategy documents set the overarching aims of policy. However, they can also designate specific application domains or enabling technologies to help operationalise these ambitions. Quantum computing (which Sections 3, 4 and 5 showed to be the most clearly emerging technological segment of the three considered in this report) remain a cornerstone for most strategies, as countries develop scalable systems and associated software infrastructures to tackle challenges in such domains as materials science, drug discovery and logistics.

Secure quantum communication is a high priority, with concentrated investments in QKD networks and post-quantum cryptography. Quantum sensing and metrology appear prominently in policy texts that foresee uses in climate monitoring, resource management and manufacturing. Finally, foundational technologies such as photonic chips, cryogenics and control electronics (the importance of which was underscored in Section 4, in the definition of "core" firms, and in Section 6, when looking at skills required by the quantum ecosystem) are widely considered essential for scalable quantum platforms and robust domestic technology supply chains. Covering 13 countries and the European Union, Figure 8.1.1 lists application areas mentioned in national strategy and policy documents. The horizontal bars show the share of 27 strategy and policy documents that reference a particular application field.

As a way of directing policy and monitoring advances in quantum technology, countries often set goals and aim to measure progress within their strategies. Approaches vary significantly, as shown in Table 8.1.1, which highlights the diversity of metrics, methodologies and data sources governments employ to set targets and track progress in their quantum technology initiatives. These range from specific targets for technological performance and readiness levels, to ecosystem metrics in such areas as skills and workforce development, adoption and preparedness, startup and spin-off activity, market shares, levels of private investment, intellectual property creation, supply chain autonomy and international collaboration.

Figure 8.1.1

Share of quantum strategy documents mentioning each field of application of quantum technologies



Source: OECD calculation based on NER model (Charnois, 2013), October 2025..

Table 8.1.1

Examples of objectives and performance metrics in quantum strategies

	Theme	Metrics/Objectives	Methodology
Korea (Ministry of Science and ICT, 2023)	**Technology Level**	From 62.5% in 2020 to 85% in 2035	The 2020 technological assessment of the Korea Institute of S&T Evaluation and Planning produced an indicator of Technological advancement based on combined expert qualitative evaluations through Delphi surveys, quantitative bibliometric analysis, and field-specific evaluations using Technological Readiness Levels (TRLs). It included citation and keyword analysis, co-authorship network mapping, and benchmarking against global leaders like the US, China, and Germany (KISTEP, 2021)
	Key Workforce	From 384 persons in 2022 to 2500 in 2035	Cumulative number of key quantum workforce cultivated through government support programmes for quantum workforce development, including quantum graduate schools, overseas assignment/training, Quantum Information Technology White Paper (Kim, 2022)
	Quantum Global Market Share	From 1.8% in 2022 to 10% in 2035	Mind Commerce's 2022 data
	Quantum Technology Supplying and Enabling Companies	From 80 companies to 1 200 in 2035	The number of Korean quantum science and technology supply companies, quantum SMEs, and quantum product/service companies registered with the Future Quantum Convergence Forum and Alliance of Leading Quantum Computing Companies
	International Cooperation & Investment	Budget from 13 billion KRW (10 million USD) between 2019 to 2022 to 210 billion KRW (154 million USD) between 2023 and 2035	Cumulative budget for international cooperation (international joint research, workforce exchange) in government quantum-specific projects
United Kingdom (DSIT, 2023)	**Quality and impact of quantum science**	From ranking third among top 10 nations for quality and impact of quantum science (2017-21) to maintaining top three position while increasing research publication volume by 2033	DSIT internal analysis using SciVal database (Elsevier). Uses field-weighted citation impact (FWCI) and publication volume. FWCI compares citations of UK publications to world average in same year, discipline and format.
	Postgraduate research students	From over 470 postgraduate research students funded since 2014 to an additional 1 000 funded by 2033	EPSRC internal analysis using UKRI student data. Manually checked PhD descriptions for alignment with QT definition.
	International quantum collaboration	From bilateral arrangements with the US to bilateral arrangements with 5 further leading quantum nations by 2033	
	Global private equity investment	From ~12% of global private equity investment in quantum technology companies (2012-22) to 15% share by 2033	DSIT internal analysis using Quantum Insider data. Tracks companies selling quantum hardware, software, developing quantum computers, quantum security, sensing and supply chain. Data collected from publicly available sources.
	Global market share	From estimated ~9% global market share in quantum technologies (2021/22) to 15% share by 2033	Analysis by Innovate UK for ISCF. Uses Crunchbase data to identify quantum companies' HQ locations and estimate revenues. UK share calculated as percentage of global estimated revenue.
	Business preparedness for quantum computing	From 25-33% of businesses having taken concrete steps to prepare for quantum computing to 75% of businesses in key relevant sectors by 2033	EY Quantum Readiness Survey 2022

	Theme	Metrics/Objectives
France (Secrétariat général pour l'investissement, 2021)	**Overall investment**	1.8 billion euros total investment by 2025
	Job creation	16 000 direct jobs by 2030
	Talent development	5 000 new talents trained in quantum technologies by 2025
	Research training	1 700 young researchers trained by 2025
	Entrepreneurship support	120 million euros for startup funding
	Research support	150 million euros for a Priority Research Programme and Equipment (PEPR)
	Industrial deployment and innovation	350 million euros total support
	NISQ development	Hosting the world's first hybrid quantum computer infrastructure
	Large Scale Quantum (LSQ) computer	Being among the first nations to develop a universal quantum computer
	Quantum Computing Capability	From 300 useful qubits in 2022 to 4000 useful qubits by 2030, with interim targets of 300 (2023), 1000 (2024-2025), and 2000 (2026) (Cour des comptes, 2024)

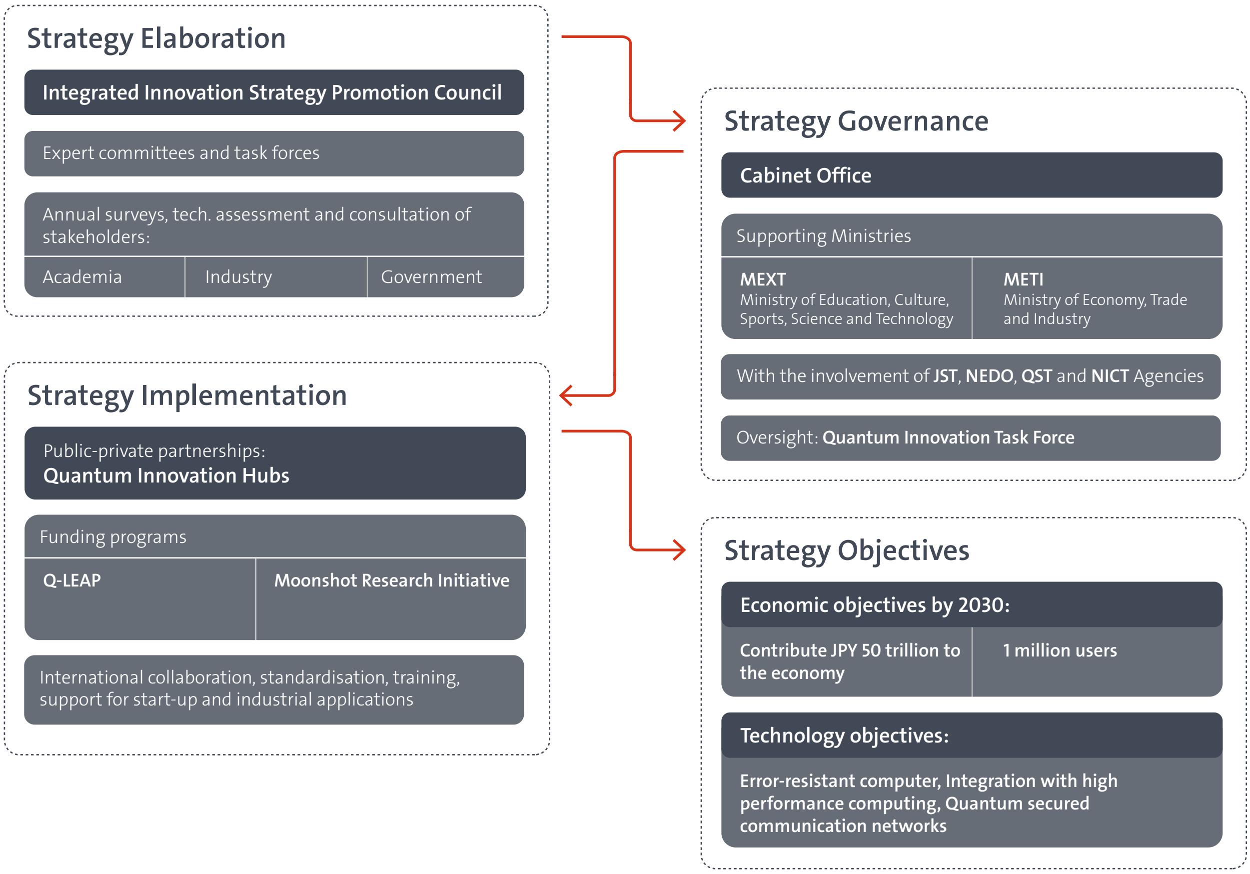
Source: (OECD, 2025c).

Current evaluations of national quantum efforts are not limited to simple output indicators like paper and patent counts, which are easy to collect but say little about whether an ecosystem is maturing. Instead, they look at features of the wider system: how many startups are created and how fast they grow, whether the talent pipeline (e.g. funded PhDs) matches demand, where skills gaps persist, and how accessible key infrastructures such as foundries, cleanrooms, fabrication facilities and testbeds are for industry. Programme milestones are increasingly tied to technology- and manufacturing-readiness levels to track progress toward deployment rather than just scientific production. At the level of the EU, the Quantum Flagship has formalised this shift with a multi-pillar KPI set (covering the ecosystem, quantum communication, computing, simulation, sensing and metrology, and education), including detailed measures such as lab-to-fab capacity, components relevant for strategic autonomy, investment and jobs, IP positioning, and technology-specific performance metrics (Quantum Flagship, 2024).

Governance arrangements for national quantum strategies differ, reflecting countries' specific priorities, institutions and levels of political commitment. Some strategies sit within broader STI agendas, while others are stand-alone and supported by dedicated legislation or councils. In several cases (e.g. France, Japan and the United States), responsibility is placed at the highest executive level, whereas others rely on dedicated quantum offices (e.g. Singapore, the United Kingdom and the United States) and expert advisory groups (e.g. Australia, Korea). Overall, most systems combine central government oversight with structured input from technical experts (OECD, 2025c). By way of example, Figure 8.1.2 depicts the governance arrangements in Japan's national quantum strategy.

Figure 8.1.2

National quantum strategy governance in Japan



Source: OECD desk research, 2025

Another pattern is the use of formal mechanisms to gather feedback from actors in the quantum ecosystem. Canada has pioneered this approach with its use of quantitative online surveys targeting academics and businesses to collect data on collaboration, talent gaps, and commercialisation barriers. The findings are then synthesised and published in "What We Heard" reports (ISED, 2022). The European Commission employed a similar method with its public "Call for Evidence" in mid-2025, which solicited written feedback from stakeholders across the continent to inform the development of its new Quantum Europe Strategy. The United Kingdom also uses this approach, commissioning independent reviews like the Quantum Infrastructure Review, which was based on extensive engagement with industry stakeholders (RAE, 2024).

8.2 A priority focus on research

Section 5 highlighted the role played by governments in financially supporting the quantum ecosystem. It explained governments' rationales for investing and provided initial evidence on the relatively large role they play. As of July 2025, an estimated USD 55.7 billion has been committed to quantum science and technology by governments worldwide since 2013 (Qureca, 2025). Yet it is important to note these estimates are based on public announcements of government investments, and they should be interpreted with care. They often represent the overall expected budget of programmes which may include legacy budgets already earmarked for quantum technologies and science before a strategy is put in place. In addition, they may not be disbursed for a long time. They may also include expected additional funding from non-governmental sources such as the private sector. Table 8.2.1 shows the funding breakdown for a selection of countries.

Table 8.2.1

Public announcements of funding in selected national quantum strategies by source of funding

Share of all announced funding for quantum: France, Korea, the United Kingdom and the United States

	Public (pre-strategy funding programmes)	Public (new post-strategy funding)	Private	EU Funds
United States	48%	52%	0%	0%
United Kingdom	29%	42%	29%	0%
Korea	9%	71%	20%	0%
France	15%	40%	30%	15%

Notes: The United States and France explicitly provide a share of the legacy budgets integrated in their strategies' budgets. For the United Kingdom and Korea the share of the pre-strategy funding is estimated based on the amount of government spending on quantum technologies in the year preceding publication of the strategy.

Source: OECD elaboration based on Subcommittee on Quantum Information Science of the National Science and Technology Council (2023), DSIT (2023a), Ministry of Science and ICT (2023) and Office parlementaire d'évaluation des choix scientifiques et technologiques (2022)..

No comprehensive and disaggregated calculation of public spending on quantum science and technology is currently available. However, the OECD Fundstat resource is a flexible infrastructure that comprises a distributed database and related analytical tools. OECD Fundstat allows estimation of quantum-specific project-level R&D funding allocations for 19 OECD countries. In 2021, for those 19 countries, this presented 51% of total government budget allocations for R&D (GBARD), excluding general university funds (GUF) – see Yamashita et al. (2021); Aristodemu et al. (2023); and Aristodemu et al. (Forthcoming). While the coverage of this data resource is not complete, it offers useful insights into trends in quantum-related public funding.

Table 8.2.2 details estimated quantum-related R&D funding allocations across 19 OECD countries and European Commission (EC) programmes for the years 2015-2023. During this period a total of 12 209 quantum-oriented R&D projects received funding awards, amounting to approximately USD 11 235 million (in purchasing power parity (PPP) terms). The average implied quantum project award size stood at USD 0.92 million (PPP), surpassing the implied average project size across all R&D fields (USD 0.75 million in PPP terms), reflecting a larger average project size. Overall, quantum R&D accounts for around 0.8% of total R&D funding and nearly 0.6% of funded projects in the OECD Fundstat database.

Table 8.2.2

Estimated R&D funding for quantum in the OECD Fundstat database: 2015-2023

R&D funding project awards for 19 OECD countries and EU-EC programmes

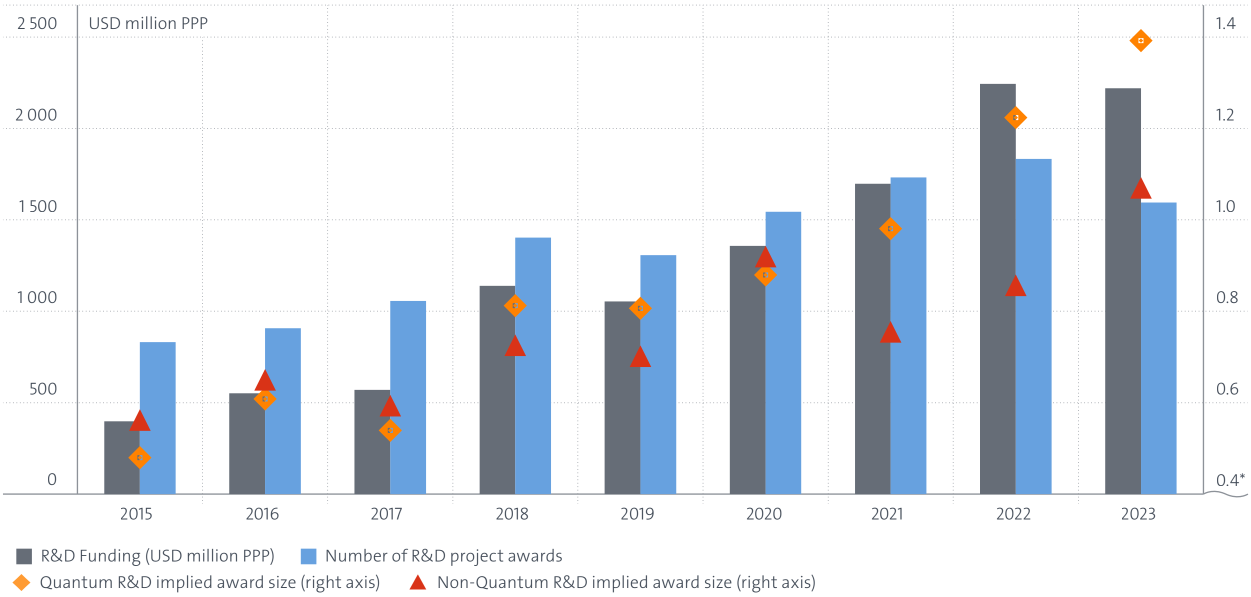
	R&D project awards ("projects")	R&D funding (USD million PPP)	Average award size (USD million PPP)
Quantum R&D	12 209	11 235	0.92
Total	1 964 701	1 475 817	0.75

Source: OECD analysis of the OECD Fundstat database (v.2024), October 2025

Figure 8.2.1 illustrates the growth and rising prominence of quantum R&D funding between 2015 and 2023. The analysis is limited to this period, when the coverage of R&D funding in the OECD Fundstat database relative to OECD R&D budget statistics is relatively stable, and to R&D projects with available funding information. Coverage of R&D funding is heterogeneous across countries and this may affect the representative nature of the projects covered. The project or award-level R&D data represent authorised financial commitments rather than actual expenditure and hence serve as indicative benchmarks rather than definitive measurements of spending. Interpretations of quantum R&D funding trends should be understood bearing this is mind, recognising potential discrepancies. Over the period 2015-2023, the share of quantum R&D funding relative to total R&D funding in the OECD Fundstat database increased

Figure 8.2.1

Estimated annual quantum R&D size: funding and implied award size 2015-2023



Notes: The OECD Fundstat database comprises R&D funding project award data from 19 OECD countries (AU, AT, BE, CA, CH, CZ, DE, EE, FIN, FR, GB, IR, JP, LT, LV, NO, PT, SE, US) and the European Union (EU) – European Commission (EC) programmes. Over the reference period 2015-2023, during which data coverage is stable, the database covers approximately 51% of the government budget allocation for R&D (GBARD) in these 19 countries (excluding general university funds, GUF), as reported in the Main Science and Technology Indicators (MSTI) Database, oecd.org/sti/msti.htm. R&D funding award data reflect authorisations rather than actual commitments or expenditure. Analysis performed on R&D project awards with available funding information.

