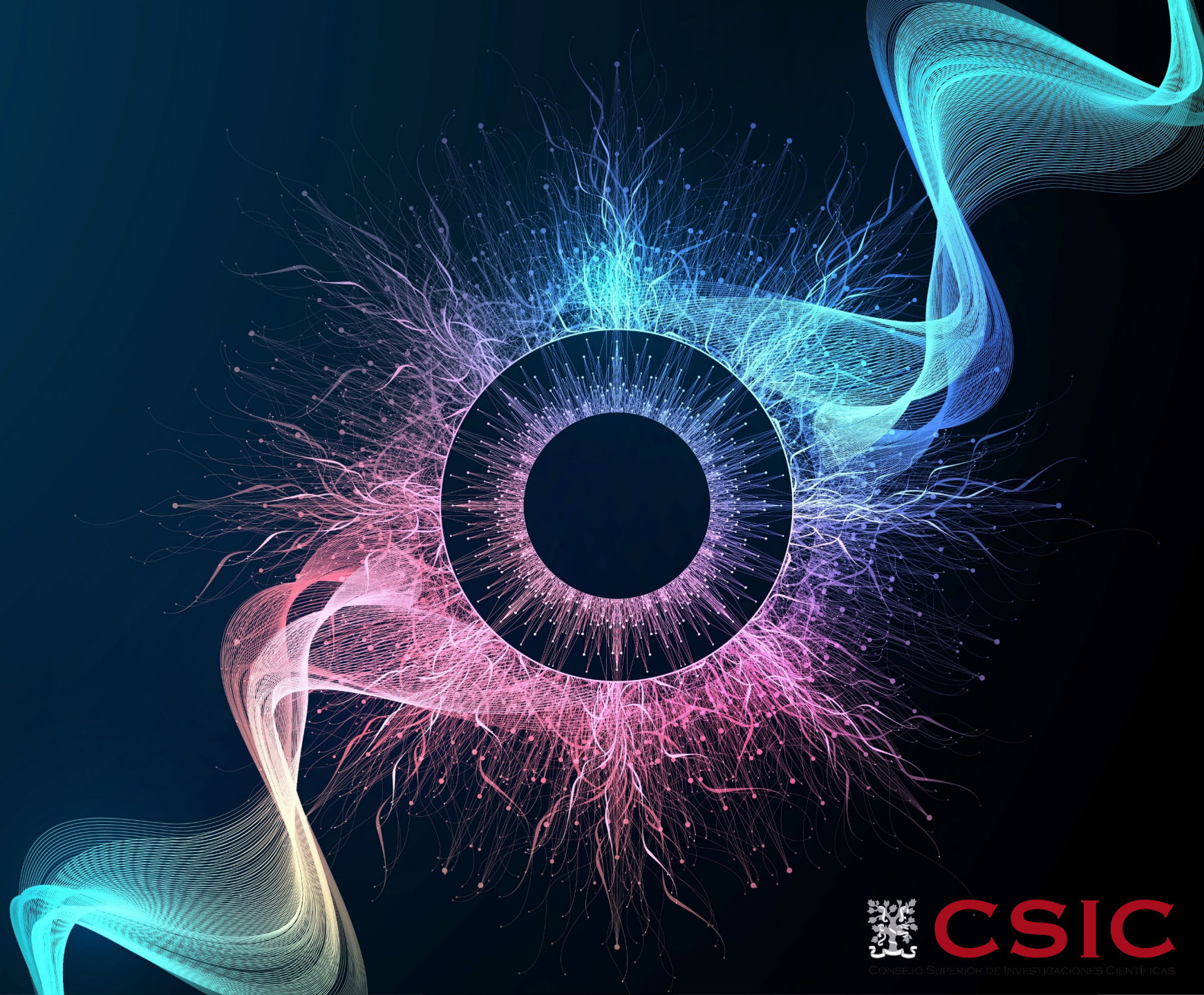




Fundación
General CSIC

Quantum Technology Scouting

Analysis Report
April 2025



CSIC

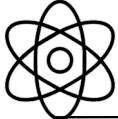
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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Executive summary





Executive summary

Investment and ecosystem

Global investment in quantum technologies is reaching unprecedented levels. Major players like the United States and China are spearheading initiatives with billions of dollars in funding, aiming to secure leadership in this transformative sector. In Europe, coordinated efforts such as the EU Quantum Flagship are fostering cross-border collaboration. Spain, in particular, has made significant strides with programs like Quantum Spain and IKUR. These initiatives are creating a robust ecosystem, integrating cutting-edge research centers, universities, and private companies. This collaborative environment is pivotal in tackling the complex challenges posed by quantum computing, sensing, and communication, ensuring Spain remains a competitive player on the global stage. Moreover, such efforts are instrumental in training the next generation of quantum professionals, advancing industry partnerships, and accelerating the translation of research into tangible innovations for diverse applications.

Research and technology progress

Quantum technologies are advancing rapidly, driven by continuous breakthroughs in quantum computing hardware, communication protocols, and sensing applications. Globally, research is focusing on achieving scalable and fault-tolerant quantum computers, enhancing the potential for solving complex problems in medicine, logistics, and cryptography. Spain has emerged as a key contributor to this progress. Institutions like ICFO and DIPC are at the forefront, pioneering research in quantum communication and developing practical quantum systems. These advancements are further bolstered by international collaborations and significant investments in quantum infrastructure, positioning Spain as a hub for innovation and scientific excellence in the field. Additionally, Spain's efforts are fostering the creation of a skilled workforce, strengthening ties between academia and industry, and promoting the transfer of knowledge to accelerate the deployment of quantum technologies in real-world applications.