Source: OECD analysis of the OECD Fundstat database (v.2024), October 2025.

steadily, from approximately 0.4% in 2015 to 1.1% in 2023, supporting the increasing role played by government support highlighted in Section 5. In parallel, the share of quantum-related project awards grew proportionally, reaching nearly 0.8% of all funded projects by the end of the period. The implied award size for quantum R&D peaked in 2023 and has consistently exceeded that of non-quantum R&D projects since 2018, except for 2020 potentially due to shifting priorities during the COVID-19 pandemic.

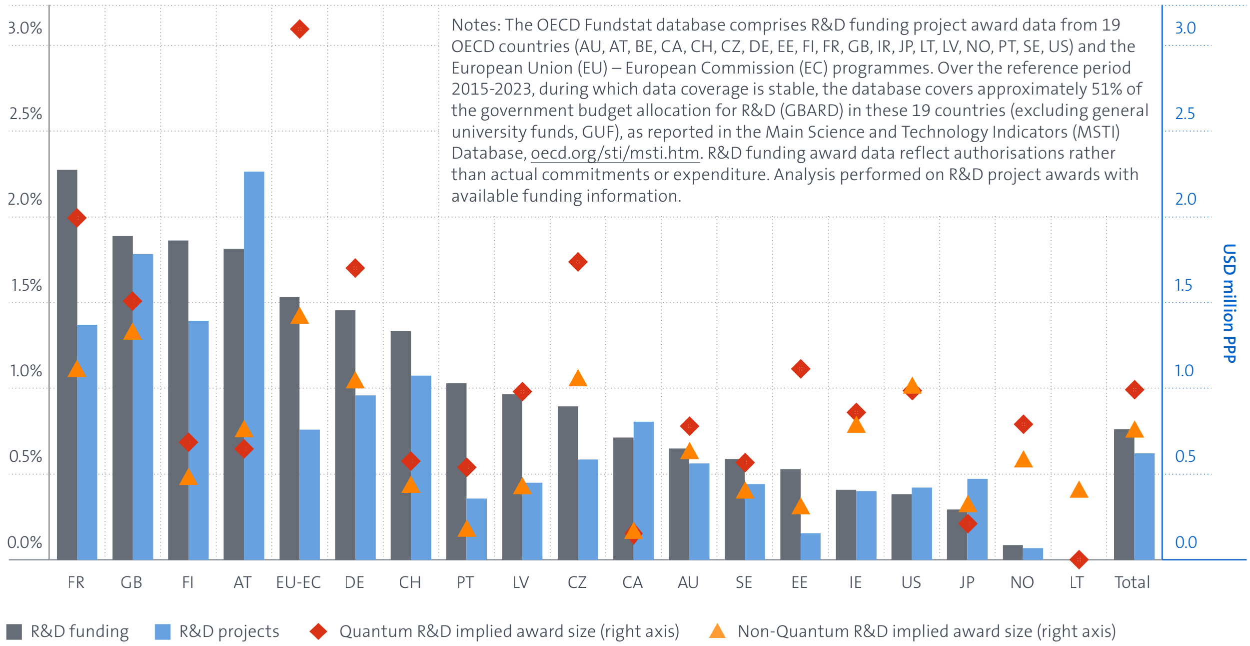
Figure 8.2.2 provides a country-specific perspective, showing quantum R&D investment intensity as a share of each country's total R&D funding recorded in the OECD Fundstat database. The highest share is found in France (2.3%), followed by the United Kingdom (1.9%) and Finland (1.8%). Variation across countries is shaped by the coverage of R&D funding in the OECD Fundstat database, domestic priorities and funding landscape specificities. Smaller economies and specialised research clusters frequently exhibit higher proportional quantum investments compared to larger economies, where quantum research, despite substantial absolute funding, represents a smaller fraction of total national R&D budgets. Additionally, quantum project awards commonly exceed the average sizes of non-quantum projects within countries. The highest implied award size is exhibited by the EU-EC (USD 2.9 million in PPP terms per project), which may be due to specific features of EC programmes, followed by France (USD 1.8 million in PPP terms per project).

Figure 8.2.3 shows each country's share of the total quantum R&D funding within the OECD Fundstat database. Funding concentration is observed in a select few countries, namely the United States (28%), the EU-EC (28%), the United Kingdom (14%), Germany (10%) and France (5%), which were also highlighted in Section 5 as some of those with the most active quantum investors. An experimental specialisation index, sensitive to potential coverage bias, has been computed as the ratio between a country's funding share in quantum relative to the country's total funding and the global funding share for quantum relative to total global funding in the OECD Fundstat database.

Figure 8.2.2

Estimated quantum R&D funding by country/area: 2015-2023

As a share of the country/area's R&D funding

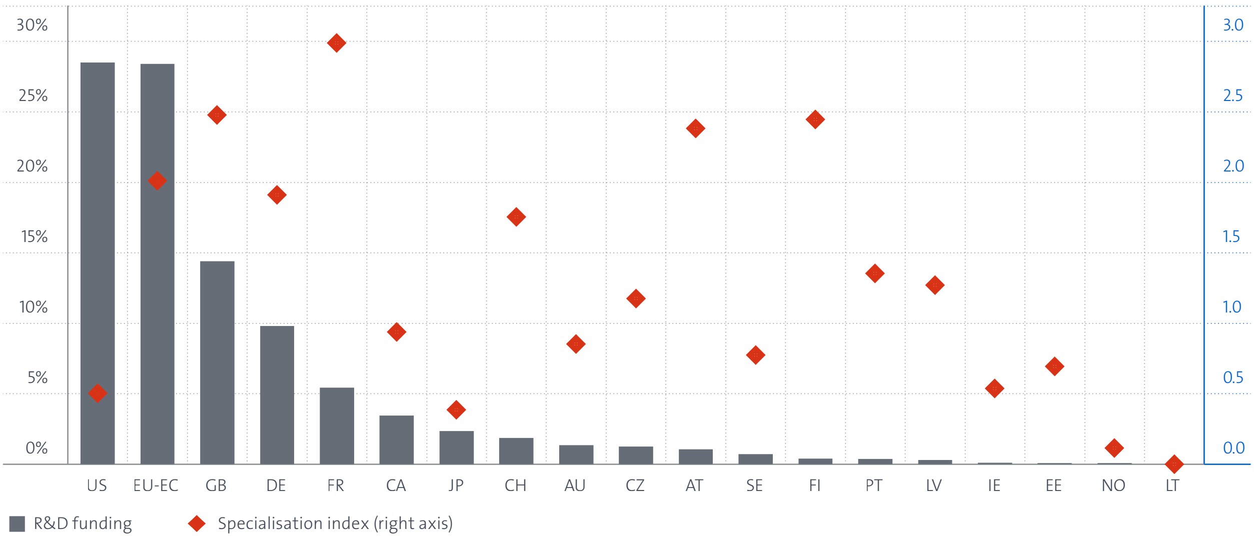


Notes: The OECD Fundstat database comprises R&D funding project award data from 19 OECD countries (AU, AT, BE, CA, CH, CZ, DE, EE, FI, FR, GB, IR, JP, LT, LV, NO, PT, SE, US) and the European Union (EU) – European Commission (EC) programmes. Over the reference period 2015-2023, during which data coverage is stable, the database covers approximately 51% of the government budget allocation for R&D (GBARD) in these 19 countries (excluding general university funds, GUF), as reported in the Main Science and Technology Indicators (MSTI) Database, oecd.org/sti/msti.htm. R&D funding award data reflect authorisations rather than actual commitments or expenditure. Analysis performed on R&D project awards with available funding information.

Source: OECD analysis of the OECD Fundstat database (v.2024), October 2025.

Figure 8.2.3

Distribution of total quantum R&D funding across countries/areas in the OECD Fundstat database: 2015-2023.



Notes: The OECD Fundstat database comprises R&D funding project award data from 19 OECD (AU, AT, BE, CA, CH, CZ, DE, EE, FI, FR, GB, IR, JP, LT, LV, NO, PT, SE, US) and the European Union (EU) – European Commission (EC) programmes. Over the reference period 2015-2023, during which data coverage is stable, the database covers approximately 51% of the government budget allocation for R&D (GBARD) in these 19 countries (excluding general university funds, GUF), as reported in the Main Science and Technology Indicators (MSTI) Database, oecd.org/sti/msti.htm. R&D funding award data reflect authorisations rather than actual commitments or expenditure. The specialisation index is sensitive to potential coverage biases and is computed as the ratio between a country's R&D funding share in quantum relative to the country's total R&D funding and the global R&D funding share for quantum relative to total global R&D funding in the OECD Fundstat database. Values above 1.00 indicate above-average relative specialisation in funding for quantum compared to the global average, while values below 1.00 suggest below-average specialisation.

Source: OECD analysis of the OECD Fundstat database (v.2024), October 2025.

The Covid-19 recovery packages in the European Union, notably NextGenerationEU and its Recovery and Resilience Facility, mobilised large-scale funding to support green and digital transitions, including quantum technologies. Several member states (e.g. Austria, Czechia, Finland, France, Germany, Italy, the Netherlands) used these funds to invest in quantum R&D, infrastructure and collaborative projects, which in turn supported the development or formalisation of national quantum strategies (OECD, 2025c).

This progressive rise of quantum technology R&D funding, displayed in Figure 8.2.1, illustrates how funding for quantum technologies was already increasing even before formal national strategies were established, albeit in a fragmented manner across different institutional channels. For example, prior to 2021, France maintained an annual investment of approximately EUR 60 million in quantum technologies (Office parlementaire d'évaluation des choix scientifiques et technologiques, 2022). The French Defence Innovation Agency (AID), established in 2018, identified quantum technologies as a high-priority area and supported research through a dedicated set of grants (ASTRID) in partnership with the French National Research Agency (ANR) in 2020 (ANR & AID, 2020). Another illustration is the QuantERA Initiative, co-funded by the European Commission and national funding agencies from various European countries since 2014, played a key role in fostering collaborative, multilateral research projects in quantum technologies.[39]

To co-ordinate efforts across ministries and initiatives, mission-oriented innovation policies (MOIPs) are being used in several national quantum strategies. These can help provide innovators with more direction, for instance in better understanding application areas where demand is likely to rise. They can also help set the conditions necessary for coordination and harmonised public actions (Larrue, 2021). This mission-oriented approach plays a particularly important role in the framing of the United Kingdom's national strategy.

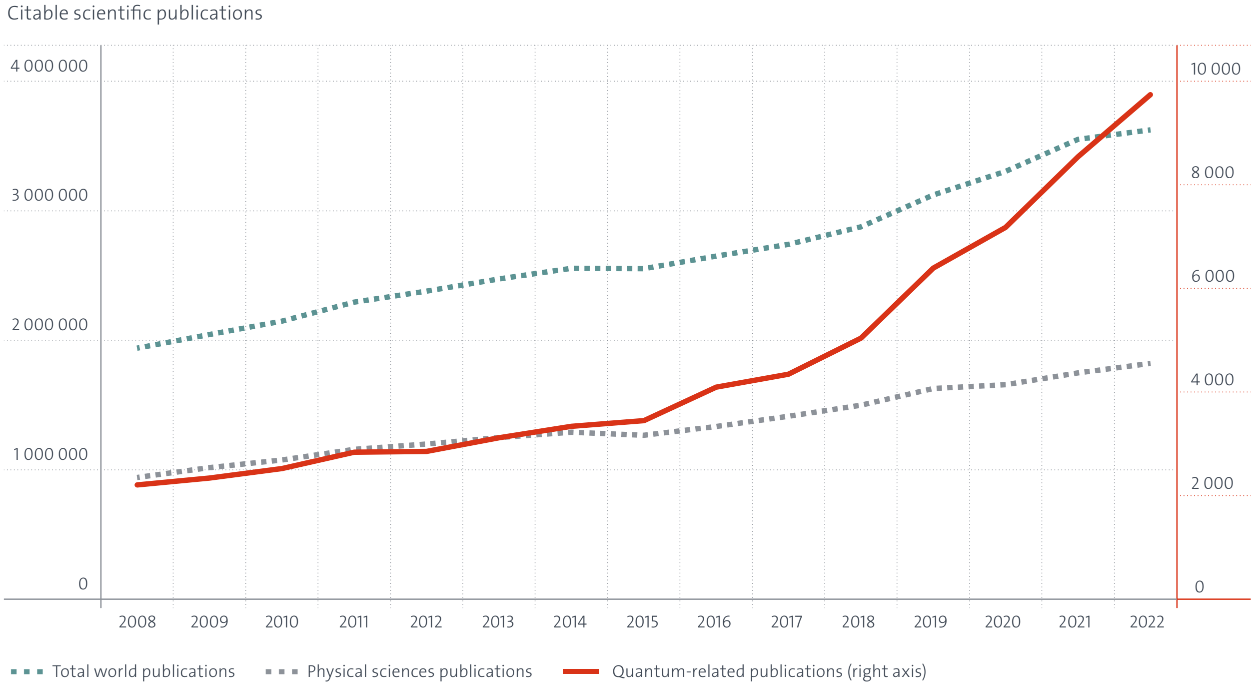
Acceleration programmes in quantum technologies are strategically designed initiatives aimed at rapidly advancing the field from fundamental scientific discovery to practical technological applications and widespread adoption. The French National Quantum Strategy is deeply linked to the broader national innovation agenda, the Programme d'Investissements d'Avenir (PIA) and the France 2030 plan (Ministère de l'Economie, 2021). The strategy has a significant budget, mostly financed by the PIA operating under the France 2030 framework, which aims to invest in key future sectors. The France 2030 plan is a five-year, EUR 54 billion investment initiative aimed at addressing societal and industrial challenges. It prioritises low-carbon energy, industrial decarbonisation, healthcare, digital sovereignty and advanced technologies like quantum. For example, a crucial acceleration programme is the PEPR Quantique (Priority Research and Equipment Programme), which aims to bridge the gap between fundamental research and industrial deployment of quantum technologies.

Global quantum-related publication volumes increased over recent decades, particularly between 2018 and 2022 (mimicking the trend for patents described in Section 3), and faster than the overall output in the physical sciences. This suggests that expanded programme funding and coordination might be associated, at least partially, with higher research output in terms of publications.

39 quantera.eu/about/

Figure 8.2.4

Total number of quantum-related, physical sciences and world publications: 2008-2022



Notes: Citable scientific publications include articles, reviews and conference proceedings. Physical sciences includes the following All Science Journal Classification fields: *15: Chemical Engineering, 16: Chemistry, 17: Computer Science, 19: Earth and Planetary Sciences, 21: Energy, 22: Engineering, 23: Environmental Science, 25: Materials Science, 26: Mathematics, 31: Physics and Astronomy.* This is an experimental indicator. Quantum-related documents among Scopus-indexed scientific publications are identified using a list of established search queries. For more details on the search strategy, see Scheidsteger, Haunschild, Bornmann, & Ettl (2021).

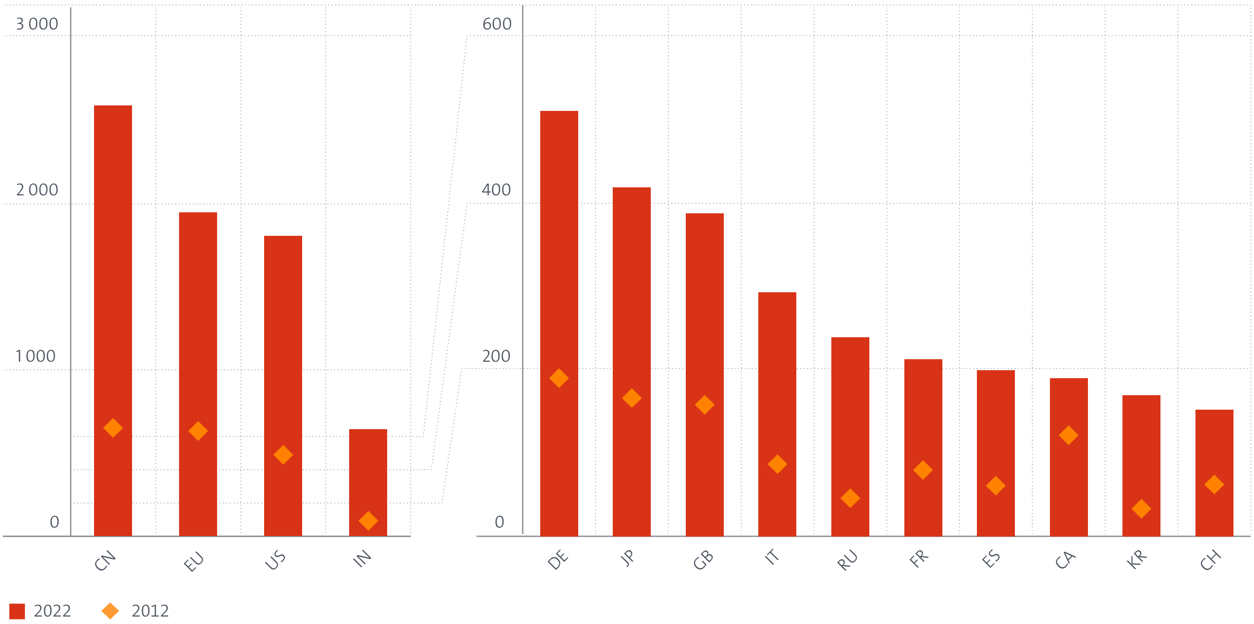
Source: OECD Bibliometric Indicators, calculations based on Elsevier's Scopus Custom Data, Elsevier, Version 1.2024, November 2024.

Over the past decade, absolute publication counts in quantum science and technology increased across all leading countries. This broad-based rise coincides with the multiplication of dedicated national strategies and initiatives among top producers of quantum research (see Figure 8.2.5). However, it has not substantially altered the global distribution of output, with the European Union, the United States and China (which were among the earliest to formalise national strategies) continuing to account for most quantum-related publications globally (see Figure 8.2.6).

Looking at the quality of national research output (shown in Figure 8.2.7), the share of a country's quantum publications in the 10% most cited worldwide, a different picture emerges compared to that seen in total publication counts. While China produces the largest volume of quantum-related papers, only about 11% of its output belongs in the top 10% most cited globally. This aligns with a trend already noted in Section 3, namely China's leading position in terms of raw patent counts; however this required adjustment to reflect the number of IPFs. By contrast, smaller research systems such as that of Switzerland, despite their modest absolute output, show a much higher proportion of highly cited work – around 38% in the Swiss case. Figure 8.2.7 also shows that countries with a higher level of international co-authorship tend to also have a stronger citation performance in quantum science.