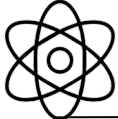
Potential economic value

The economic impact of quantum technologies is projected to surpass hundreds of billions of euros by 2035, with transformative applications in sectors such as telecommunications, finance, healthcare, and energy. For Spain, the potential extends beyond direct economic benefits; it includes fostering innovation ecosystems, creating high-value jobs, and enhancing industrial competitiveness. Strategic investments in quantum research and its commercialization promise to unlock unprecedented opportunities, empowering Spanish industries to lead in emerging markets. By leveraging its growing talent pool and fostering public-private partnerships, Spain is well-positioned to capitalize on the economic revolution driven by quantum advancements, ensuring long-term growth and global recognition in the quantum sector.



Introduction





Integration of Quantum Technologies into Core Domains



Quantum Computing (QC):

- * **Quantum Simulation (QSim):** Uses quantum systems to simulate complex phenomena.
- * **Quantum Information (QInfo):** Processing information using quantum systems.
- * **Quantum Materials (QMat):** Materials required for quantum hardware.

Quantum computing uses quantum mechanics to achieve exponential performance gains for specific tasks, enabling new computational possibilities. Early devices, like quantum simulators, solve complex problems beyond classical systems' capabilities.



Quantum Communications (QComms):

- ⚙️ **Quantum Communication (QComm):** Secure transfer of quantum information.
- ⚙️ **Quantum Metrology (QM):** Supports precision in quantum communications.
- ⚙️ **Quantum Information (QInfo):** Cryptography and secure data transmission.

Quantum communications enable ultra-secure data transfer using quantum cryptography, resistant to threats from quantum computers. It leverages quantum entanglement to build secure networks and a future quantum internet.



Quantum Sensing (QS):

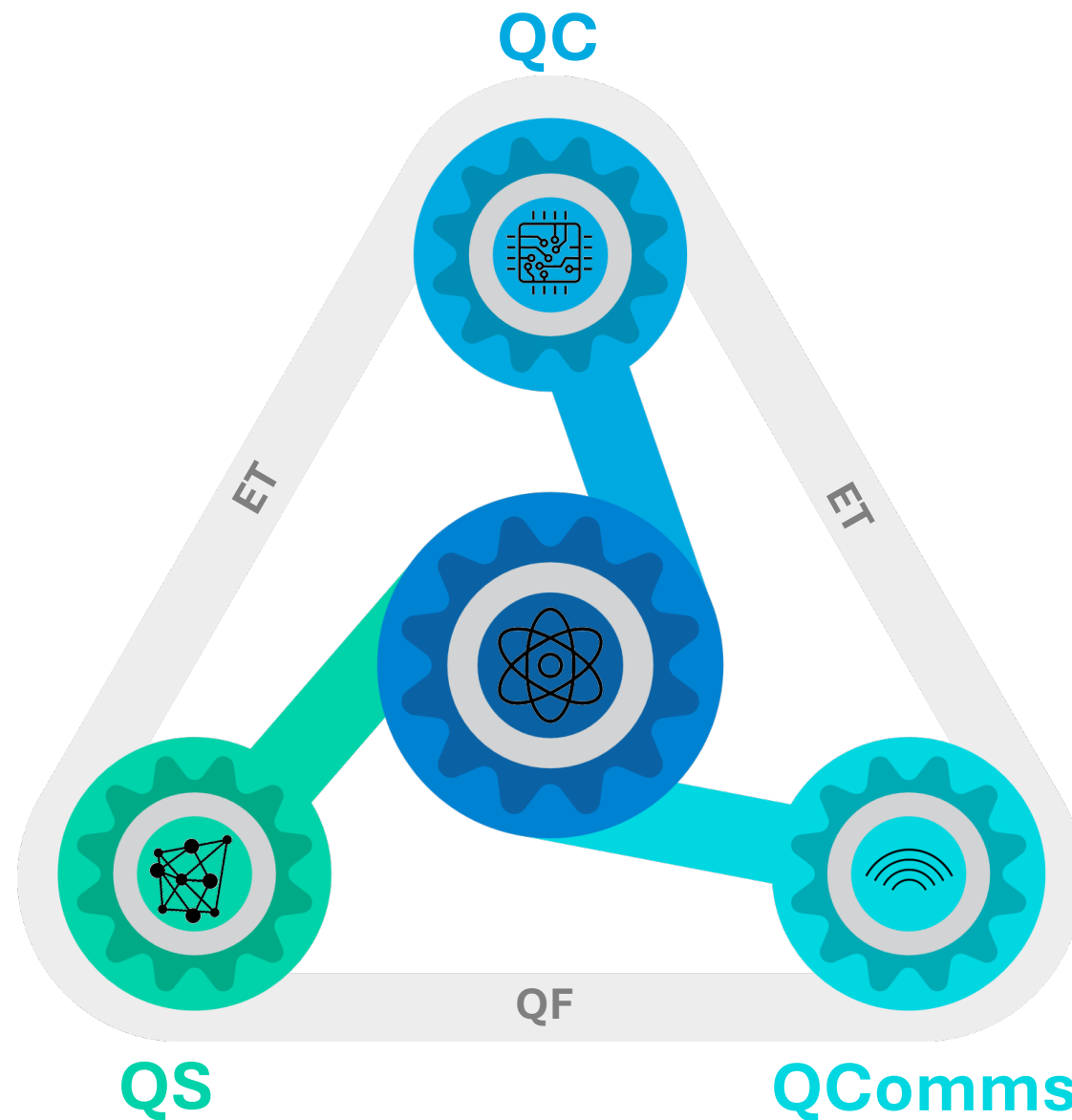
- ⚙️ **Quantum Sensing (QS):** Advanced sensors for precise measurements.
- ⚙️ **Quantum Metrology (QM):** Ultra-precise measurement techniques.
- ⚙️ **Quantum Imaging (Qi)** uses quantum principles to achieve ultra-precise and high-resolution imaging beyond classical limits.