Figure 8.2.5

Top countries with quantum-related publications, numbers: 2012 and 2022

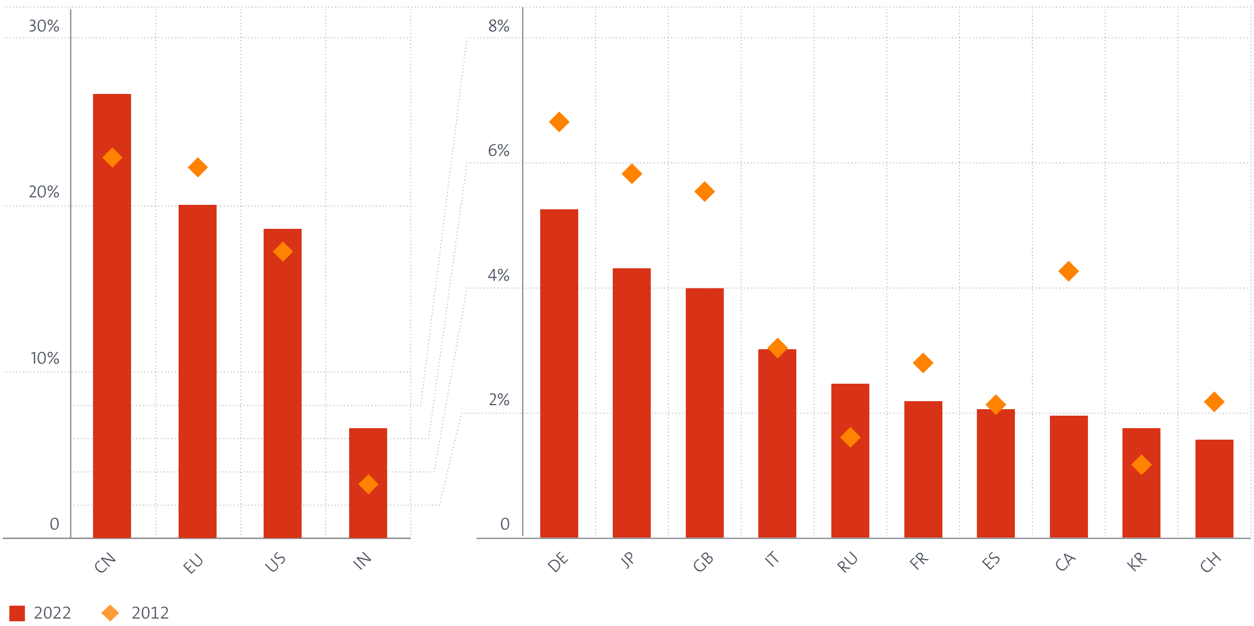


Notes: Data refer to citable scientific publications by country of affiliation of the authors, using fractional counts. Citable scientific publications include articles, reviews and conference proceedings.

Source: OECD Bibliometric Indicators, calculations based on Elsevier's Scopus Custom Data, Elsevier, Version 1.2024, November 2024.

Figure 8.2.6

Top countries with quantum-related publications, percentages: 2012 and 2022

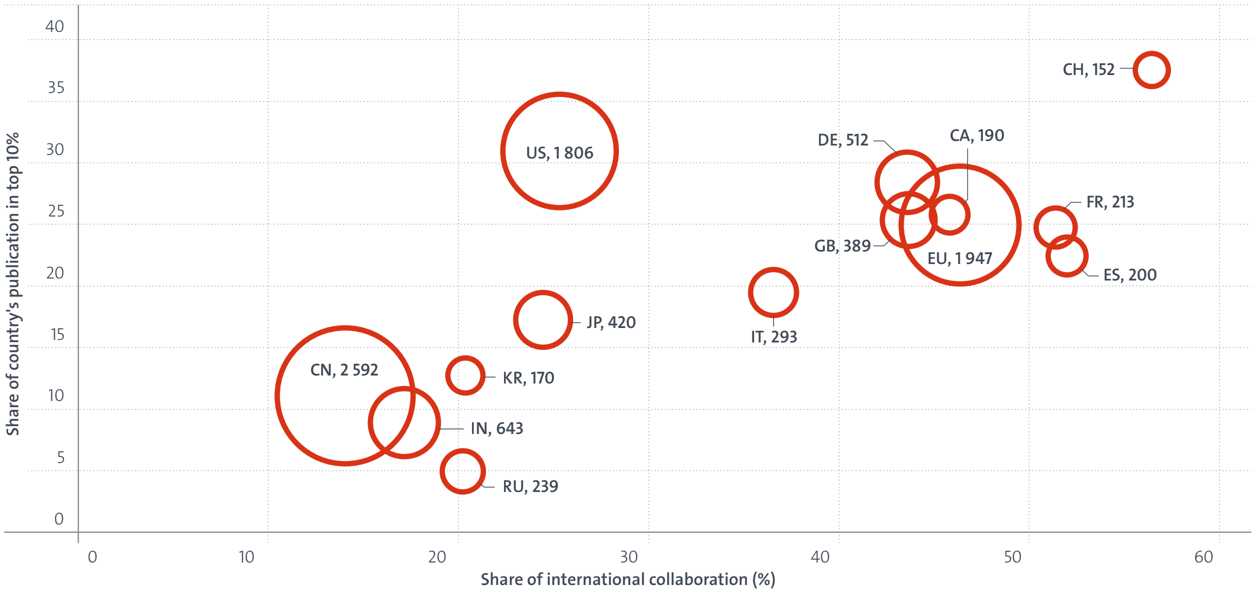


Notes: Data refer to citable scientific publications by country of affiliation of the authors, using fractional counts. Citable scientific publications include articles, reviews and conference proceedings.

Source: OECD Bibliometric Indicators, calculations based on Elsevier's Scopus Custom Data, Elsevier, Version 1.2024, November 2024.

Figure 8.2.7

Top countries with top 10% quantum-related publications intensity and their international scientific collaboration intensity: 2022



Notes: Share of country's publication in top 10% refer to domestic quantum-related publications in global 10% most cited, as a percentage of all domestic quantum-related publications, based on fractional counts.

Source: OECD Bibliometric Indicators, calculations based on Elsevier's Scopus Custom Data, Elsevier, Version 1.2024, November 2024.

The generic observation that international co-operation is beneficial for research is especially the case in the field of quantum. International co-operation is recognised as important in most countries' national strategies. This is illustrated by the intensity of international collaboration in quantum, which has historically been marked compared to other domains (OECD, 2025c. However, the longitudinal data reveal that while quantum research had a consistently higher level of internationalisation than physical sciences and all fields of science throughout the period 2008-2022, collaboration intensity began to level off and then decline, with international co-authorship rates falling from around 33% to below 30% during the period 2019-2022. This recent slowing could be a sign of changes in key features of quantum research internationally, including, most notably of rising geopolitical tensions around technologies deemed critical and associated policies such as the widened use of export controls with a bearing on quantum technologies (OECD, 2025c).

8.3 Strategy instruments: a renewed emphasis on industry and commercial applications

While science and research have been a policy focus for the initial elaboration of national strategies and initiatives, recent trends in quantum strategies show a renewed emphasis on industry engagement and the development of commercial applications. One example can be found in the ongoing work on the future of quantum policy at European Union level; the Quantum Europe Strategy unveiled in July 2025 is the culmination of a self-assessment of past efforts. The core finding was the recognition that, despite its concentration in quantum talent and competitive output in scientific publications, the EU was "lagging behind in translating its innovation capabilities into real market opportunities". (European Commission, 2025).

8.3.1 Commercialisation of academic research

Government interest in commercialising quantum research reflects a range of motivations. At a macroeconomic level the push seeks to enhance national competitiveness and maximise the return on public investment in science. At the institutional level, rising research costs increasingly drive universities and PROs to diversify their funding sources. On the business side, firms are outsourcing more of their R&D to public institutions, particularly in basic science, which accentuates the importance of structured pathways for commercialisation. Government action therefore plays a pivotal role, not only in direct funding but also in shaping the frameworks, incentives and institutional environments that support the translation of research outcomes into market applications.

These dynamics play out in similar fashion for quantum science and technology, but with sharper challenges. Universities are key members of the quantum ecosystem (see Section 4) and account for a significant share of innovative outputs in the field of quantum technologies (see Section 3); however, finding commercial applications remains difficult, not just for universities but in the ecosystem in general. National initiatives illustrate the breadth of approaches taken. Italy's National Quantum Science and Technology Institute (2023-2026) channels around USD 120 million into a consortium of 20 research centres, aiming to span basic research through to prototype development, with a strong focus on academic spin-offs and industrial innovation. Austria's Quantum Science Austria initiative (2023-2029) aims to build a cluster of excellence anchored at the University of Innsbruck, combining interdisciplinary research with outreach and technology transfer programmes. Beyond the OECD, Brazil's Competence Centre for Quantum Technologies (2022-2027, USD 10 million) similarly fosters market-driven research, startup creation and international collaboration (OECD, 2025c).

For economies with dedicated quantum strategies, the issue of commercialisation has become a renewed priority, particularly at a time when several strategies are undergoing revision, updating and evaluation. The US National Quantum Initiative Reauthorization Act of 2024 rebalanced priorities from basic research towards applied development, creating new testbeds and prize challenges, and formalising the inclusion of agencies such as the National Institutes of Health and the Small Business Administration (United States Senate Committee on Commerce, Science and Transportation, 2024). In Europe, internal evaluations of the Quantum Flagship revealed lagging performance in turning research into market opportunities, due to lack of coordination across member states' policies (European Commission, 2025). The 2025 Quantum Europe Strategy proposes coordinated pan-European infrastructure, pilot production lines and a Quantum Skills Academy, with the forthcoming European Quantum Act expected to codify these efforts by 2026.

OECD work has consistently underlined that successful commercialisation does not follow a single pathway but depends on a wide array of mechanisms (OECD, 2015). These range from public-private collaborative research projects, faculty mobility and consulting, and contract research to academic entrepreneurship. To support these diverse channels, intermediary organisations have proliferated; they include, including technology transfer offices, incubators, accelerators and science parks. Governments in turn can strengthen these structures by ensuring access to seed funding, supporting proof-of-concept grants and fostering connections between academia and industry. IP policies are central; landmark frameworks such as the US Bayh-Dole Act (1980) empowered universities to own inventions from federally funded research, spurring a wave of academic patenting (OECD, 2013). Other measures include collaborative IP tools, guidelines for knowledge transfer and funding incentives that reward institutions excelling in commercialisation.

8.3.2 Technology adoption

Even though most quantum technologies have low levels of technology readiness, preparation today can influence business' adoption timelines tomorrow (OECD, 2025a). Studies of technology diffusion in firms show that disruptive innovations often diffuse slowly, even after becoming commercially available. Existing research suggests that a complex interplay of factors drives the adoption of advanced technologies (Jibril & Stephen, 2025). Several theoretical models developed since the 1960s frame these dynamics (see for example: Rogers, 1962; Davis, Bogozzi and Warshaw, 1989; Lai, 2017 and Tornatzky & Fleischer, 1990).[40]

40 Rogers (1962) emphasises adopter categories and the attributes of innovations such as relative advantage, compatibility and complexity as central drivers of diffusion. The Technology Acceptance Models (TAM) found in the work of Davis, Bogozzi and Warshaw (1989) and Lai (2017) explain individual technology adoption through two key perceptions: usefulness and ease of use. The Technology-Organisation-Environment Framework (TOE) from Tornatzky and Fleischer (1990) shifts the focus to the organisational level, recognising technological, organisational and environmental factors as joint determinants of adoption.

Velu et al. (2023) address adoption challenges facing firms in relation to quantum technologies, drawing parallels with the classical computing revolution. Likewise, in a series of interviews conducted with quantum stakeholders in Germany and the Netherlands, Martens et al. (2025) identify eleven barriers to the uptake of quantum computing. These reflect limitations and uncertainty in the technology itself, and the challenges to knowledge transfer and collaboration between academia, industry, policymakers and society. These topics are shown in Table 8.3.1.

Table 8.3.1

Barriers to quantum adoption

Barrier	Themes
Limited relevance	Limited to resolving specific classes of problems; continuous relevance of classical computers
Incompatibility with classical computing	A significant shift from classical computing; incompatibility with the skills of the existing workforce and IT infrastructure in a company
Cost and time of knowledge acquisition	Need for quantum computing expertise; lack of access to quantum experts; building quantum expertise is a difficult and lengthy process
Inequalities and conflicting objectives of stakeholders	Unequal access to quantum computing resources; diverse and conflicting incentives for engagement with quantum computing
Difficulty in identifying problems and their quantum solutions	Difficulty in recognising business problems where quantum computing is applicable; difficulty in defining business problems accurately and in detail to enable their mapping to computational problems
Uncertainty in advances in quantum computing	Uncertainty in the timeline of quantum computing development; uncertainty in the capabilities and use cases of the next-generation quantum computers; quantum hype and the spreading of misinformation
Shallow engagement	Engagement for PR purposes only; engagement to keep in touch with the technology development
Challenging communication	The perceived complexity of quantum theory; diversity in target groups; difficulty in selecting the appropriate level of complexity for target groups
Limited exemplary use cases	Businesses have difficulty finding exemplary use cases in quantum research publications; researchers have difficulty in getting actual or illustrative use cases from businesses
Limited capabilities of quantum computers	The lack of quantum computers (with sufficient qubits); its negative impact on research, investment from business, and the quantum software market
Insignificant or unclear business impact	A quantum solution does not improve the business sufficiently; the cost of replacing an existing classical solution is higher; unclear impact of a quantum investment

Notes: The barriers are ordered according to the number of interview respondents who identified them as relevant, with those discussed most frequently listed first. This table provides a selection of incipient examples of institutions and initiatives that actively support the diffusion of quantum technologies. The examples are not exhaustive, but intended to illustrate the range of early efforts.

Source: OECD elaboration, adapted from Martens, et al. (2025)..

8.4 Conclusion

The multiplication of national quantum strategies illustrates the growing policy attention devoted to this field. Governments have expanded their initial focus from defence and security to broader objectives, including scientific capacity, industrial competitiveness and workforce development. Substantial public funding has supported these ambitions, increasingly framed through mission-oriented approaches. Yet funding alone is not sufficient to guarantee impact; even when quantum technologies achieve high levels of technical readiness, adoption barriers are likely to be high, with firms struggling to identify relevant uses. Policy instruments are, in consequence, shifting from a focus on individual measures to strengthen scientific capabilities to fostering ecosystem adoption, supporting commercialisation and encouraging early experimentation with quantum technologies in industry. Maintaining balanced support for basic research while supporting translation into applications, helping ensure public investments generate both scientific and industrial impact, will be a key challenge for policymakers in the years ahead.

Topics related to quantum science and technology and the policies that support their development are also the subject of other OECD work which, among other things, provides resources giving further detail on some of the points in this report, and offers other foci and types of analysis. The Quantum Policy Primer (OECD, 2025a), the Overview of Quantum Strategies and Policies (OECD, 2025c) and forthcoming reports offer a broad perspective on quantum ecosystems, strategies and policies. These resources also contain deep dives into several individual country ecosystems and instruments, together with a general discussion of the technologies, their applications and the related challenges for policymakers.

9. Concluding remarks

Quantum developments in communication, computing and sensing represent foundational next-generation technologies with the potential to drive substantial societal and economic progress. Despite this transformative promise, quantum technologies remain at an early stage of maturity: multiple technological pathways continue to coexist, commercialisation is still limited and advances rely on sustained progress in scientific research, skills, finance and access to critical inputs. Research organisations, startups, established companies and policymakers form a growing quantum ecosystem that is dedicating significant resources to bringing quantum science closer to practical applications. Understanding these dynamics is essential to align efforts across the ecosystem and turn quantum potential into real-world impact.

This joint EPO-OECD study provides a comprehensive mapping of the global quantum ecosystem. The analysis offers an overview of innovation activity based on patent data, describes the characteristics of the firms active in the ecosystem and examines investment patterns across countries and technologies. It also examines the skills in demand and the supply chains for quantum-relevant equipment, goods and raw materials. Finally, the report assesses government actions to promote and stimulate quantum development.

The findings reveal that the quantum ecosystem is expanding rapidly, with innovation activity, firm entry and investment all on the rise. Across technological areas, quantum communication continues to play a central role, yet quantum computing has emerged as the most dynamic area, recording the fastest growth in both firms and patent activity. Geographically, the US stands out as the leading player across all quantum domains in terms of firm entry, innovation output and total investment mobilised. Europe follows as the second most important global hub, with the United Kingdom, Germany, France, the Netherlands, Finland and Switzerland all contributing significantly. Other countries, including Japan, China, Korea and Canada, also play major and complementary roles in shaping the emerging global quantum landscape.

The ecosystem combines a relatively small group of "core" companies focused on developing quantum and quantum-enabling technologies with a much broader set of established organisations whose main business lies outside quantum technologies. This wider group drives much of today's innovation and labour demand and is also well placed for future commercialisation, as established players can integrate quantum technologies into their existing operations once the technologies mature. By contrast, core companies are typically startups that rely heavily on early-stage investment and public funding for scaling up deep-tech.

Investment in those core quantum companies has grown significantly over the past decade, driven by both private and public actors. Large funding rounds, including those involving corporate venture capital, signal the sector's gradual maturation, even as recent investment patterns point to some moderation in growth. Public support remains essential given the long development timelines, scientific uncertainty and high capital requirements associated with quantum technologies.

The ecosystem as a whole remains in a pre-commercial stage and several bottlenecks could slow the transition from scientific advance to market deployment. The industry is still strongly science-driven, with highly educated founders and a workforce concentrated in technical and research roles. At the same time, trade data suggest rising concentration and dependencies for key raw materials, components and specialised equipment, highlighting potential supply-chain vulnerabilities that may become increasingly important as the ecosystem scales.