Quantum sensing utilizes quantum systems to measure gravity, time, and electromagnetism with exceptional precision. These sensors outperform classical ones, enabling breakthroughs in healthcare, navigation, and geophysics.



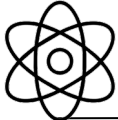
Cross-Cutting Areas:

- 🏠 **Quantum Foundations (QF):** Theoretical basis for all areas.
- 🏠 **Enabling Technologies (ET):** Infrastructure and tools to support all applications.



QComms





Introduction

A Technical Overview of the Quantum Landscape

In the past decade, quantum computing and the broader quantum landscape have experienced transformative growth, evolving from academic research into a burgeoning commercial industry. Quantum systems have become increasingly powerful, with expanded use cases across diverse industries, driving heightened interest in the field.

Quantum technologies now encompass not only quantum computing but also quantum communication, sensing, and networking. This includes the emergence of quantum-secure communication protocols and advanced quantum sensors. The quantum ecosystem has progressed in parallel with technological advancements, transitioning from theoretical potential to practical utility.

Key Areas of Quantum Technology:

1. Quantum Computing: Quantum computing leverages the principles of quantum mechanics, such as superposition, to solve complex problems beyond the reach of classical computers. The field spans:

- Hardware providers building quantum machines.
- Software developers creating specialized quantum tools.
- QCaaS (Quantum Computing as a Service) platforms delivering quantum computing capabilities via cloud services.

2. Quantum Communication: Quantum networks

enable secure, high-speed data transfer through phenomena like quantum entanglement and teleportation. Applications include quantum key distribution (QKD) for enhanced cybersecurity and post-quantum cryptography to safeguard against quantum threats.

3. Quantum Sensing: Quantum sensors provide ultra-precise measurements for applications in navigation, environmental monitoring, and geophysics. This segment has also served as a revenue driver for early quantum computing companies.

Quantum Use Cases and Industry Adoption:

Quantum computing has found early adoption in industries such as finance, pharmaceuticals, and sustainability:

- Finance: Optimization, risk profiling, and predictive modeling.
- Pharmaceuticals: Simulating molecular dynamics for drug discovery.
- Sustainability: Climate modeling and low-carbon material design.

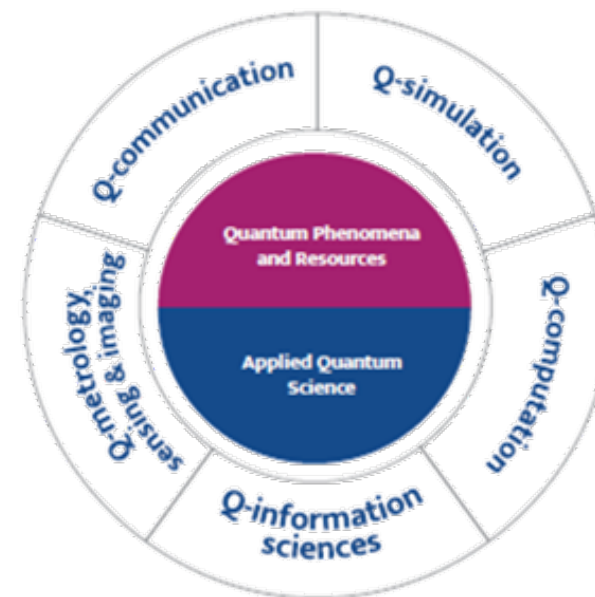
Barriers to Quantum Advancement:

Quantum computing faces challenges in scaling systems and improving coherence times. Current systems, with around 1,000 qubits, must scale to tens of thousands to realize full potential. Error correction and hybrid quantum-classical approaches are critical development areas.

Outlook and Future Directions:

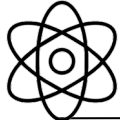
With advancements in hardware, software, and hybrid computing models, quantum technologies are poised to transform industries. Strategic roadmaps, such as IBM's plan for a 100,000-qubit system by 2033, highlight the sector's growth trajectory. The integration of AI with quantum systems further amplifies the potential for groundbreaking applications.

The quantum landscape is transitioning from its early commercialization phase into a robust and impactful market, shaping the future of computing and innovation.

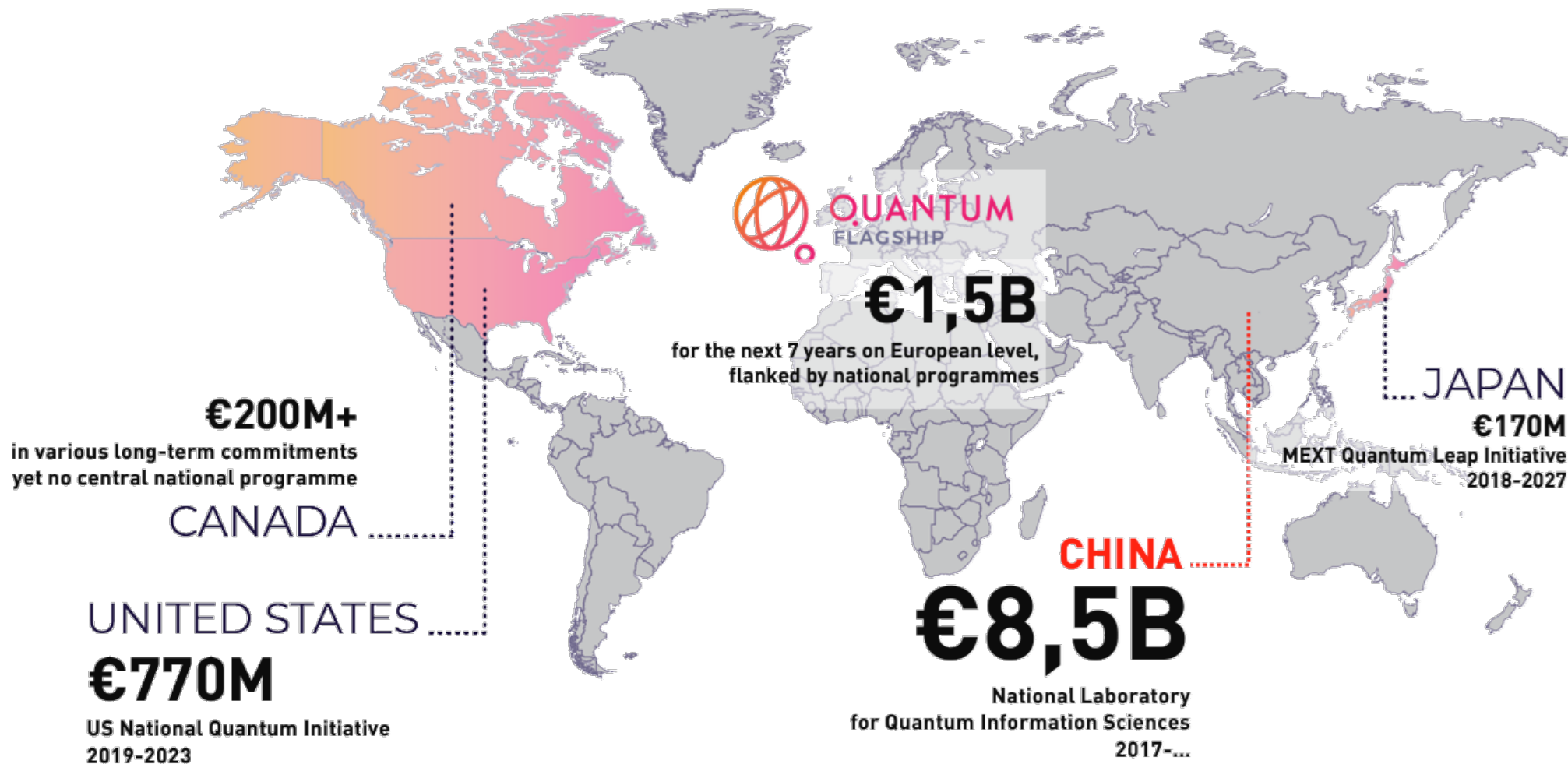


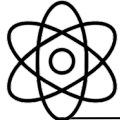
Global context of quantum technologies





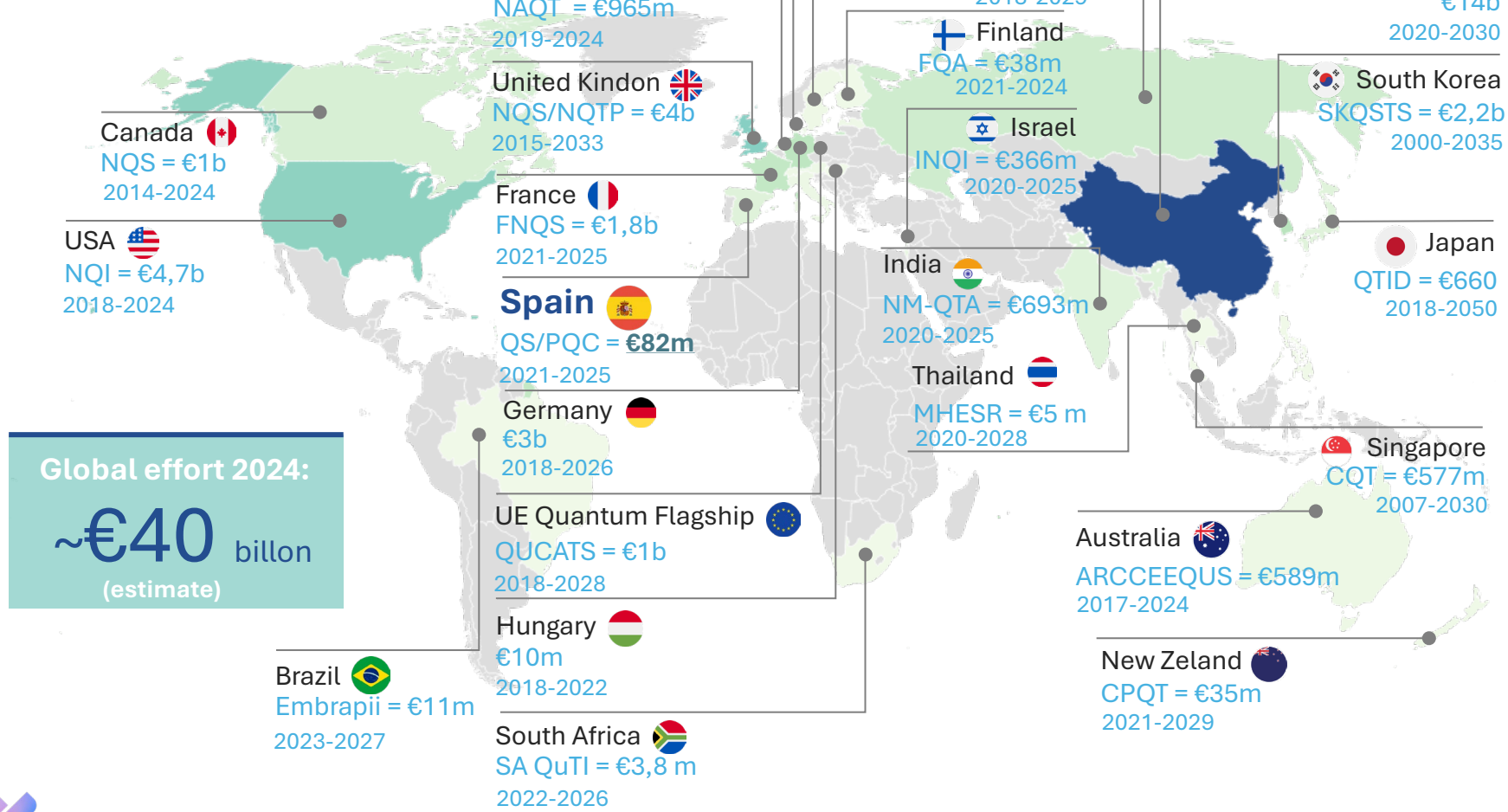
Main Focus Quantum Effort: Driving Innovation and Research