Governments have recognised these developments and responded with a proliferation of national quantum strategies, accompanied by growing levels of public R&D funding. Recent policy initiatives increasingly focus not only on scientific excellence but also on strengthening industrial competitiveness, supporting technology adoption and helping firms to navigate early experimentation and commercialisation. Ensuring steady progress will require a balanced mix of support for basic research and incentives to translate it into applications, alongside efforts to build resilient value chains and deepen talent pipelines.

Taken together, the evidence presented in this report underscores both the promise and the fragility of the quantum ecosystem. The field benefits from strong scientific foundations, sustained policy attention and growing private-sector participation. Yet it also remains highly dependent on specialised skills, vulnerable supply chains and evolving technologies whose dominant paradigms have not yet emerged. Strengthening co-ordination across research, industry and policy communities, as well as across countries, will be essential to ensure that scientific breakthroughs have a widespread economic and societal impact.

This joint effort by the EPO and the OECD reflects an ongoing commitment to providing the evidence base needed to support scientific and industrial competitiveness. By offering rigorous insights into the opportunities and challenges of quantum technologies, this study seeks to support policymakers and the wider quantum community in guiding the field's evolution toward broad economic and societal benefit.

Case study: C12

Headquarters	Paris, France
Founded	2020
No. of employees	60
Products	Carbon nanotube quantum processors and emulator for algorithm development and testing for quantum applications
Webpage	www.c12qe.com
Full EPO innovation case study	link.epo.org/elearning/en-sme-case-study-c12.pdf

C12 Quantum Electronics, a Paris-based spin-off from the École Normale Supérieure (ÉNS), has emerged as one of Europe's most promising deep-tech ventures. The company was founded by twin brothers Matthieu and Pierre Desjardins and builds quantum computers using carbon nanotubes, a novel approach that promises unprecedented stability and scalability. Alongside its hardware roadmap, C12 introduced a cloud-based quantum emulator that allows researchers and businesses to experiment with quantum algorithms before physical processors are available. In just five years, C12 has grown from a lab experiment into a 60-person team with €30 million in funding, a robust intellectual property portfolio and recognition from leading innovation programmes.

Turning discovery into advantage

In a pivotal experiment at ÉNS, researchers successfully coupled an electron spin in a carbon nanotube to a microwave photon, creating a highly stable quantum bit (qubit). The achievement addressed one of quantum computing's biggest challenges: error-prone qubits. Matthieu and Pierre immediately recognised the commercial potential of the research and partnered with CNRS Innovation to prepare a spinout and secured an exclusive license for the foundational patent. This early IP move gave C12 freedom to operate and credibility with investors.

The brothers combined complementary skills when they established C12. Matthieu brought scientific depth as a quantum physicist, while Pierre contributed business insight and fundraising expertise. Together, they accelerated the transition from research to commercialisation, raising €10 million in seed funding by 2021 and filing additional patent families.

Matthieu (left) and Pierre (right) Desjardins, co-founders of C12

IP at the core

From the outset, C12 adopted a "patent-first, publish-second" approach. Before any scientific results were shared, the company ensured protection through patents or trade secrets. The strategy has produced a portfolio of several patent families across Europe, the US and Asia, covering nanotube qubit design, fabrication methods and readout techniques.

Patents safeguard visible innovations, such as device architecture and assembly processes, while trade secrets protect internal know-how, including calibration algorithms and nanotube growth recipes. This layered approach creates strong barriers for competitors and reassures business partners and investors.

C12 also implemented structured IP management early on. Invention disclosures are reviewed quarterly, and filing decisions are based on strategic relevance and enforceability. Freedom-to-operate analyses and patent landscape reviews guide portfolio development, ensuring that filings target genuine white space in the quantum IP landscape.

Growth enabler

By 2025, C12 had raised approximately €30 million in equity financing from venture firms and public programmes, including 360 Capital, Varsity Capital, Airbus Ventures, Bpifrance and the European Innovation Council Fund. These resources enabled C12 to scale rapidly from two founders to more than 60 employees, including 20 PhDs in quantum physics, nanofabrication and software engineering.

C12's cleanroom

The company invested in a custom nano-fabrication lab in Paris, giving it direct control over critical manufacturing processes and know-how. The facility includes a cleanroom, nanotube growth equipment and dilution refrigerators for cryogenic testing. At the same time, C12 has established several partnerships, such as with CEA-Leti for advanced semiconductor processes, combining in-house capability with external expertise.

Deep-tech ventures require significant upfront investment due to long R&D cycles and specialised infrastructure. C12's ability to secure funding reflects investor confidence in its IP position and technical roadmap. For investors, an IP strategy was not a formality, it was the foundation of the business.

The quantum computing conundrum

Quantum computers exploit quantum phenomena such as superposition and entanglement to solve problems beyond the reach of classical machines. The main obstacle is error: qubits are fragile and easily disturbed. C12's approach uses carbon nanotubes to create spin qubits, offering intrinsic stability and long coherence times, essential for error correction. These qubits are integrated on silicon chips using CMOS-compatible processes, paving the way for industrial-scale manufacturing. Competing platforms, such as superconducting circuits or trapped ions, face challenges in scalability or noise control. C12's nanotube qubits combine high performance with a practical path to mass production.

In 2023, the company launched Callisto, a cloud-based quantum emulator developed with OVHcloud. Callisto allows researchers and companies to test algorithms on a realistic model of C12's hardware, accelerating application development ahead of physical quantum processors. This early engagement strategy ensures that when C12's hardware is ready, a community of users and proven use cases will already exist.

Finding the right partners

Strategic collaborations have helped the company to accelerate development and align its technology with real-world needs. Academic ties with ÉNS and CNRS ensure access to cutting-edge research and talent. Industrial partnerships with OVHcloud, Thales, Air Liquide and TotalEnergies help validate use cases in sectors such as energy, aerospace and logistics. These collaborations follow clear IP frameworks: C12 retains ownership of core technology where possible, while co-developed applications are shared under negotiated terms that reflect business interests of all partners.

Attracting attention

Though still a young company, C12 has already earned a strong reputation in the quantum technology ecosystem. It secured the i-Lab Grand Prize in 2021, was named a French Tech 2030 laureate in both 2023 and 2025 and received support from the EIC Accelerator in 2022. Other distinctions include a category win in the Hello Tomorrow Global Challenge and participation in Creative Destruction Lab's quantum stream.

As quantum computing moves from research to industry, C12's combination of breakthrough science, disciplined IP strategy and collaborative ecosystem positions it as a frontrunner. Its story illustrates how intellectual property can transform a laboratory discovery into a globally competitive technology platform.

Case study: PASQAL

Headquarters	Paris, France
Founded	2019
No. of employees	300
Products	Neutral atom quantum computers, application software and cloud services
Webpage	www.pasqal.com
Full EPO innovation case study	link.epo.org/elearning/en-sme-case-study-pasqal.pdf

Pasqal has progressed from foundational physics research to industrial deployment on a global scale. Founded in 2019 as a spin-off from the Institut d'Optique Graduate School, the company's technology builds on the Nobel Prize-winning work of Alain Aspect, who now serves as president of its Scientific Advisory Board. The company underpins its advanced neutral-atom quantum processing units (QPUs) with a robust IP strategy. Its focus on quality patents, complemented by a strong corporate standardisation strategy, targeted acquisitions, and public procurement and grants, has enabled the company to secure over €125 million in funding. The company is today recognised as a leader in quantum computing with operations in Europe, North America, Asia and the Middle East.

Moving beyond theory

The origins of Pasqal's technology stem from decades of research into controlling individual atoms with laser light. When the company was founded in 2019, the transfer of technology from the Institut d'Optique relied on an initial patent, proprietary know-how, trade secrets and the involvement of researchers from the Institut d'Optique's scientific team, who later became founders. This approach ensured the effective transfer of intellectual assets and made IP a key foundation for building a commercial enterprise.

Pasqal develops quantum processors based on neutral atoms that function as high-performance qubits. Using precisely controlled laser light to trap and manipulate these atoms, the processors deliver capabilities beyond those of classical computers. The company offers both on-premises hardware (QPUs) and cloud-based access through its own platform and via major providers such as Google Cloud, Microsoft Azure Quantum, OVHcloud and Scaleway.

Validation and early adoption of its technology have been supported by public procurement programmes, including those led by the European High Performance Computing Joint Undertaking (EuroHPC). This model has helped accelerate the technology's industrial readiness in real computing environments at customer sites and broaden its use for Europe's strategic quantum computing initiatives. These deployments accelerate technical maturity and market adoption, and strengthen Europe's supply chain resilience by equipping it with critical quantum computing capabilities.

Business model

Pasqal's business model combines on-premise hardware delivery with cloud-based access. The primary business stream is delivering quantum computers to high-performance computing (HPC) centres and industry. Since 2024, Pasqal has installed two 100-qubit systems in France and Germany, and one 200-qubit system in Saudi Arabia, with further deployments planned in Canada and Italy in 2026. Each installation includes maintenance services and is supported by software tools such as Pulser and Pulser Studio, which help users develop and optimise quantum algorithms. Most of the software is open source to encourage market adoption across key economic sectors.

The second business stream is cloud access to Pasqal's quantum processors via its own platform and major providers. While on-premise delivery of quantum computers currently dominates user demand, this is expected to shift towards cloud-based services as the technology matures. Public procurement instruments, notably EuroHPC, play a key role in early adoption by enabling deployments in HPC centres and providing quantum access to researchers and SMEs, both of which can also provide operational feedback on access to the quantum computers.

The two-tier approach

Pasqal's IP strategy swiftly transitioned from securing foundational assets to developing a fully-fledged portfolio encompassing about 90 patent families that protect both hardware and computer-implemented inventions (CII), alongside trade secrets, copyrights on software, and trade marks for branding.

The company's patenting strategy works on two complementary levels. First, it protects the core hardware and system architecture to ensure freedom to operate and guard against imitation. Second, it secures patents for inventions that improve performance, such as error-correction methods. This strengthens the company's competitive position as quantum processors mature. A dedicated corporate IP governance structure, with an IP department and an executive IP committee, manages decisions on which inventions to patent.

Further, Pasqal has strategically used mergers and acquisitions. For example, it acquired the Canadian photonic integrated circuits specialist Aeponyx in 2025. This move strengthened the company's patent portfolio, while integrating essential know-how and technical expertise.

Balancing openness with protection

An important part of Pasqal's go-to-market strategy is its balanced approach to software IP. To encourage adoption and maximise the utility of its hardware, much of the underlying software, including programming tools such as Pulser, is intentionally released as open source.

When an invention delivers a technical effect that offers a competitive advantage, such as algorithms for optimising hybrid quantum-classical workflows, patent protection is actively pursued. In these cases, the company avoids standard open-source licences that automatically grant patent rights to users, thereby preventing implied patent licensing. Instead, Pasqal applies a tailored licensing approach that allows software to be shared openly while maintaining control over patented technologies and preventing unintended transfer of exclusion rights.

The company also manages the balance between scientific publication and IP creation. It recognises that credibility in the fast-moving quantum field depends on scientific output, so rigorous internal clearance processes are in place. Patent drafting can be accelerated when deadlines loom, such as PhD defences or conference submissions. All managers and staff receive IP training to assess patent potential and trade secret risks before any public disclosure. This ensures that scientific achievements strengthen the company's reputation without compromising patentability.

Scaling and investment

The impact of Pasqal's IP strategy is reflected in its fundraising journey. Intellectual property played an important role in securing both Series A (€25 million) and Series B (€100 million) rounds.

In the seed and Series A phases, investor focus was on ensuring Pasqal's core technology was properly protected while the company maintained freedom to operate. Investor expectations evolved at Series B, and they wanted a detailed, robust and well-structured IP strategy aligned with the company's technology roadmap and business objectives. Pasqal demonstrated how its expanding portfolio would support future development, providing confidence to attract global investors such as Temasek and the European Innovation Council (EIC) Fund. This approach also helped secure grants from public entities such as Bpifrance and the EIC.

Future-proof patent protection

Pasqal's global go-to-market strategy includes broad geographical patent coverage, focusing on Europe, North America and Asia. The company uses the Patent Cooperation Treaty (PCT) system to maintain flexibility, allowing it to postpone national phase entry decisions until market conditions justify the investment.

In Europe, Pasqal has adopted the Unitary Patent system for its latest granted patents after a positive cost-benefit analysis. This approach replaces traditional national validation and provides streamlined protection across multiple EU jurisdictions. Confidence in the Unified Patent Court (UPC) and its consistency in decision-making were key factors in this corporate choice.

Pasqal also holds a leading position in shaping industrial quantum computing standards at the European and international levels. The company serves as convenor of Working Group 3 on Quantum Computing and Simulation Standards within the Joint Technical Committee 22 (JTC22) of the EU-recognised standardisation bodies CEN and CENELEC. Proactive involvement in shaping European quantum computing standards is considered key for the company, given the rapid technological and industrial maturation of its systems, which are already deployed in several countries. First, it ensures that Pasqal will be able to build quantum computers compatible with classical computing infrastructure, and thereby support market adoption. Second, it reduces the risk of market lock-out by ensuring that standards are designed to align with the technical specifications of Pasqal's technology.

Annex

A.1 Quantum patent cartography: supplementary material

Table A1.1

Quantum subdomain definitions

Area / fields and subfields		Description
1. Quantum communication	1.1 Optical realisations	Technical adaptations to improve stability, efficiency and error rates in transmitting quantum information using optical systems.
	1.2 Quantum memories	Devices capable of storing quantum states with long coherence times, essential for long-distance communication (e.g. satellite-based networks with non-trusted nodes).
	1.3 Quantum key distribution (QKD)	Secure communication through quantum-encrypted keys.
	1.4 Quantum information networks	Architectures linking quantum devices (computers, sensors) via quantum states (typically photons), forming the backbone of a future quantum internet.
2. Quantum computing	2.1 Models	Conceptual frameworks for processing quantum information, including gate-based, adiabatic, measurement-based models and quantum simulations.
	2.1.1 Simulation	Use of quantum models to simulate complex physical, chemical or material processes, showing substantial patenting activity.
	2.1.2 Non-simulation models	Theoretical or practical computing models beyond simulation, aimed at general-purpose or specialised computation.
	2.2 Physical realisations	Hardware platforms for building quantum computers, such as superconducting circuits, trapped ions, spins and photonics.
	2.2.1 Super-conducting	Circuits based on superconducting materials; currently the most advanced platform for commercialisation.
	2.2.2 Trapped ion or atom	Systems using individual ions or atoms as qubits, offering long coherence times and high precision.
	2.2.3 Spin-based	Approaches exploiting electron or nuclear spins, often in solid-state systems such as semiconductors or diamond defects.
	2.2.4 Quantum optics	Computing schemes based on manipulating photons as qubits.
	2.2.5 Others	Alternative or emerging approaches not yet dominant (e.g. topological qubits).
	2.3 Algorithms	Quantum-specific algorithms designed to leverage quantum speed-up, including optimisation and cryptographic applications.
	2.4 Error correction	Techniques for stabilising fragile quantum states against noise and decoherence, a prerequisite for scalable systems.
	2.5 Programming	Development of software, languages and frameworks tailored to quantum hardware.
	2.6 Others	Miscellaneous computing-related filings not captured by the categories above.

Area / fields and subfields		Description
3. Quantum sensing	3.1 Gravitation, rotation, acceleration	Devices such as cold atom interferometers enabling ultraprecise measurements of gravity, acceleration and rotational forces.
	3.2 Time	Quantum clocks with unprecedented accuracy (up to 10-18), with applications in navigation, geodesy and fundamental physics.
	3.3 Magnetic fields	Sensors exploiting quantum properties for extremely sensitive detection of magnetic phenomena.
	3.4 Chemical detection	Quantum-enabled methods for identifying minute chemical or biological changes with high specificity.
	3.5 Imaging	Imaging systems using quantum correlations (e.g. entanglement) to enhance resolution, sensitivity or contrast beyond classical limits.

Table A1.2

Randomly selected highly cited quantum applications in the dataset

Patent	Top inventions: forward citations	Applicant	Pub. year	Citations
EP3456083	Network architecture, methods, and devices for a wireless communications network	Ericsson Telefon AB LM [SE]	2019	860
EP2484045	Apparatus for use in quantum key distribution	Qinetiq LTD [GB]	2012	150
EP2156617	Enhancing security in a wireless network	Hart Comm Foundation [US]	2010	446
EP2320344	Key generation	Massachusetts Inst Technology [US]	2011	407
EP3642959	Parametrically activated quantum logic gates	Rigetti & Company [US]	2018	85
EP2915021	System and method for developing, updating, and using user and device behavioral context models to modify user, device, and application state, settings and behavior for enhanced user security	Lookout INC [US]	2015	288
EP1851693	Analog processor comprising quantum devices	D-Wave Systems Inc. [CA]	2007	264
EP3111380	Processing signals in a quantum computing system	Rigetti & Company [US]	2003	251
EP3127266	System and method for communication using orbital angular momentum with multiple layer overlay modulation	Nxgen Partners IP LLC [US]	2017	185
WO2009073736A1	Spin based magnetometer	Harvard College [US]	2009	167
WO2013040446A1	High-precision GHZ clock generation using spin states in diamond	Univ Columbia [US]; Harvard College [US]	2016	72

Table A1.3

International collaboration between different applicants (not MNE subsidiaries)

APPLICANT 1	APPLICANT 2	PATENTS
GB	US	42
US	JP	39
US	NL	37
CA	US	36
DE	US	29
US	CN	21
FR	US	19
US	CH	11
US	KR	11
SG	US	10
FR	CA	9
US	SA	9
CA	NL	9
SA	US	9
VG	US	8
NL	FR	8
KR	CH	8
CN	TW	8
HK	CN	7

Notes: this table shows the number of IPFs involving applicants from two different economies, where applicants are not part of the same corporate group. EPC member states shown in red, EU member states with a coloured background.