Global Quantum Effort: Driving Innovation and Research (details)

€ Millions



Global effort 2024: ~€40 billion (estimate)

The global effort in quantum science and technology is witnessing rapid growth, with current investments exceeding €40 billion. This reflects the increasing recognition of quantum technologies' transformative potential across various sectors. Looking ahead, the global quantum technology market is projected to reach €97.52 billion by 2040, highlighting its substantial economic and societal impact.

Rather than being a competitive race, the development of quantum technologies is evolving into a collaborative global ecosystem. Nations and organizations worldwide are spearheading major programs and initiatives to advance quantum research, innovation, and commercialization. These coordinated efforts aim to harness quantum technologies' capabilities for solving complex problems and unlocking new frontiers in computing, communications, and sensing.

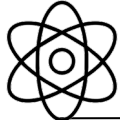
This cooperative approach underscores the importance of international partnerships and shared expertise in shaping the quantum landscape, ensuring its benefits extend to all facets of society.



Fuente: Qureca and Techunwrapped.

Quantum
landscape in
Europe





Quantum Landscape in Europe



HORIZON EUROPE

DIGITAL EUROPE

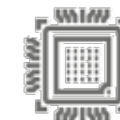
QUANTERA

QUANTUM FLAGSHIP

QUANTUM COMMUNICATION INFRASTRUCTURE (QCI)

QUANTUM COMPUTING INFRASTRUCTURE

QUANTERA



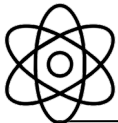
Give funding support to international research projects in quantum technologies

Bring quantum technologies from the lab to the market and consolidate European scientific leadership

Build and deploy in the next decade a certified secure pan-European end-to-end QCI for cybersecurity services

Build and deploy an infrastructure for big data, AI, high-performance computing, and more



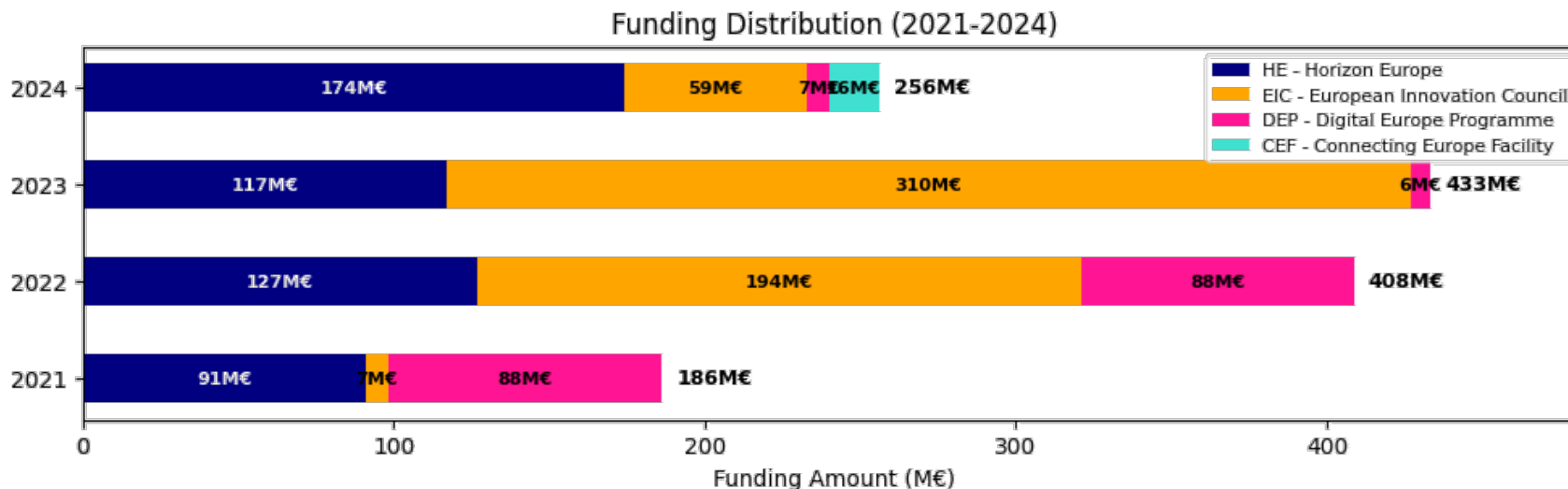


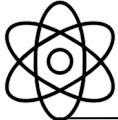
Quantum Landscape in Europe

The European Union offers a comprehensive suite of funding opportunities to advance quantum technologies, spanning early-stage research, applied research, and the development of cutting-edge infrastructure. Key programs include Horizon Europe (HE), the Digital Europe Programme (DEP), the European Innovation Council (EIC), and the Connecting Europe Facility (CEF). Together, these initiatives form the backbone of the **EU's quantum strategy**, reflecting its commitment to global leadership in this transformative field.

Horizon Europe is the EU's flagship research and innovation program. From 2021 to 2024, it has allocated approximately €509 million to quantum technology projects. These funds encompass the Quantum Flagship Projects, which focus on areas like quantum communication, computing, and sensing, as well as the EuroHPC Joint Undertaking for high-performance computing and the Chips Joint Undertaking for advanced semiconductor technologies. In 2024 alone, €174 million was dedicated to quantum technologies under Horizon Europe, reflecting a year-on-year increase.

The **Digital Europe Programme** (DEP) emphasizes building essential digital capacities, including quantum infrastructure. Between 2021 and 2024, DEP has allocated €190 million for quantum-related initiatives, focusing on practical applications and integration of quantum technologies into European industries. The **European Innovation Council** (EIC) supports high-risk, high-impact innovations, particularly those transitioning from research to market-ready solutions. Between 2021 and 2024, the EIC has contributed a significant €570 million to quantum technology projects. This funding aims to support startups, scale-ups, and SMEs in commercializing quantum innovations. Additionally, the **Connecting Europe Facility** (CEF), introduced in 2024, has begun funding projects that strengthen the Quantum Communication Infrastructure (EuroQCI). This initiative enhances ultra-secure data transfer capabilities across Europe, an essential step for ensuring data sovereignty and cybersecurity. Collectively, these programs have invested over €1,2 billion in quantum technology projects from 2021 to 2024. This substantial investment underscores the EU's ambition to establish a robust quantum ecosystem, integrating research, industry, and policymaking. These efforts aim to position Europe as a global leader in quantum technologies, fostering breakthroughs in sectors such as healthcare, energy, telecommunications, and cybersecurity.

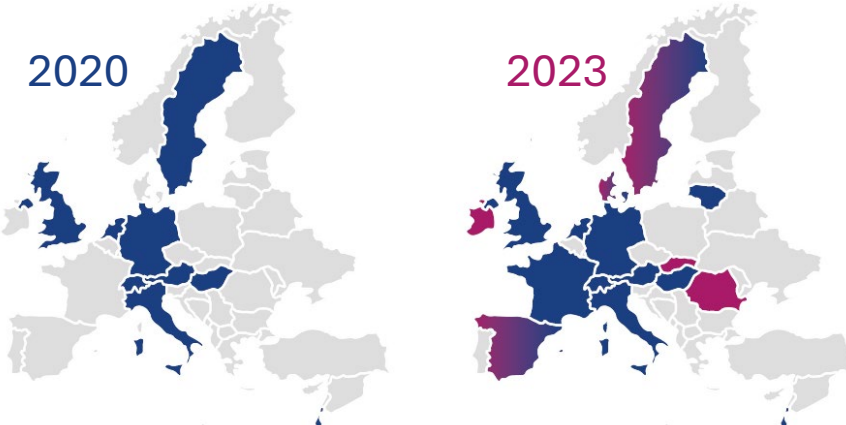




Quantum Landscape in Europe



- Countries with developed national quantum strategy and/or significant government contribution
- Countries with national quantum strategy in progress
- Countries with significant government contribution and national quantum strategy in progress



To analyze a more manageable dataset, we will use **data sampling** to narrow the **focus of our analysis to European calls specifically designed for quantum technologies**. This includes the Quantum Flagship and QuantERA programs. The program accelerates quantum technology (QT) development and fosters connections between academia, industry, and policymakers. Complementing this is the Quantum Community Network (QCN), which includes members from 32 countries, working to align national strategies with European goals.

As national quantum strategies evolve, the **QuantERA** program monitors and supports these developments. National approaches fall into three categories:

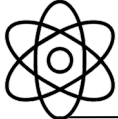
1. Countries with coordinated national programs.
2. Countries with significant funding but no national strategy.
3. Countries primarily active through international initiatives like QuantERA.

Out of 31 QuantERA countries, 15 have dedicated or developing programs for QT funding, while others rely on alternative mechanisms. A new trend involves strategies without assigned budgets but with defined priorities that guide future funding, including:

- **Spain:** Quantum Spain (QS) and Plan for Quantum Communication (PQC) (€82M).
- **Germany:** Quantum Systems.
- **Denmark:** Mapping Quantum Technologies.
- **Estonia:** Research, Development, Innovation, and Entrepreneurship Strategy (2021–2035).
- **Finland:** Quantum Agenda.
- **Greece:** Operational Program for Competitiveness, Entrepreneurship, and Innovation (2021–2028).
- **Luxembourg:** National Research Priorities.
- **Norway:** Long-Term Plan for Research and Higher Education (2023–2032).
- **Romania:** 4th National Plan for Smart Specialization (2022–2027).
- **Türkiye:** 11th Development Plan (2019–2023).