Table A1.4

List of organisations involved in international collaboration

Applicant	Location	Co-applicant	Location	Patent families
QUBITEKK	US	QINETIQ	GB	8
PRAD R&D	VG	SERVICES PETROLIERS SCHLUMBERGER	FR	5
TELECOM	KR	ID QUANTIQUE	CH	5
STANFORD UNIV	US	JAPAN SCI & TECH AGENCY	JP	4
DELFT UNIV OF TECH	NL	INTEL	US	4
FOXCONN	TW	HONGFUJIN PRECISION IND SHENZHEN	CN	4
LG ELECTRONICS	KR	UNIV OF HONG KONG	CN	4
HEWLETT PACKARD DEV	US	NAT INST OF INFORMATICS	JP	4
SAUDI ARABIAN OIL	SA	ARAMCO SERVICES	US	3
KVASER	SE	CONCIO HLDGS	US	3
QD VISION	US	SAMSUNG	KR	3
ID QUANTIQUE	CH	SEOUL NAT UNIV	KR	3
INT IBERIAN NANOTECHNOLOGY LAB	PT	CONSIGLIO NAZ DELLE RICERCHE	IT	2
NANOSYS	US	SHARP	JP	2
IMPERIAL COLLEGE OF LONDON	GB	SAMSUNG	KR	2
UNIV OF GLASGOW	GB	INST NAT RECH SCIENT	CA	2

Applicant	Location	Co-applicant	Location	Patent families
COVESTRO DEUTSCHLAND	DE	QC WARE	US	2
NANOSYS	US	SHOEI CHEM	JP	2
CNRS CENT NAT DE LA RECH SCI	FR	NANYANG TECHNOLOGICAL UNIV	SG	2
AVAGO	SG	AGILENT TECH	US	2
STANFORD UNIV	US	NTT	JP	2
SCHLUMBERGER	FR	GEOQUEST SYSTEMS	NL	2
FRAUNHOFER	DE	GE GEN ELECTRIC	US	2

Notes: this table shows the number of IPFs between applicant pairs. EPO member states in red, EU member states with a coloured background

A.2 Identifying quantum firms

The identification of quantum companies relies on several distinct data sources; the starting point is a list of manually identified quantum firms found in previous work conducted by the OECD. This list was expanded through data from the OECD/STI Microdata Lab, Startup Database (which includes firm-level data from Crunchbase (CB) and Dealroom (DR) as well as patents documents from the EPO Worldwide Patent Statistical Database (PATSTAT) database and Cordis data. The four different datasets are described in turn below; the consolidation process of these sources is described in the last section.

A.2.1 Sources on quantum firms

Manually validated list
The starting point for the present analysis is a list of 396 quantum firms that were manually identified in previous work conducted by the OECD. The list is based on participants in exhibitions, consortia and trade fairs in the quantum sector, which were manually verified to ensure they meet the definition of quantum startups used in this work.

Microdata Lab – Startup Database
The startup database included within the OECD/STI Microdata Lab, based on data from Crunchbase and Dealroom, was used as a second source for identifying quantum firms, and as a key source of information on quantum firms once identified as such through the various methods. A keyword-based search was adopted to identify quantum-related firms. The definition of the quantum keywords list relied on extensive technical knowledge and successive refinements, with the final aim of achieving the best possible trade-off between precision (avoiding including non-quantum firm) and recall (identifying all existing quantum firms).

Table A2.1

List of keywords

Specific keyword	Category	Broad keywords
avalanch, photodiod	Photonics	hamiltonian
determin, single-photon		qbit
herald, single-photon, sourc		qdit
indistinguish, photon		qkd
integr, beam, splitt		quantum, accelerator
low-loss, fiber, coupl		quantum, algorithm
mach-zehnder, interferomet		quantum, applicat
multi-photon, entangl		quantum, application
on-chip, entangl, photon		quantum, architectur
photon, number, resolv, detect		quantum, batter
polariz, maintain, fiber, array		quantum, behavior
programm, photon, process		quantum, bit
quantum, frequenc, convers		quantum, cascade
quantum, transduc		quantum, chemistr

Specific keyword	Category	Broad keywords
reconfigur, photon, circuit		quantum, chip
silicon, photon, quantum, chip		quantum, circuit
single-photon, sourc		quantum, cloud
spontan, parametr, down-convers		quantum, communicat
superconduct, nanowir, single-photon, detect		quantum, component
transit, edg, sensor		quantum, comput
ultra-low, dark, count, detect		quantum, control
waveguid, single-photon, detect		quantum, device
automat, sampl, exchang	Cryogenics	quantum, dot
closed-cycle, cryostat		quantum, driven
closed-cycle, helium, refriger		quantum, electron
cryo-CMOS		quantum, engineer
cryogen, cabl		quantum, gate
cryogen, circulat		quantum, hardwar

Specific keyword	Category	Broad keywords
cryogen, control, electron		quantum, inertial
cryogen, digital-to-analog, convert		quantum, inform
cryogen, hermet, connect		quantum, infrastructure
cryogen, interconnect		quantum, internet
cryogen, low-nois, amplifi		quantum, machine, learn
cryogen, signal, rout		quantum, material
cryogen-free, cryostat		quantum, measurement
cryogen-free, dilut, unit		quantum, mechanic
dilut, refrigerat		quantum, memor
low, thermal, conduct, coaxial, cabl		quantum, metrolog
low-loss, microwav, filter		quantum, modem
microwav, cryogen, cabl, assembl		quantum, motion
millikelv		quantum, mri
optic, access, cryostat		quantum, network
puls, tube, cryocool		quantum, photonic
puls, tube, precool		quantum, physic
quantum, devic, readout		quantum, process
quantum-limit, amplifi		quantum, product
superconduct, reson		quantum, programm
superconduct, wir		quantum, propert
ultra-low, vibrat		quantum, protocol
quantum, entrop, sourc	Communication	quantum, research
BB84, protocol		quantum, sens
Bell, state, measure, network		quantum, simulat
downlink, polariz, entangl		quantum, softwar
entangl, base, network		quantum, system
entangl, swapp, protocol		quantum, technolog
herald, entangl, distribut		quantum, tunnel
homodyn, detect, QRNG		qubit
multi, node, quantum, link		qubo
photon, arriv, time, random		qudit
photon, matter, interfac		silicon, spin

Specific keyword	Category	Broad keywords
quantum, channel, authent		trap, ion
quantum, internet, node		
quantum, network, infrastructur		
quantum, optic		
quantum, repeat		
quantum, switch		
quantum, teleport		
satellit, photon, uplink		
space, ground, quantum, link		
trust, node, satellit, QKD		
vacuum, state, entrop (Ultra-High Vacuum)		
aluminum, ion, clock	Sensing	
atom, interferomet, acceleromet		
atom, vapor, cell, magnetomet		
bos, einstein, condens, gravimetr		
femtosecond, frequenc, comb		
femtotesl, sensit		
light, puls, atom, interferometr		
micrograv, quantum, sensor		
nano, diamond, magnetometr		
nitrogen, vacanc, center, magnetomet		
optic, detect, magnet, reson		
optic, frequenc, standard		
optic, lattic, clock		
quantum, acceleromet		
quantum, biosens		
quantum, enhanc, biosensor		
quantum, enhanc, detect		
quantum, ghost, imag		
quantum, gravimet		
quantum, illumin, radar		
quantum, imag		

Specific keyword	Category	Broad keywords
quantum, lidar, entangl		
quantum, magnetomet		
quantum, project, nois		
quantum, radar		
singl, spin, biosens		
spin, base, magnetometr		
spin, depend, fluoresc		
gate-bas, quantum	Computing	
atomic, array		
chimer, graph		
electron, spin		
entangl, photon		
integrat, photon		
isotopical, purifi, silicon		
laser, cooling		
neutral, atom, trap		
nitrogen-vacanc, center		
optic, tweezer (Optical Tweezers)		
photonic, qubit		
rydberg, atom		
semiconduct, qubit		
silicon, qubit		
singl-photon, source		
superconduct, transmon		
atomic, clock	General	
cold, atom		
neutral, atom		
quantum, anneal		
quantum, entangl		
quantum, error, correct		
quantum, key, distribut		
quantum, random, number		

Source: OECD

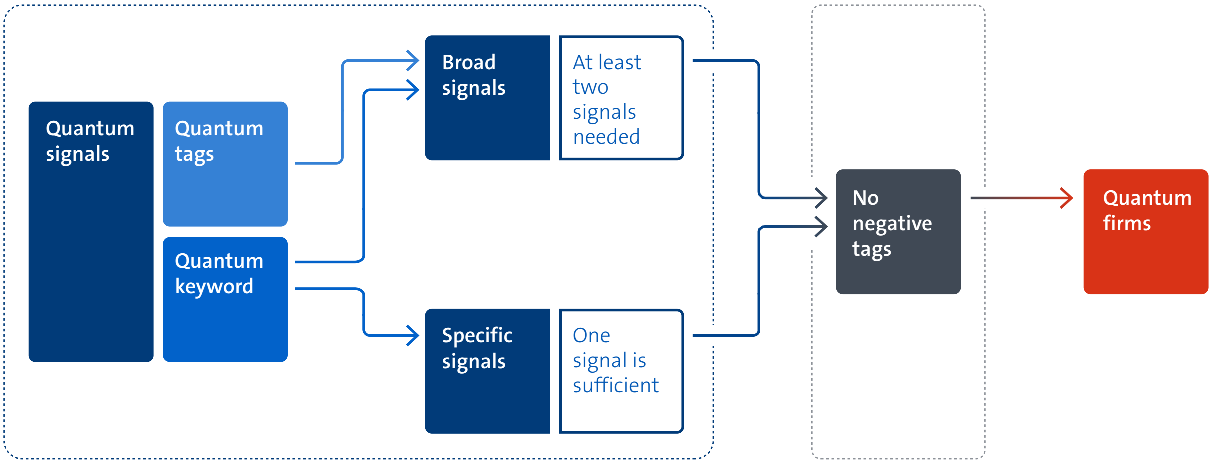
As reported in Figure A2.1, the approach adopted is based on two categories of quantum signals: specific and broad ones. These, in turn, are determined by how tightly the signals relate to quantum concepts. In most cases the quantum signals are quantum keywords (where keyword implies a specific term which can be constitute by more than one individual word, like in the case of "quantum sensing"). The complete list of keywords, divided into specific and broad, is provided above in Table A2.1. However, industrial tags provided by both Crunchbase and Dealroom are also included as quantum signals, and are always considered broad signals. As shown in Figure A2.1 to be defined as such quantum firms must have at least one specific quantum signal or two broad ones. In addition, they also need to not have among their tags a list of industrial tags that characterise industries very remote from quantum, which was established after a manual revision of the first extracted firms: advertising, advice, alternative medicine, architecture, art, association, B2C, brand marketing, call center, cannabis, casual games, charity, child care, cosmetics, cryptocurrency, digital media, e-commerce, e-learning, education, event management, funding platform, higher education, impact investing, insurance, legal, marketing, marketing automation, media and entertainment, news, non-profit, personal health, publishing, retail, small and medium businesses, social media, therapeutics, training, universities, venture capital, web design, web development, web hosting, wellness.[41]

Various refinements are implemented to maximise the completeness of the search strategy. These include case normalisation (lowercasing), stemming of most keywords (this can be seen in Table A2.1), and the application of distance operators for multi-word terms. As a result, matches are identified even when terms like "quantum computing" are separated by punctuation or additional words, as in "quantum advanced computing" or "quantum-technologies". Finally, companies identified were additionally checked using calls to OpenAI to categorise them into core quantum technologies, enabling technologies, user industries of quantum technologies, or not quantum at all. Checks conducted

41 Note that this condition only applies to Crunchbase.

Figure A2.1

Schematic view of quantum extraction procedure



Source: OECD

manually on this sample concluded that some non-quantum technologies were still included in the sample (93) and were therefore removed.

There are important caveats to this approach. First, given that the companies identified have not been done so manually, it is possible that some quantum companies have been missed, or some non-quantum companies included. The categorisation process described above makes the second possibility unlikely, but it cannot be ruled out entirely. Second, the approach is heavily based on company descriptions, which are not available for all companies in Crunchbase and Dealroom. As a result, the sample tends to capture established companies, filtering out those that are more ephemeral or speculative.

Patent holders

The owners of patents in quantum technologies are identified using the EPO PATSTAT, in its Spring 2025 edition. Patents in quantum were identified using a search strategy developed by the EPO as described in Section 3. The quantum patent portfolio of companies can be split into communication, computing and sensing/metrology, using fractional counts, and refer to patent families (using the EPO Docdb definition). Holders of quantum patents are the consolidated using the harmonised patent applicant name (the OECD HAN identifier) to correct for variations in applicant names in the database and ensure each applicant in the sample is unique.

Further information on quantum patent applicants is gathered using links established between PATSTAT and the OECD/STI Microdata Lab Startup database, and with the ORBIS© database, a company-level database maintained by Moody's. The ORBIS IP module available at the OECD was mapped to the PATSTAT database to collect additional information on quantum patent holders.

Cordis

The Community Research and Development Information Service (Cordis) is a European Commission-maintained database including comprehensive information on EU Research & Development projects. For the purposes of this study it provides an especially valuable source of information compared to other data sources because it includes recipients of grants financed by the EU. These companies may be different from patent filers covered by PATSTAT or firms identified in Crunchbase and Dealroom. Compared to PATSTAT, Cordis can provide information on firms which have started research projects that have not led yet to a patent. Compared to Crunchbase and Dealroom, Cordis can provide a view into more diversified companies that are less likely to cite quantum-relevant keywords in their description. The main limitation is that it only covers projects with an EU funding component.

Data for this work were extracted on 2 May 2025. The list of projects identified as relevant for quantum technologies is based on the table of all-EU funded on the Quantum Flagship website. An automated tool extracted projects IDs from this source and queried Cordis to recover the relevant details, including participants. A limited number of projects (9) listed on the Quantum Flagship website without their IDs could not be recovered through this method (Quantum Flagship, 2025).

A.2.2 Consolidation

The criteria considered for the extraction from each of the above-mentioned datasets -as well as their focuses and characteristics -are different. Therefore the companies extracted from each are likely to differ. For instance, PATSTAT allows retrieval of quantum companies that have filed a patent but cannot identify companies that did not. The extractions from Crunchbase and Dealroom are not bounded by this restriction, but cannot identify quantum companies that either lack a description on the two platforms, or do not mention any quantum keywords in their description when one is available.

Nevertheless, there can be overlaps between the various sources. Simply combining the companies extracted from each data source would cause concerns about double counting. For example, quantum companies that both filed a patent in PATSTAT and mentioned a specific quantum keyword in their descriptions on either Crunchbase or Dealroom would be effectively counted twice. These firms could be even triple counted if they were also recipients of quantum-related funding from the EU, and thus recorded in Cordis.

As a consequence, matching the various data sources and disambiguating is crucial to create a reliable sample of quantum firms. The matching procedure adopted in this work was carried out in two steps. First, a fuzzy matching process was applied to company names, supported by exact matching on firms' countries, to identify: (1) perfect matches across data sources, and (2) likely matches. Several string-matching algorithms (e.g. Levenshtein or Jaro-Winkler distances, cosine similarity and weighted token frequency measures) were used for this step, enhanced by the removal of a custom-built dictionary of stop words specific to each country (for example, "corporation"). In the second step, all perfect matches were retained; all non-perfect matches above the 90-93% threshold of similarity (depending on the string-matching algorithm used) were manually investigated. For both types of matches a unique source was retained to ensure that the final sample is composed solely of "unique" companies.

Information on the majority of companies retrieved is available through Crunchbase and Dealroom linkages, but for a notable portion of the ecosystem (approximately half) it is only available through PATSTAT (where the original quantum firm was identified) or ORBIS©, thanks to a link via ORBIS IP (in its version of April 2025).

The following table provides an overview of the firms extracted for the entire ecosystem, and where the information was drawn from.

Table A2.2

Sources of information on quantum firms for overall ecosystem

Source	Count	%	Cumulative %
Orbis IP	1 072	23.19	23.19
PATSTAT	1 063	23.00	46.19
Crunchbase & Dealroom	2 487	53.81	100.00
Total	**4 622**	**100.00**	

Source: OECD.

The last step involved selecting companies whose activity most closely revolves around quantum and quantum-enabling technologies. This implies, for instance, removing companies that are merely users of quantum technologies, or that have only a small portion of their activities dedicated to quantum. To this end, a subsample was identified that focuses on a) companies with a high share of quantum patents in their patent portfolios (at least 50%), b) manually identified companies, and c) high-quality companies (i.e. those with at least one investment received or patent filed before 2022, or founded after 2022) identified through the keywords previously listed. This subsample was identified in Crunchbase and Dealroom, for which more information are available. The companies identified in Crunchbase and Dealroom were then integrated with those for which only partial information was available – that is, firms listed solely in Orbis IP or Patstat – provided they had a high share of quantum-related patents (at least 65%) and at least two quantum patents, to account for the comparatively less information available. This is the fifth search strategy referenced in Section 4.

The resulting sample was manually refined to ensure consistency with the adopted definition of core firms, namely as companies primarily focused on quantum technologies or on key enabling technologies for quantum. The following table provides an overview of the companies thus identified, listing for each one the means by which each was originally identified as quantum.

Table A2.3

Sources of identification for core quantum firms

Source Quantum	Freq.	Percent.	Cum.
cordis; manual	2	0.24	0.24
cordis; patent	1	0.12	0.36
keywords	347	41.81	42.17
keywords; cordis	20	2.41	44.58
keywords; cordis; manual	15	1.81	46.39
keywords; cordis; manual; patent	19	2.29	48.67
keywords; cordis; patent	4	0.48	49.16
keywords; manual	135	16.27	65.42
keywords; manual; patent	89	10.72	76.14
keywords; patent	66	7.95	84.10
manual	76	9.16	93.25
manual; patent	17	2.05	95.30
patent	39	4.70	100.00
Total	**830**	**100.00**	

Source: OECD.

A.3 Selection of investments in the quantum ecosystem

This study considers two types of firms to identify investment in the quantum ecosystem. The first group includes companies whose primary activities are directly linked to the quantum ecosystem, covering both core and non-core technologies; these are defined as core companies. The second includes organisations whose main activities lie elsewhere, but which nevertheless play an important role in advancing the quantum ecosystem. These are highly diversified multinationals; not only technology giants like Amazon, Google, IBM and Microsoft, but also large firms active in other sectors such as banking (e.g. Wells Fargo) or transportation (e.g. Volkswagen).

The analysis includes only investments in the first type of firm, i.e. core firms. While Section 4 acknowledged that organisations of the second type also belong to the quantum ecosystem, including them would risk conflating investment genuinely aimed at quantum technologies with investment targeting the many other activities of highly diversified companies. This approach risks excluding some funding intended for diversified firms' quantum activities: however, this risk is outweighed by the need to avoid overstating quantum investment by mixing it with unrelated sectors, which would give a misleading picture of the financing actually directed to the quantum ecosystem.