These efforts highlight Europe's commitment to quantum technologies, ensuring competitiveness and fostering cross-border collaboration in this strategic field.





Quantum Landscape in Europe (focus in specific Quantum technologies calls)



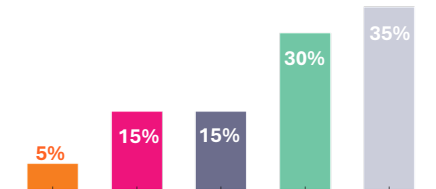
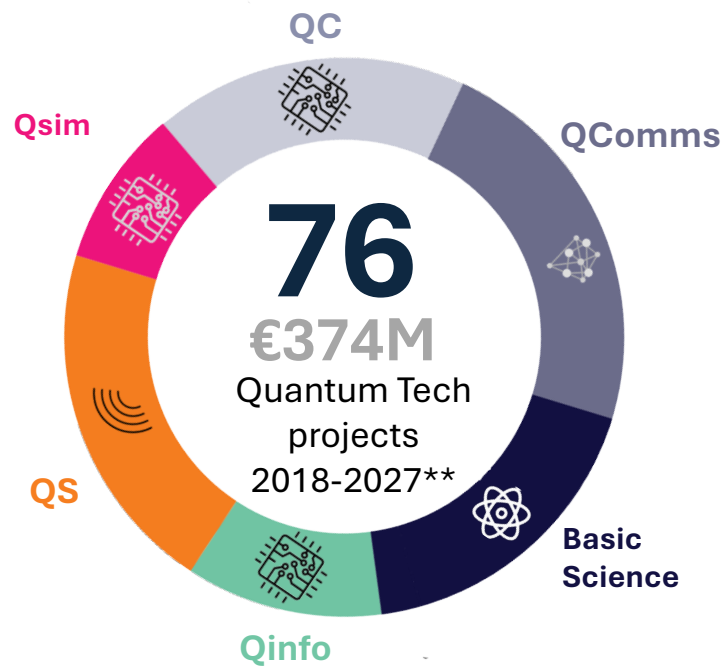
The **Quantum Flagship** is a major initiative launched by the European Commission in 2018 under Horizon 2020, with a total budget of €1 billion over ten years to secure Europe's leadership in quantum technologies (QT). It aims to advance research, develop applications, and strengthen collaboration between academia, industry, and policymakers.

In its initial phase (2018–2022), **20 projects** were selected with an estimated investment of **€132 million**, focusing on key areas such as quantum computing (**QC**), quantum communication (**QComms**), quantum sensing (**QS**), quantum simulation (**QSim**), and quantum information sciences (**QInfo**), laying the foundation for Europe's quantum ecosystem. In the subsequent 2021–2024 call, **32 projects** were granted with an estimated financing of **€207,34 million**, further propelling Europe's QT.

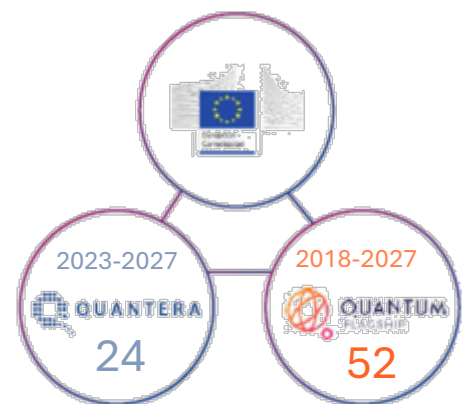


In addition, the **QuantERA program** has complemented these efforts by funding **24 additional projects** in its latest call, with an estimated investment of **€34,3 million**. These projects span areas such as quantum communication, sensing, simulation, and computation, further aligning national strategies with European goals.

Together, these **76 projects**, representing a total investment of approximately **€374 million**, reinforce Europe's position as a global leader in quantum technologies. This unified framework promotes QT integration into critical sectors such as healthcare, energy, and cybersecurity, while supporting the development of infrastructure like the **Quantum Communication Infrastructure (EuroQCI)** for ultra-secure data transfer.



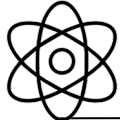
% Área de Investigación Adicional:
Refleja el porcentaje de áreas de investigación principales que contribuyen a campos secundarios, complementando los objetivos del proyecto con aplicaciones interdisciplinarias



***The analyzed projects focus on the specific QT Quantum Flagship and QuantERA calls in Europe (2018-2027). QT projects from the EIC (33), Horizon FET (17), EuroQCS (7), Horizon Space (5), Digital Europe (2), Horizon WIDERA (2), EuroQCI (1), and EURAMET (1) calls have not been considered for this sampling*

The flag icon represents projects in which there is a Spanish institution among the project participants.





Quantum Landscape in Europe (focus in specific Quantum technologies calls)

Basic Science

QS

QComms



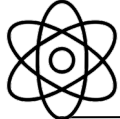
QC

Qinfo

Qsim






ET










Quantum Landscape in Europe






Basic Science:

- MACQSIMAL:** Development of advanced quantum sensors for metrology and communication applications.  
- QIA:** Creation of a quantum internet infrastructure for ultra-secure long-distance communications. 
- S2QUIP:** Integration of quantum photonics in information and communication systems.  **CSIC**
- QMICS:** Study of quantum communication in the microwave range for superconducting quantum computing. 
- Qombs:** Development of quantum frequency combs for metrology and communication applications.
- PhoG:** Generation of quantum photonic states for communication and computing.
- Qusco:** Exploration of complex quantum systems for advancing new technologies.