The selection of the core subsample was described in Annex A.2. The remaining part of this annex focuses on providing descriptive evidence on the sample of investment which can be attributed to this subsample of quantum firms.

Table A3.1. shows descriptive statistics on the amounts invested, broken down by amount of investment, receiving firm and investor. Unsurprisingly, the first sample is larger than the second, as companies can receive multiple investments (3 on median in this sample), but smaller than the third, as multiple investors can participate in each round of investment. Overall, 2 235 investments that targeted the entire quantum ecosystem are retained (information on funding amounts is available for 1 539 of these), and 587 firms are recorded as having received an investment (467 of them with them amount invested). Mean, median, and maximum values are higher in the second sample compared to the first because it aggregates multiple investments per firm. The total value invested in core is USD 23 658 million; USD 20 008 million was invested over the period 2014-2024.

These investments were performed by 2 114 different investors (information on invested amount is available for 1 750 of these. Information on investors is not available for all 2 235 investments identified in the final sample, only for 1 936 of them. This accounts for approximately USD 20 969 million, or 89% of the USD 23 658 million invested in the selected quantum ecosystem. In the original database investment is not split by investor for a given investment. Therefore, for this analysis investment is considered split equally among all participating investors.

Table A3.2. shows the distribution of investment across different types: Seed and Grant are the most common types of investments, but among the lowest in terms of average amount invested. Growth, IPO-related and late-stage are the investments providing the largest amount on average. Overall, early-stage and late-stage provide the highest amount of resources to core quantum firms. Finally, Table A3.3 focuses on the quantum firms that received the highest amount of funding in the period 2014-2024. While most of the largest recipients are well known firms active in quantum technologies "proper", like Psiquantum, the companies also include some active in enabling technologies, for example Lightmatter.

Table A3.1

Descriptive evidence on investment in core firms

Observation	N	Min (USD million)	Max (USD million)	Median (USD million)	Mean (USD million)
Investments	1 539	0.0017	616.67	2.61	15.37
Firms	467	0.0017	2 039.45	5.42	50.66
Investors	1 750	0.0067	524.83	2.96	11.98

Notes: These figures include only investments, companies and investors for which we have monetary values.

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Table A3.2

Descriptive evidence on investment in core firms, by type of investment

Type of investment	Mean investment	Total investment	Number of deals
EARLY STAGE	21.80	6 975.49	352
LATE STAGE	61.46	5 899.80	102
POST IPO PUBLIC	75.57	5 138.42	73
GRANT	4.48	2 171.40	564
SEED	3.16	1 521.57	641
GROWTH	138.88	1 249.92	16
DEBT ALTERNATIVE	9.79	450.36	49
UNKNOWN TYPE	12.63	164.18	118
UNDISCLOSED	16.01	80.03	6
OTHER	0.42	6.69	126
SPINOUT	-	-	188

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

Table A3.3

Quantum core with the highest funding

Name	Total funding (USD million)
PSIQUANTUM, CORP.	2 039.45
SB TECHNOLOGY INC.	1 575.00
IONQ, INC.	1 479.60
D-WAVE SYSTEMS, INC.	956.78
RIGETTI COMPUTING INC.	934.41
LIGHTMATTER, INC.	822.00
ROCKLEY PHOTONICS LTD.	808.50
INFINERA	718.80
QUANTINUUM, LTD.	647.00
ARQIT LIMITED	477.34
QUANTUM MACHINES LTD.	421.25

Source: OECD calculations based on OECD, STI Micro-data Lab, October 2025.

A.4 Categorisation of investment types

The classification adopted in this work follows previous work carried out in the OECD Microdata Lab (see Table A4.1. for a schematic overview) as presented in Berger, et al. (forthcoming). Table A4.2. provides the categorisation for other forms of investment not classified as venture capital.

Table A4.1

Deal type aggregation in OECD Start-up database

Aggregated funding stages	Seed and Angel	Early-stage	Late-stage	Growth
Crunchbase				
Deal types I	Angel Pre-seed Seed Equity-crowdfunding	Series A Series B	Series C - J	Private Equity
Deal types II	Convertible note Corporate round Series unknown < USD 3 million	Convertible note Corporate round Series unknown USD 3 to 15 million	Convertible note Corporate round Series unknown > USD 15 million	
Dealroom				
Deal types I	Angel Seed	Series A Series B	Series C - I	Growth Equity VC Growth Equity Non-VC
Deal types II	Convertible Early VC Late VC < USD 3 million	Convertible Early VC Late VC USD 3 to 15 million	Convertible Early VC Late VC > USD 15 million	

Notes: Deal types I are directly used as listed in the primary databases. Deal types II use additional information on funding volumes. For funding rounds that show up in both databases, the deal type provided by Crunchbase is used. In the current work, "Seed and angel" is labelled "VC seed"; "Early-stage" is "VC early-stage"; "Late-stage" is "VC late -stage"; "Growth" is "VC growth".

Source: Berger, et al. (forthcoming).

Table A4.2

Additional categorisation adopted for quantum work

Aggregated funding stages	Original deal types included
IPO-related	Post Ipo Equity, Post Ipo Debt, Post Ipo Convertible, Post Ipo Secondary, Spac Ipo, Spac Private Placement, Private Placement Non VC
Debt	Debt Financing
Spinout	Corporate Spinout, Spinout
Other	Non-Equity Assistance, Secondary Market, Support Program, Private Placement Vc, Initial Coin Offering

Notes: Only deal types that targeted quantum-core firms and were not already labelled in Berger, et al. (forthcoming), have been labelled.

A.5 Skills: data construction methodology

The analysis draws on a large dataset of job postings encompassing all vacancies web-scraped by Lightcast in Canada, the United Kingdom and the United States between January 2021 and July 2025. To manage this scale effectively, the data construction methodology was designed to identify quantum-related job postings and followed a series of sequential steps, each producing an output for the next stage. The process began with data preparation and subsetting, where job postings were filtered into three analytical groups: (i) quantum-related online job postings from any employer, (ii) quantum-enabling online job postings from any employer and (iii) all job postings from core quantum firms.

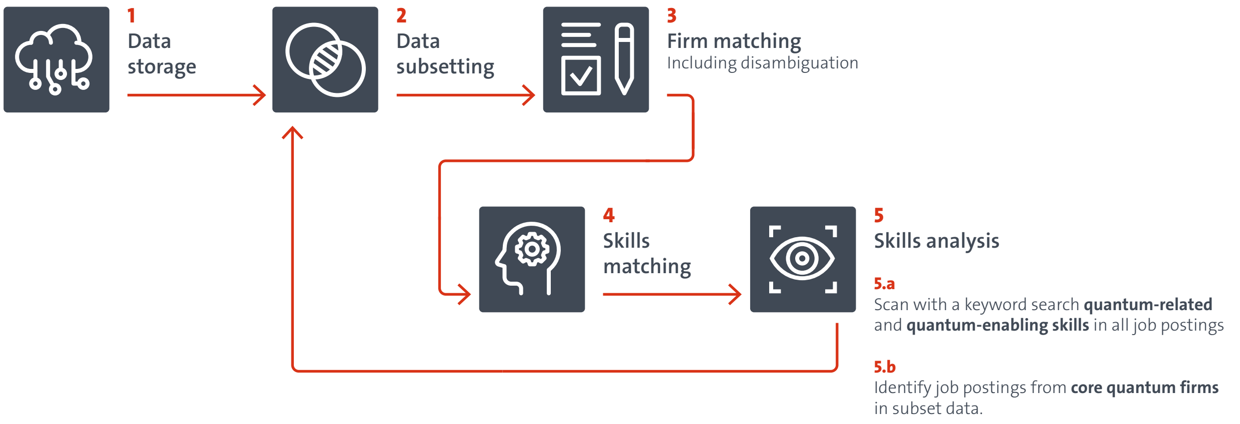
Analytical groups (i) and (ii) were obtained using keyword searches, with the corresponding terms listed in Annex A.6 and Annex A.7. Skill names within job postings were scanned for mentions of the relevant keywords to identify the first two groups. The third group (iii, core quantum firms) was identified through a matching process that aligned employer identifiers from the job postings with firm-level information such as company names and locations, building on Squicciarini and Dernis (2013). This step produced an initial list of firms active in quantum technologies.

The list of core quantum firms then underwent a thorough disambiguation process. False positives were removed, firms whose main activities were unrelated to quantum technologies were excluded, and companies with identical names but different activities were distinguished. This refinement yielded a validated set of firms belonging to the quantum ecosystem for which Lightcast job postings were available during the study period (2021-2025).

Once the firm matches had been established, the analysis focused on extracting skills data. Skill mentions were linked to each job posting according to the firm matches created in the previous step, enabling the analysis of skill patterns across firms, occupations, regions, and years in a coherent framework. The data analysis workflow for the sequential steps involved in this exercise, including, data subsetting, firm matching and skills matching, is provided in Figure A5.1.

Figure A5.1

Data analysis workflow



Notes: Job postings including quantum-related skills and quantum-enabling skills are obtained in step 5a and job postings from core quantum firms are obtained in step 5b.

Source: OECD

A.6 Skills: list of quantum-related skills

Table A6.1 shows the list of quantum-related skills identified in Lightcast from the job postings that required one quantum-related skill. These skills were retrieved using keywords searches based on the list shown in Annex A.2. All skills appearing within these job postings were collected to construct the dataset for analysis, ensuring that the skill composition reflects the full range associated with quantum-related labour demand.

Table A6.1

List of quantum-related skills found in Lightcast

Amazon Quantum Ledger Database (QLDB)	Quantum Dots	Quantum Physics
Heteronuclear Multiple Quantum Coherence	Quantum Dynamics	Quantum Point Contact
Heteronuclear Single Quantum Coherence Spectroscopy	Quantum Error Correction	Quantum Programming
IBM Quantum Platform	Quantum ESPRESSO	Quantum Scalar Servers
Microsoft Azure Quantum	Quantum Gates	Quantum Sensors
Neutral Atom Quantum Computing	Quantum Imaging	Quantum Technology
Photonic Quantum Computing	Quantum Information	Quantum Walks
Qiskit	Quantum Information Sciences	Silq (Quantum Computer Programming Language)
Q#	Quantum Information Theory	Superconducting Quantum Interference Device (SQUID)
Quantum Algorithms	Quantum Internet	Superconducting Qubits
Quantum Approximate Optimization Algorithm (QAOA)	Quantum Link	Temenos Quantum Visualizer
Quantum Chemistry	Quantum Machine Learning	Topological Quantum Computing
Quantum Computing	Quantum Mechanics	Trapped Ion Quantum Computing
Quantum Cryptography	Quantum Mechanics/Molecular Mechanics (QM/MM)	
	Quantum Networks	
	Quantum Phase Transition	

Notes: Skills containing "quantum" were also considered, excluding false positives such as Quantum Geographic Information System (QGIS).

Source: OECD.

A.7 Skills: list of quantum-enabling skills

Table A7.1 shows the list of enabling skills used to identify job postings for employers seeking quantum-enabling skills. For this group, identification relied on four key terms: photonics, cryogenics, optical tweezers and ultra-high vacuum, all of which have applications in quantum technologies but broader uses too. Once these job postings had been retrieved, all skills listed within them were collected to construct the dataset for analysis. Although the set of enabling keywords is limited, enabling skills such as optics, lasers and chemistry engineering also appear in the skill composition results, reflecting the wider technical context in which these enabling skills are applied.

Table A7.1

List of quantum-enabling skills
Photonics
Cryogenics
Optical tweezers
Ultra-high vacuum

Source: OECD.

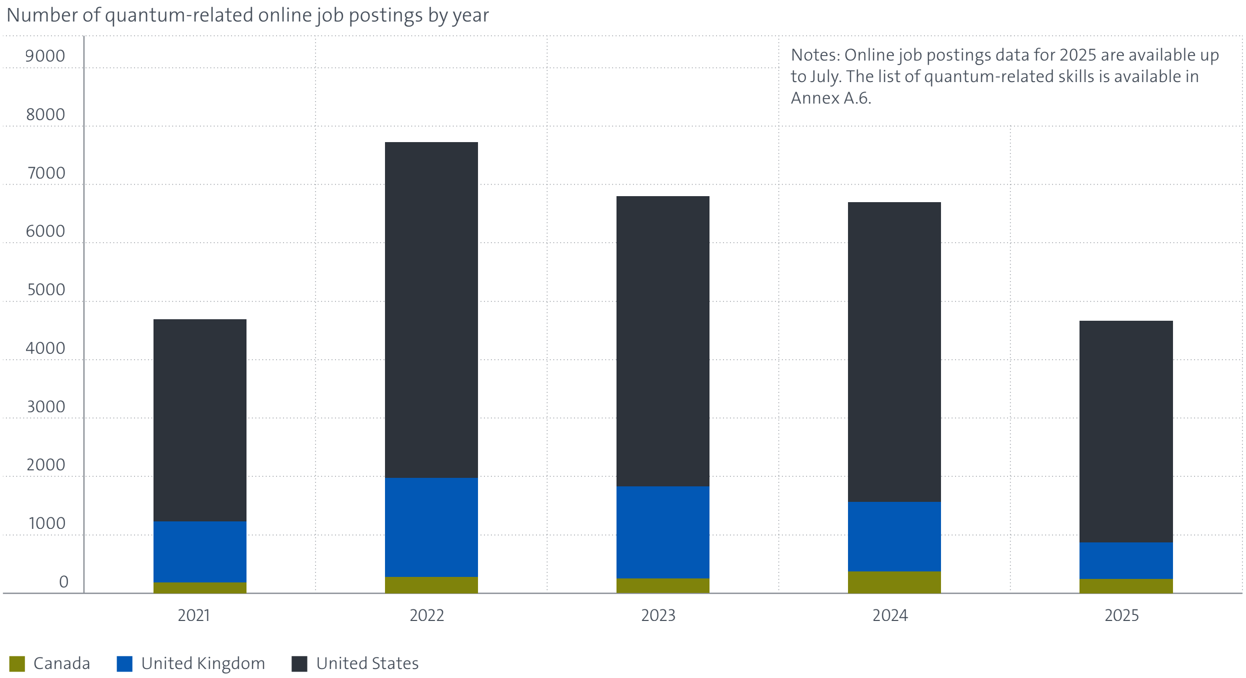
A.8 Skills: additional quantum-related demand insights

This annex provides additional insights into the main analysis and supports the interpretation of results related to the structure of the quantum labour market, for instance the geographical distribution of job postings.

Moving down to the occupation level, quantum-related online job postings are led by research-focused roles. Research associates accounted for the largest share, decreasing slightly from 7.9% in 2021 to 6.8% in 2024, while postings for research scientists increased from 4.6% to 5.7% (Figure A8.2).

Figure A8.1

The United States has the highest offer of quantum-related online job postings

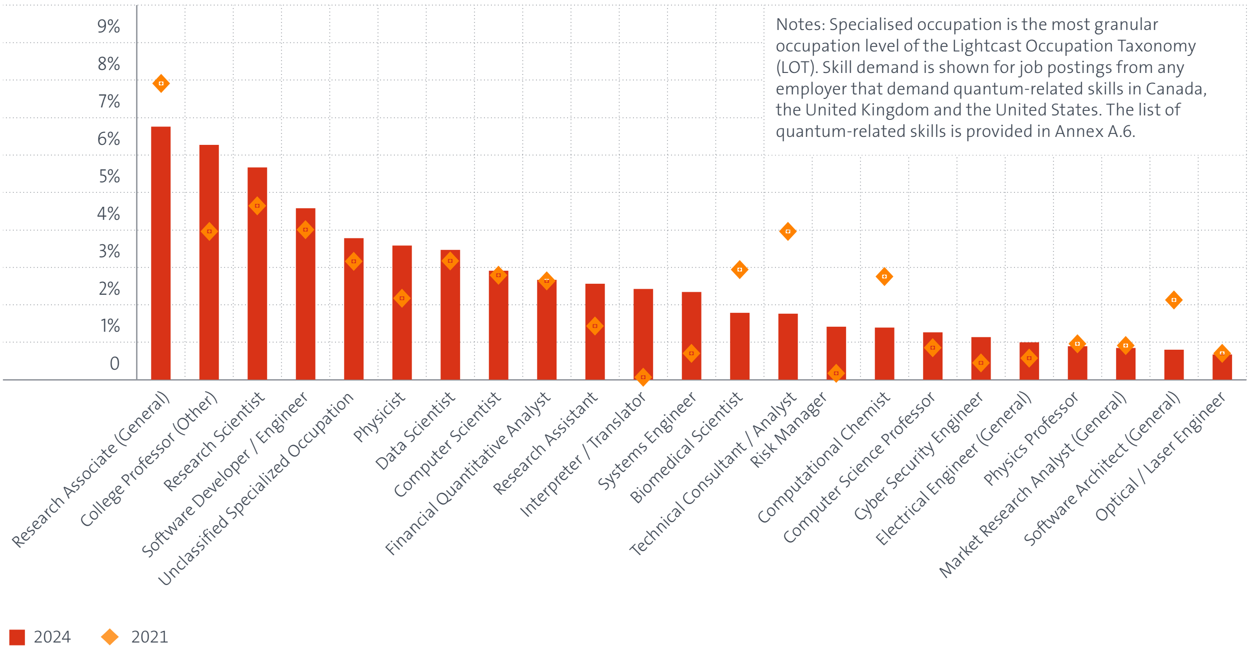


Source: OECD calculations based on Lightcast, October 2025.

Figure A8.2

Research specialised occupations are the main users of quantum-related skills

% of total quantum-related online job postings number of core quantum firms by year



Source: OECD calculations based on Lightcast, October 2025.

Academic positions also expanded, with college professors moving from 4% to 6.3%. On the technical side, software developers and engineers grew from 4% to 4.6%, while computer scientists and data scientists held steady at around 3%. Specialised scientific roles such as physicists increased from 2.2% to 3.6%, while demand also appeared in fields like financial quantitative analysis (3%) and systems engineering (2% in 2024). A notable outlier is interpreters and translators, which jumped to 2.4% of postings by 2024, reflecting niche but growing needs alongside more traditional science, research and computing occupations.

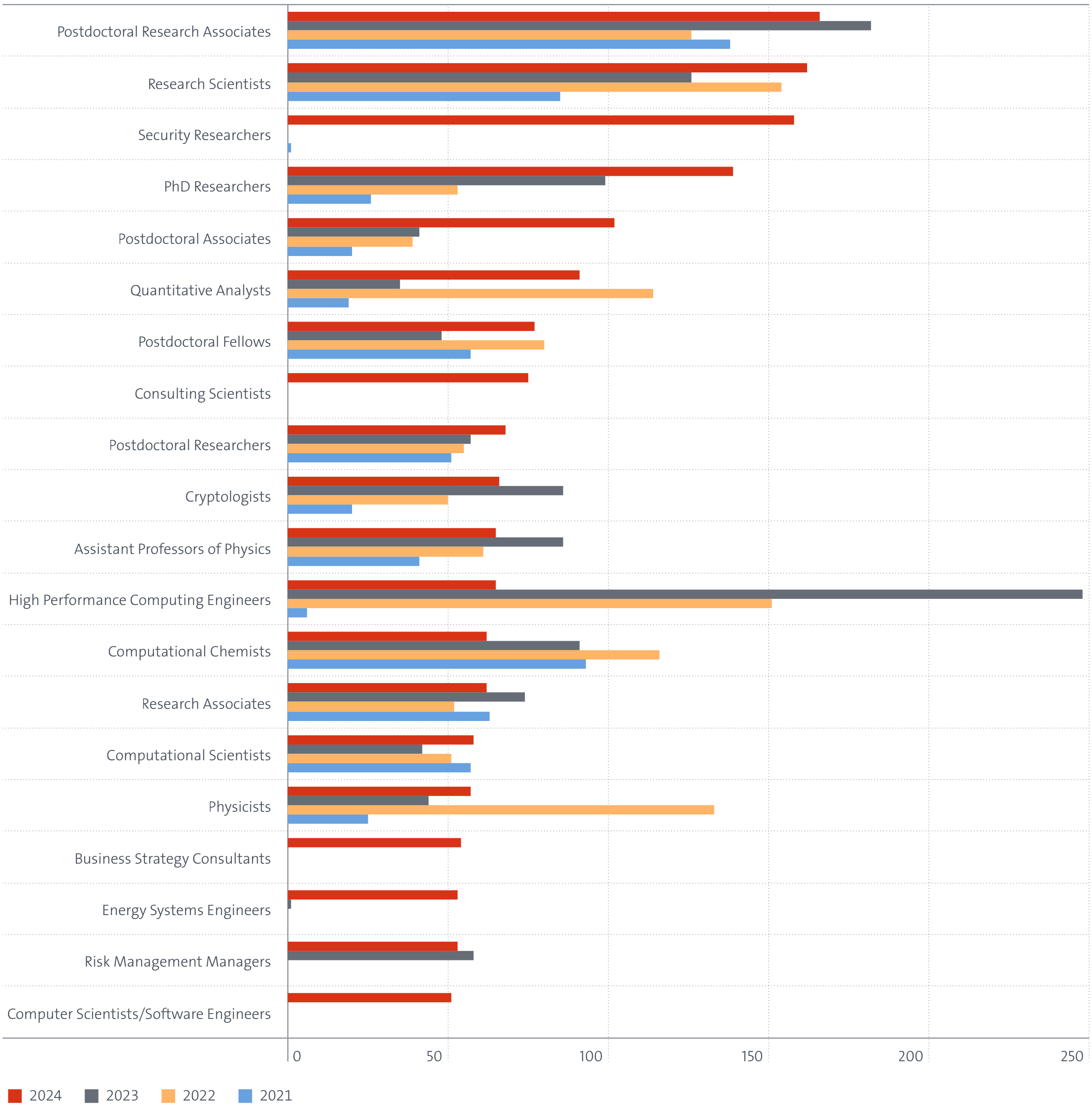
Job titles

The composition of job titles in quantum-related postings similarly highlights the predominance of research-focused roles. Postdoctoral research associates consistently accounted for a large share of openings, with 138 positions in 2021 rising to 166 in 2024, while research scientists also grew from 85 to 162 postings over the same period (Figure A8.3). Doctoral-level roles such as PhD researchers and postdoctoral associates/fellows similarly increased, reflecting ongoing demand for highly trained scientific talent in academia. Technical and computational roles, including high-performance computing engineers, computational chemists and computational scientists feature prominently, indicating the ecosystem reliance on advanced computational skills. Emerging or niche positions such as security researchers, cryptologists and risk management managers appeared in later years, suggesting expanding applications of quantum knowledge beyond core scientific research. By 2024 positions in consulting, business strategy and applied engineering also appear, pointing to a gradual diversification of job functions as firms integrate quantum capabilities into broader technological and commercial contexts.

Figure A8.3

Research roles are mainly focused on research, expanding into technical and applied roles

Number of quantum-related online job posting occurrences by most common title, by year



Notes: Skill demand is shown for job postings from any employer that demand quantum-related skills) in Canada, the United Kingdom and the United States. The list of quantum-related skills is provided in Annex A.6.

Source: OECD calculations based on Lightcast, October 2025

A.9 Identification of relevant HS codes

The identification of the HS codes used for the analysis presented in this section took place in two main steps. First, a list of products (both raw materials and equipment) relevant for the quantum ecosystem was identified. Second, this list was matched to HS (Harmonized System) codes at the 6-digit level (2022 edition). The results of this process are presented in Table A9.1.

The first step involved compiling information from multiple sources – (Ezratty, 2024, Lee, 2023) and the specialised website Azoquantum (azoquantum.com) – which were integrated with the support of different large language models and finally discussed with experts in the field of quantum technologies. The resulting list includes 26 raw materials and 24 types of equipment.

In the second step, these products were linked to relevant HS codes. This is a complex task, given that some of the products listed in Table A9.1 are too granular for 6-digit HS codes, while others are too broad. To identify suitable HS codes, three different large language models (Chatgpt, Gemini and Copilot) and one website specialised in HS code identification (thehscode.com) were queried. The overlap between the resulting HS codes was not complete, which was expected given the complexity of the task. Therefore identification of the final HS code for each product was based on those provided by these services, but finalised by a manual review of the 2022 HS Nomenclature published by the World Customs Organization, and enriched by exchanges with colleagues at the Department for Science, Innovation and Technology (DSIT) in the United Kingdom, who are also mapping the quantum value chain but using a different approach to identify relevant quantum-relevant goods and their associated HS codes. The final list of HS codes was discussed with experts in the field of quantum technologies.

Overall, 38 HS codes, accounting for 50 quantum-relevant products, were identified. Of these, 18 are raw materials, and 20 are equipment. Table A9.1 includes the products with their linked HS codes and descriptions (based on the 2022 HS nomenclature) of each 6-digit code. The table includes two editions for HS codes: 2022 and 2017. For the final analysis, which covers the period 2017-2023, the 2017 edition was adopted, to account for modifications that occurred across the last two editions. This implies, for instance, that code 284540, which in the 2022 edition identifies helium-3, was not available in the 2017 edition. This is translated to code 284590 (the same as Silicon-28).

Table A9.1

List of quantum-relevant products (raw materials and equipment)

Name	HS 2022	HS 2017	Description 2022
RAW MATERIALS			
Arsenic	280480	280480	28.04.80: Arsenic
Aluminium	760110	760110	76.01: Unwrought aluminium. - Aluminium, not alloyed
Aluminum Oxide	281820	281820	28.18: Artificial corundum, whether or not chemically defined; aluminium oxide; aluminium hydroxide - Aluminium oxide, other than artificial corundum
Barium	280519	280519	28.05: Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Alkali or alkaline-earth metals. -- Excluding Sodium and Calcium
Barium Titanate	284190	284190	28.41 Salts of oxometallic or peroxometallic acids. - Excluding Sodium dichromate, other chromates and dichromates; peroxochromates, manganites, manganates and permanganates, molybdates and tungstates

Name	HS 2022	HS 2017	Description 2022
Bismuth	810610	810600	81.06: Bismuth and articles thereof, including waste and scrap. - Containing more than 99.99 % of bismuth, by weight
Caesium	280519	280519	28.05: Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Alkali or alkaline-earth metals. -- Excluding Sodium and Calcium
Diamond	710221	710221	71.02 Diamonds, whether or not worked, but not mounted or set. - Industrial : -- Unworked or simply sawn, cleaved or bruted
Erbium	280530	280530	28.05 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed
Europium	280530	280530	28.05 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed
Gallium	811292	811292	81.12: Beryllium, chromium, hafnium, rhenium, thallium, cadmium, germanium, vanadium, gallium, indium and niobium (columbium), and articles of these metals, including waste and scrap. - Other than Beryllium, Chromium, Hafnium, Rhenium, Thallium and Cadmium. -- Unwrought; waste and scrap; powders
Gallium Arsenide	381800	381800	38.18.00: Chemical elements doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics.
Germanium	811292	811292	81.12: Beryllium, chromium, hafnium, rhenium, thallium, cadmium, germanium, vanadium, gallium, indium and niobium (columbium), and articles of these metals, including waste and scrap. - Other than Beryllium, Chromium, Hafnium, Rhenium, Thallium and Cadmium. -- Unwrought; waste and scrap; powders
Helium-3	284540	284590	28.45.40: Helium-3
Indium	811292	811292	81.12: Beryllium, chromium, hafnium, rhenium, thallium, cadmium, germanium, vanadium, gallium, indium and niobium (columbium), and articles of these metals, including waste and scrap. - Other than Beryllium, Chromium, Hafnium, Rhenium, Thallium and Cadmium. Unwrought -- Waste and scrap; powders
Indium Phosphide	285390	285390	28.53: Phosphides, whether or not chemically defined, excluding ferrophosphorus; other inorganic compounds (including distilled or conductivity water and water of similar purity); liquid air (whether or not rare gases have been removed); compressed air; amalgams, other than amalgams of precious metals. - Other than Cyanogen chloride (chlorcyan)
Lithium Niobate	382499	382499	38.24: Prepared binders for foundry moulds or cores; chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products), not elsewhere specified or included - Other than Prepared binders for foundry moulds or cores; Non-agglomerated metal carbides mixed together or with metallic binders; Prepared additives for cements, mortars or concretes; Non-refractory mortars and concretes; Sorbitol other than that of subheading 2905.44 and goods specified in Subheading Note 3 to this Section. -Other than Mixtures and preparations consisting mainly of (5-ethyl-2-methyl2-oxido-1,3,2-dioxaphosphinan-5-yl)methyl methyl methylphosphonate and bis[(5-ethyl-2-methyl-2-oxido-1,3,2-dioxaphosphinan-5-yl)methyl] methylphosphonate; Polyglycol esters of methylphosphonic acid.
Niobium	811292	811292	81.12: Beryllium, chromium, hafnium, rhenium, thallium, cadmium, germanium, vanadium, gallium, indium and niobium (columbium), and articles of these metals, including waste and scrap. - Other than Beryllium, Chromium, Hafnium, Rhenium, Thallium and Cadmium. Unwrought; -- Waste and scrap; powders
Nitrogen	280430	280430	28.04.30: Nitrogen
Rubidium	280519	280519	28.05: Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Alkali or alkaline-earth metals -- Excluding Sodium and Calcium
Silicon Carbide (SiC)	284920	284920	28.49 Carbides, whether or not chemically defined. - of silicon

Name	HS 2022	HS 2017	Description 2022
Silicon-28	284590	284590	28.45: Isotopes other than those of heading 28.44; compounds, inorganic or organic, of such isotopes, whether or not chemically defined. - Other than Heavy water (deuterium oxide), Boron enriched in boron-10 and its compounds, Lithium enriched in lithium-6 and its compounds, and Helium-3
Strontium	280519	280519	28.05: Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Alkali or alkaline-earth metals -- Excluding Sodium and Calcium
Tantalum	810320	810320	81.03 Tantalum and articles thereof, including waste and scrap. - Unwrought tantalum, including bars and rods obtained simply by sintering; powders
Titanium	810820	810820	81.08 Titanium and articles thereof, including waste and scrap. - Unwrought titanium; powders
Ytterbium	280530	280530	28.05 Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed; mercury. - Rare-earth metals, scandium and yttrium, whether or not intermixed or interalloyed
EQUIPMENT			
Arbitrary Waveform Generators (AWGs)	854320	854320	85.43 Electrical machines and apparatus, having individual functions, not specified or included elsewhere in this Section. - Signal generators
Cables and connectors	854442	854442	85.44 Insulated (including enamelled or anodised) wire, cable (including co-axial cable) and other insulated electric conductors, whether or not fitted with connectors; optical fibre cables, made up of individually sheathed fibres, whether or not assembled with electric conductors or fitted with connectors. - Other electric conductors, for a voltage not exceeding 1 000 V -- Fitted with connectors
Cleaning equipment (plasma cleaners, wet benches)	848620	848620	84.86: Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays; machines and apparatus specified in Note 11 © to this Section; parts and accessories - Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits
Connectors	853669	853669	85.36 Electrical apparatus for switching or protecting electrical circuits, or for making connections to or in electrical circuits (for example, switches, relays, fuses, surge suppressors, plugs, sockets, lamp-holders and other connectors, junction boxes), for a voltage not exceeding 1 000 volts; connectors for optical fibres, optical fibre bundles or cables. - Lamp-holders, plugs and sockets -- Other than Lamp-holders
Cryostats	841950	841950	84.19 Machinery, plant or laboratory equipment, whether or not electrically heated (excluding furnaces, ovens and other equipment of heading 85.14), for the treatment of materials by a process involving a change of temperature such as heating, cooking, roasting, distilling, rectifying, sterilising, pasteurising, steaming, drying, evaporating, vaporising, condensing or cooling, other than machinery or plant of a kind used for domestic purposes; instantaneous or storage water heaters, non-electric. - Heat exchange units
Current supply / Constant voltage generator	850440	850440	85.04 Electrical transformers, static converters (for example, rectifiers) and inductors. - Static converters
Deposition systems (PVD, CVD, ALD)	848620	848620	84.86: Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays; machines and apparatus specified in Note 11 © to this Section; parts and accessories - Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits

Name	HS 2022	HS 2017	Description 2022
Diode lasers (including laser diodes modules)	854141	854140	85.41 Semiconductor devices (for example, diodes, transistors, semiconductor-based transducers); photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light-emitting diodes (LED), whether or not assembled with other light-emitting diodes (LED); mounted piezo-electric crystals. - Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light-emitting diodes (LED) -- Light-emitting diodes (LED)
Electrical connectors and circuit components	853690	853690	Electrical apparatus for switching or protecting electrical circuits, or for making connections to or in electrical circuits (for example, switches, relays, fuses, surge suppressors, plugs, sockets, lamp-holders and other connectors, junction boxes), for a voltage not exceeding 1,000 volts; connectors for optical fibres, optical fibre bundles or cables. -Other than Fuses; Automatic circuit breakers; Other apparatus for protecting electrical circuits; Other switches; Lamp-holders, plugs and sockets; Connectors for optical fibres, optical fibre bundles or cables
Electrical apparatus	853890	853890	Parts suitable for use solely or principally with the apparatus of heading 85.35, 85.36 or 85.37. - Other than Boards, panels, consoles, desks, cabinets and other bases for the goods of heading 85.37, not equipped with their apparatus
Etching equipment (RIE, ICP)	848620	848620	84.86: Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays; machines and apparatus specified in Note 11 © to this Section; parts and accessories - Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits
High Electron Mobility Transistor (HEMT)	854129	854129	Semiconductor devices (for example, diodes, transistors, semiconductor-based transducers); photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light-emitting diodes (LED), whether or not assembled with other light-emitting diodes (LED); mounted piezo-electric crystals. - Diodes, other than photosensitive or light-emitting diodes (LED) -- Other than with a dissipation rate of less than 1 W
Laser systems (excluding diode lasers)	901320	901320	90.13 Lasers, other than laser diodes; other optical appliances and instruments, not specified or included elsewhere in this Section. - Lasers, other than laser diodes
Mask aligners / Lithography tools	848620	848620	84.86: Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays; machines and apparatus specified in Note 11 © to this Section; parts and accessories - Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits
Microscopes & Spectrometers	902730	902730	90.27 Instruments and apparatus for physical or chemical analysis (for example, polarimeters, refractometers, spectrometers, gas or smoke analysis apparatus); instruments and apparatus for measuring or checking viscosity, porosity, expansion, surface tension or the like; instruments and apparatus for measuring or checking quantities of heat, sound or light (including exposure meters); microtomes - Spectrometers, spectrophotometers and spectrographs using optical radiations (UV, visible, IR)
Optical components	900190	900190	90.01 Optical fibres and optical fibre bundles; optical fibre cables other than those of heading 85.44; sheets and plates of polarising material; lenses (including contact lenses), prisms, mirrors and other optical elements, of any material, unmounted, other than such elements of glass not optically worked. - Other than Optical fibres, optical fibre bundles and cables; Sheets and plates of polarising material; Contact lenses; Spectacle lenses of glass; Spectacle lenses of other materials
Optical frequency equipment	902750	902750	90.27 Instruments and apparatus for physical or chemical analysis (for example, polarimeters, refractometers, spectrometers, gas or smoke analysis apparatus); instruments and apparatus for measuring or checking viscosity, porosity, expansion, surface tension or the like; instruments and apparatus for measuring or checking quantities of heat, sound or light (including exposure meters); microtomes - Other instruments and apparatus using optical radiations (UV, visible, IR)
Pulse counter	902750	902750	90.27 Instruments and apparatus for physical or chemical analysis (for example, polarimeters, refractometers, spectrometers, gas or smoke analysis apparatus); instruments and apparatus for measuring or checking viscosity, porosity, expansion, surface tension or the like; instruments and apparatus for measuring or checking quantities of heat, sound or light (including exposure meters); microtomes - Other instruments and apparatus using optical radiations (UV, visible, IR)

Name	HS 2022	HS 2017	Description 2022
RF & Microwave Amplifiers	854233	854233	85.42 Electronic integrated circuits - Electronic integrated circuits -- Amplifiers
Photon detectors	903089	903089	90.30 Oscilloscopes, spectrum analysers and other instruments and apparatus for measuring or checking electrical quantities, excluding meters of heading 90.28; instruments and apparatus for measuring or detecting alpha, beta, gamma, X-ray, cosmic or other ionising radiations. - Other than Instruments and apparatus for measuring or detecting ionising radiations; Oscilloscopes and oscillographs; Other instruments and apparatus, for measuring or checking voltage, current, resistance or power (other than those for measuring or checking semiconductor wafers or devices); Other instruments and apparatus, specially designed for telecommunications (for example, cross-talk meters, gain measuring instruments, distortion factor meters, psophometers) -- Other than for measuring or checking semiconductor wafers or devices (including integrated circuits); Other, with a recording device
Qubit control electronics -other	854239	854239	85.42 Electronic integrated circuits - Electronic integrated circuits - Other than – Processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits; memories; amplifiers.
Qubit control electronics -processors	854231	854231	85.42 Electronic integrated circuits - Electronic integrated circuits -- Processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
Time & Frequency Recording (Rubidium clocks)	910690	910690	91.06 Time of day recording apparatus and apparatus for measuring, recording or otherwise indicating intervals of time, with clock or watch movement or with synchronous motor (for example, time registers, time-recorders). - Other than Time registers; time-recorders
Vacuum Chambers / Pumps	841410	841410	84.14: Air or vacuum pumps, air or other gas compressors and fans; ventilating or recycling hoods incorporating a fan, whether or not fitted with filters; gas-tight biological safety cabinets, whether or not fitted with filters. - Vacuum pumps

Notes: The table shows descriptions as follows: the first row shows the 4-digit description, the second row displays the 5-digit and, if applicable, the third row displays the 6-digit descriptions, preceded by the symbols "-" and "--," respectively. In the case of Other categories, the description includes categories not included in the 6-digit HS code. If the 6-digit description is self-explanatory, it is reported directly in the first row.

Source: OECD and World Customs Organization

References

AbuGhanem, M. (2024), "Photonic Quantum Computers", researchgate.net/publication/383985852_Photonic_Quantum_Computers

ANR & AID (2020), "Appel à projets thématique sur les technologies quantiques", anr.fr/fileadmin/aap/2020/ANR-AAP-quantique-2020_.pdf

Aristodemou, L. et al. (Forthcoming), "Assessing the direction of R&D funding towards the Sustainable Development Goals (SDGs) with a new classifier and the OECD Fundstat infrastructure", OECD Science, Technology and Industry Working Papers, oecd.org/en/publications/oecd-science-technology-and-industry-working-papers_18151965.html

Aristodemou, L. et al. (2023), "Measuring governments' R&D funding response to COVID-19: An application of the OECD Fundstat infrastructure to the analysis of R&D directionality", *OECD Science, Technology and Industry Working Papers,* No. 2023/06, OECD Publishing, Paris, doi.org/10.1787/4889f5f2-en.

Australia Government DISR (2024), "Leading quantum company chooses Australia as site for its groundbreaking utility scale quantum computer", industry.gov.au/news/leading-quantum-company-chooses-australia-site-its-groundbreaking-utility-scale-quantum-computer

Awschalom, D. et al. (2018), "Quantum technologies with optically interfaced solid-state spins", Nature Photonics, Vol. 12/9, pp. 516-527, doi.org/10.1038/s41566-018-0232-2.

Bennett, C. and G. Brassard (2014), "Quantum cryptography: Public key distribution and coin tossing", Theoretical Computer Science, Vol. 560, pp. 7-11, doi.org/10.1016/j.tcs.2014.05.025.

Berger, M. et al. (forthcoming), "The OECD/STI Start-ups Database: A New Lens on the Global Start-up Ecosystem".

Berger, M. et al. (2025), "Acquisitions and their effect on start-up innovation: Stifling or scaling?", OECD Science, Technology and Industry Working Papers, No. 2025/10, OECD Publishing, Paris, doi.org/10.1787/b4efd3ab-en.

Berger, M., C. Criscuolo and A. Dechezleprêtre (2025), "Understanding Government Venture Capital: A primer and a taxonomy", OECD Science, Technology and Industry Working Papers, No. 2025/06, OECD Publishing, Paris, doi.org/10.1787/2157a5b3-en.

Berger, M., A. Dechezleprêtre and M. Fadic (2024), "What is the role of Government Venture Capital for innovation-driven entrepreneurship?", OECD Science, Technology and Industry Working Papers, No. 2024/10, OECD Publishing, Paris, doi.org/10.1787/6430069e-en.

Branstetter L. (2005), "Exploring the Link between Academic Science and Industrial Innovation", Annals of Economics and Statistics, 79/80: 119-142.

Browaeys, A. and T. Lahaye (2020), "Many-body physics with individually controlled Rydberg atoms", Nature Physics, Vol. 16/2, pp. 132-142, doi.org/10.1038/s41567-019-0733-z.

Bruzewicz, C. et al. (2019), "Trapped-ion quantum computing: Progress and challenges", Applied Physics Reviews, Vol. 6/2, doi.org/10.1063/1.5088164.

Bundesministerium für Bildung und Forschung (2022), "Forschungsprogramm Quantensysteme", quantentechnologien.de/fileadmin/public/Redaktion/Dokumente/PDF/Publikationen/BMBF-Forschungsprogramm-Quantensysteme_web_bf_C1.pdf.

Cabinet Office (2024), "Promotion Measures for the Development of Quantum Industries", www8.cao.go.jp/cstp/ryoshigijutsu/240409_q_measures.pdf.

Callaert J., B. Van Looy, A. Verbeek, K. Debackere, and B. Thijs (2006), "Traces of Prior Art: An Analysis of Non-Patent References Found in Patent Documents", Scientometrics, 69(1): 3-20. doi.org/10.2139/ssrn.874906

Cassiman, B., R.Veugelers, and P. Zuniga (2008). "In search of performance effects of (in)direct industry science links", Industrial and Corporate Change, 17(4): 611–646. doi.org/10.1093/icc/dtn023

Criscuolo, C. et al. (2022), "Are industrial policy instruments effective? A review of the evidence in OECD countries", OECD Science, Technology and Industry Policy Papers, No. 128, OECD Publishing, Paris, doi.org/10.1787/57b3dae2-en.

Degen, C., F. Reinhard and P. Cappellaro (2017), "Quantum sensing", Reviews of Modern Physics, Vol. 89/3, p. 035002, doi.org/10.1103/RevModPhys.89.035002.

Department for Science, Innovation & Technology (2023), "National Quantum Strategy", assets.publishing.service.gov.uk/media/6411a602e90e0776996a4ade/national_quantum_strategy.pdf.

DSIT (2023), “National Quantum Strategy: Technical Annexes”, assets.publishing.service.gov.uk/media/6410885e8fa8f5560f2ebdf0/quantum-strategy-technical-annexes.pdf.

DSIT (2023a), “National Quantum Strategy”, assets.publishing.service.gov.uk/media/6411a602e90e0776996a4ade/national_quantum_strategy.pdf.

Dushnitsky, G. and M. Lenox (2006), “When does corporate venture capital investment create firm value?”, Journal of Business Venturing, Vol. 21/6, pp. 753-772, doi.org/10.1016/j.jbusvent.2005.04.012.

EPO (2025), “Digital agriculture, towards sustainable food security”, ISBN 978-3-89605-406-7, epo.org/insight-digital-agriculture)

European Commission (2025), “Quantum Europe Strategy: Quantum Europe in a Changing World”, digital-strategy.ec.europa.eu/en/library/quantum-europe-strategy.

European Commission (2024), “Strategic Research Agenda 2030”, qt.eu/media/pdf/Strategic-Reseach-and-Industry-Agenda-2030.pdf.

European Quantum Industry Consortium (2025), “Strategic Industry Roadmap 2025”, euroquic.org/wp-content/uploads/2025/04/Public-Strategic-Industry-Roadmap-2025-1.pdf

Ezratty, O. (2024), “Understanding Quantum Technologies 2024”.

Georgescu, I., S. Ashhab and F. Nori (2014), “Quantum simulation”, Reviews of Modern Physics, Vol. 86/1, pp. 153-185, doi.org/10.1103/RevModPhys.86.153.

Gidney, C. (2025), “How to factor 2048-bit RSA integers with less than a million noisy qubits”, arxiv.org/abs/2505.15917

Gisin, N. et al. (2002), “Quantum cryptography”, Reviews of Modern Physics, Vol. 74/1, pp. 145-195, doi.org/10.1103/RevModPhys.74.145.

Greinert, F. et al. (2024), “Advancing quantum technology workforce: industry insights into qualification and training needs”, doi.org/10.1140/epjqt/s40507-024-00294-2

Griffiths, D. and D. Schroeter (2018), “Introduction to quantum mechanics”, Cambridge University Press.

Grumbling, E. and M. Horowitz (eds.) (2019), “Quantum Computing”, National Academies Press, Washington, D.C., doi.org/10.17226/25196.

Hall, B.H., Jaffe A. and M. Trajtenberg (2005), “Market Value and Patent Citations”, Rand Journal of Economics, No. 36, Spring.

Harhoff, D., F. M. Scherer, and K. Vopel (2003), “Citations, Family Size, Opposition and the Value of Patent Rights”, Research Policy, 32(8): 1343-1363.

Herfindahl, O.C. (1950). “Concentration in the U.S. Steel Industry”. PhD dissertation, Columbia University.

Hirschman, A. O. (1945). “National Power and the Structure of Foreign Trade”. University of California Press.

ISED (2022), “National Quantum Strategy Consultations”, What We Heard Report, ised-isde.canada.ca/site/national-quantum-strategy/sites/default/files/documents/2022-07/1032_06_21_nqs_wwh_report_en_v4.pdf.

Jibril, H. and R. Stephen (2025), “Factors influencing firms’ adoption of advanced technologies: A rapid evidence review”, gov.uk/government/publications/barriers-and-enablers-to-advanced-technology-adoption-for-uk-businesses/factors-influencing-firms-adoption-of-advanced-technologies-a-rapid-evidence-review#:~:text=Advance%20Market%20Commitments%2C%20%C2%A0such%2.

Kjaergaard, M. et al. (2020), “Superconducting Qubits: Current State of Play”, Annual Review of Condensed Matter Physics, Vol. 11/1, pp. 369-395, doi.org/10.1146/annurev-conmatphys-031119-050605.

Kowalski, P. and C. Legendre (2023), “Raw materials critical for the green transition: Production, international trade and export restrictions”, OECD Trade Policy Papers, No. 269, OECD Publishing, Paris, doi.org/10.1787/c6bb598b-en.

Ladd, T. et al. (2010), “Quantum computers”, Nature, Vol. 464/7285, pp. 45-53, doi.org/10.1038/nature08812.

Lai, P. (2017), “The literature review of technology adoption models and theories for the novelty technology”, Journal of Information Systems and Technology Management, Vol. 14/1, pp. 21-38, doi.org/10.4301/s1807-17752017000100002.

Larrue, P. (2021), “The design and implementation of mission-oriented innovation policies: A new systemic policy approach to address societal challenges”, OECD Science, Technology and Industry Policy Papers, No. 100, OECD Publishing, Paris, doi.org/10.1787/3f6c76a4-en.

Lee, M. (2023), “A Framework for Assessing Vulnerabilities in the Quantum Computing Materials Supply Chain”, GTG Policy White Paper.

Ludlow, A. et al. (2015), “Optical atomic clocks”, Reviews of Modern Physics, Vol. 87/2, pp. 637-701, doi.org/10.1103/RevModPhys.87.637.

Martens, J. et al. (2025), “Acceptance and Development of Quantum Computing in the Netherlands and Germany: Barriers and Remedies From a Multistakeholder Perspective”, IEEE Transactions on Engineering Management, Vol. 72, pp. 62-77, doi.org/10.1109/tem.2024.3493600.

Mckinsey (2025), “The Year of Quantum: From concept to reality in 2025”, mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025#/

Ministère de l’Economiel (2021), “France 2030”, info.gouv.fr/upload/media/content/0001/13/70266a92ff2e787d16e483ace4c78f550713cb6e.pdf

Ministère des Armées (2013), “Livre Blanc - Défense et Sécurité Nationale”.

Ministry of Science and ICT (2023), “Korea’s National Quantum Strategy”, quantuminkorea.org/wp-content/uploads/2024/06/Koreas-National-Quantum-Strategy-2023_c.pdf.

National Quantum Initiative Advisory Committee (2024), “Quantum Networking: Findings and Recommendations for Growing American Leadership”, quantum.gov/wp-content/uploads/2024/09/NQIAC-Report-Quantum-Networking.pdf.

National Science & Technology Council (2021), “NQI supplement to the President’s FY 2021 Budget”, quantum.gov/wp-content/uploads/2021/01/NQI-Annual-Report-FY2021.pdf.

National Science and Technology Council (2009), “A Federal Vision for Quantum Information Science”, science.osti.gov/-/media/_/pdf/initiatives/qis/FederalVisionQIS.pdf.

Nielsen, M. and I. Chuang (2010), “Quantum computation and quantum information”, Cambridge University Press.

NPI (2018), “The Role of the Defense Department in the NQI”, lightourfuture.org/NPI/media/npi/Resources/FINAL-DOD-Role-in-the-NQI-Apr-3-2018.pdf?ext=.pdf.

OEC (2025), “Observatory of Economic Complexity”, oec.world/en

OECD (2025a), “A quantum technologies policy primer”, OECD Digital Economy Papers, No. 371, OECD Publishing, Paris, doi.org/10.1787/fd1153c3-en.

OECD (2025b), “Mapping the semiconductor value chain: Working towards identifying dependencies and vulnerabilities”, *OECD Science, Technology and Industry Policy Papers*, No. 182, OECD Publishing, Paris, doi.org/10.1787/4154cdbf-en.

OECD (2025c), “Overview of national strategies and policies for quantum technologies”.

OECD (2024), “Key concepts and current technical trends in cryptography for policy makers”, OECD Digital Economy Papers, No. 364, OECD Publishing, Paris, doi.org/10.1787/29d9fbad-en.

OECD (2023), “OECD Science, Technology and Innovation Outlook 2023: Enabling Transitions in Times of Disruption”.

OECD (2015), “The Innovation Imperative – Contributing to Productivity, Growth and Well-Being”, OECD Publishing, doi.org/10.1787/9789264239814-en.

OECD (2013), “Commercialising Public Research : New Trends and Strategies”, OECD Publishing, doi.org/10.1787/9789264193321-en.

Office parlementaire d’évaluation des choix scientifiques et technologiques (2022), “La Stratégie quantique de la France”, senat.fr/fileadmin/Office_et_delegations/OPECST/Syntheses/2022-01_Strategie_quantique_FR.pdf.

Perrier, E. (2022), “The Quantum Governance Stack: Models of Governance for Quantum Information Technologies”, Digital Society, Vol. 1/3, doi.org/10.1007/s44206-022-00019-x.

Preskill, J. (2018), “Quantum Computing in the NISQ era and beyond”, Quantum, Vol. 2, p. 79, doi.org/10.22331/q-2018-08-06-79.

Quantum Flagship (2025), “All-EU funded projects”, qt.eu/structure-governance/quantum-coordination-board#project-list.

Qureca (2025), “Quantum Initiatives Worldwide 2025”, qureca.com/quantum-initiatives-worldwide/

RAE (2024), “Quantum Infrastructure Review”, raeng.org.uk/media/rrqjm2v3/quantum-infrastructure-review.pdf.

Roffe, J. (2019), “Quantum Error Correction: An Introductory Guide”, doi.org/10.1080/00107514.2019.1667078

Rogers, E. (1962), “Diffusion of Innovations”, Free Press of Glencoe. doi.org/10.1002/jps.2600520633

Schmoch, U. (2008). “Concept of a Technology Classification for Country Comparisons – Final Report to the World Intellectual Property Organisation (WIPO)”. [online] Available at: wipo.int/documents/2948119/3215563/wipo_ipc_technology.pdf

Squicciarini, M. and H. Dernis (2013), “A Cross-Country Characterisation of the Patenting Behaviour of Firms based on Matched Firm and Patent Data”, OECD Science, Technology and Industry Working Papers, No. 2013/5, OECD Publishing, Paris, doi.org/10.1787/5k40gxd4vh41-en.

Strategic Advisory Board of the European Quantum Flagship (2024), “Key Performance Indicators for Quantum Technologies in Europe”, qt.eu/media/pdf/KPI_booklet_2024.pdf?m=1710851729&.

Subcommittee on Quantum Information Science of the National Science and Technology Council (2023), “National Quantum Initiative Supplement to the President’s FY 2024 Budget”, quantum.gov/wp-content/uploads/2023/12/NQI-Annual-Report-FY2024.pdf.

Sze, S. and K. Ng (2006), “Physics of Semiconductor Devices”, Wiley, doi.org/10.1002/0470068329.

Top500 (n.d.), “El Capitan Retains Top Spot in 65th TOP500 List as Exascale Era Expands”, top500.org/news/el-capitan-retains-top-spot-65th-top500-list-exascale-era-expands/.

Tornatzky and Fleischer (1990), “The Processes of Technological Innovation”, Lexington Books, Lexington. doi.org/10.1007/bf02371446

Trajtenberg, M. (1990), “A Penny for Your Quotes: Patent Citations and the Value of Innovation”, RAND Journal of Economics, 21 (1): 172-187.

UK DSIT (2024), “Semiconductor sector study”.

United States Senate Committee on Commerce, Science and Transportation (2024), “Cantwell, Young, Durbin, Daines Introduce National Quantum Initiative Reauthorization Act”, commerce.senate.gov/2024/12/cantwell-young-durbin-daines-introduce-national-quantum-initiative-reauthorization-act.

Velu, C. and F. Putra (2023), “How to introduce quantum computers without slowing economic growth”, Nature, Vol. 619/7970, pp. 461-464, doi.org/10.1038/d41586-023-02317-x.

Wang, B. (2023), “Intel and AMD Path to Zettaflop Supercomputers”, nextbigfuture.com/2023/02/intel-and-amd-path-to-zettaflop-supercomputers.html

WIPO (2025). Available at: wipo.int/ipstats/en/docs/ipc_technology.xlsx

Wootters, W. and W. Zurek (1982), “A single quantum cannot be cloned”, Nature, Vol. 299/5886, pp. 802-803, doi.org/10.1038/299802a0.

Yamashita, I. et al. (2021), “Measuring the AI content of government-funded R&D projects: A proof of concept for the OECD Fundstat initiative”, OECD Science, Technology and Industry Working Papers, No. 2021/09, OECD Publishing, Paris, doi.org/10.1787/7b43b038-en.

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