QS:

- ASTERIQS:** Quantum sensors using diamond defects for precise magnetic and electric field measurements. 
- MetaboliQs:** Quantum sensors for metabolic imaging in biomedical applications.
- iqClock:** Affordable, ultra-precise optical clocks using quantum technology.
- V-MAG:** Advanced quantum magnetometers for imaging.
- EXTRASENS:** High-precision sensors for quantum imaging.
- QM3:** Quantum multi-modal microscopy.
- AQuSeND:** Nano-diamond-based advanced quantum sensing. 
- CoQuaDis:** Collective quantum phenomena for metrology and sensing applications. **CSIC** 
- OPTRIBITS:** Optically addressable trityl radical qubits  **CSIC**
- QRaDES:** Sensors for quantum relic axion detection in astrophysics. 



QC:

- OpenSuperQ:** Superconducting quantum computer for European scientific accessibility.  
- AQTION:** Compact quantum computer using ion traps for industrial integration. 
- SQUARE:** Improving quality and scalability of quantum computing via error correction. 
- QUDOT-TECH:** Quantum dot technologies for sensors and communication.
- HSM-QCC:** Secure hardware for delegated quantum cloud computing.
- PROTEQT:** Development of fault-tolerant quantum computing techniques.
- GeMOS:** Germanium MOSFETs for quantum computation.
- QNet:** Quantum-secure networks for critical infrastructures. 






Qsim:

- PASQuanS:** Programmable large-scale quantum simulators for complex problems. 
- QUTEGA:** Quantum algorithms for chemistry and material science applications.
- TouQan:** Quantum information theory and networked system applications.  **CSIC**
- MOLAR:** Optimization of logical quantum operations. **CSIC** 

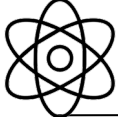
Qinfo:

- ClusSTAR:** Quantum simulations in cluster state architectures. 
- COMPUTE:** Optimization of non-commutative polynomials for quantum networks. 
- ElQuRes:** Exploration of electronic quantum resources.
- QuCABOoSE:** Quantum coherence activation in open systems.
- ResourceQ:** Studying quantum resources for simulation.

Qcomms:

- CiViQ:** Versatile quantum communication systems for telecommunication networks.  
- QRANGE:** Research on quantum random number generation for enhanced cryptographic security. 
- UNIQORN:** Integration of quantum components into photonic platforms for communication and information processing.
- QCALL:** Training researchers in quantum communication technologies. 
- COMPHORT:** Development of quantum-secure communication protocols. 
- EQSOTIC:** Advancing entangled quantum systems for communication.
- MEEDGARD:** Simulations for studying quantum materials.
- QISS:ME:** Investigation of quantum information theory in advanced systems.
- FiGAnti:** Simulations of quantum phenomena in antiferromagnetic materials.





Quantum Landscape in Europe

Basic Science:



UVQuant: Deep Ultraviolet Laser For Quantum Technology.

ASPECTS: Quantum Thermodynamics of Precision in Electronic Devices.

TruePA: Truly Resilient Quantum Limited Traveling Wave Parametric Amplifiers.

CLUSTEC: Scalable Continuous Variable Cluster State Quantum Technologies.

ONCHIPS: On-chip Integration of Quantum Electronics and Photonics.

SuperMeQ: Exploring nonclassical states of center-of-mass mechanical motion with superconducting magneto- and levitomechanics.

QC:



EuRyQa: European infrastructure for Rydberg Quantum Computing.

EQUALITY: Efficient Quantum Algorithms for Industry.

QCfD: Quantum Computational Fluid Dynamics.

OpenSuperQPlus: Open Superconducting Quantum Computers.

Millenion: Modular Industrial Large-scaLE quaNtum computing with trapped IONs.

EPIQUE: European Photonic Quantum Computer.

FoQaCiA: Foundations of quantum computational advantage.

IGNITE: Integrated germanium quantum technology.

Qsim:



PASQuanS2: Programmable Atomic Large-scale Quantum Simulation 2.1.

SPINUS: Spin-based Quantum Computer and Simulator.

Qcomms:



HyperSpace: HYPER entanglement in SPACE.

NeQST: Next level Quantum information processing for Science and Technology.

QS:



SEQUOIA: Sensing using Quantum OCT with AI.

QUANTIFY: QUantum enhANced phoTonic Integrated sensors For metrology.

MuQUABIS: Multiscale Quantum Bio-Imaging and Spectroscopy.

MIRAQLS: Mid-Infrared Quantum Technology for Sensing.

C-QuENS: Capacitation of Quantum-Entangled NV-Center Sensing.

FiQUgS: Field Quantum Gravity Sensors.

AQuRA: Advanced Quantum Clock for Real-World Applications.

AMADEUS: Advancing the Market Uptake of Diamond Defects Quantum Sensors.

QUENCH: Quantum-enhanced benchtop NMR spectrometer.

ET:



QLASS: Quantum Glass-based Photonic Integrated Circuits.

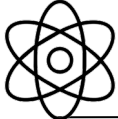
QU-PIC: Quantum Universal Photonics Integrated Circuit platform.

QPIC1550: Quantum photonic integrated circuits at 1550 nm.

QU-TEST: Open Testing and Experimentation.

QU-PILOT: Experimental production capabilities for quantum technologies in Europe. **CSIC**





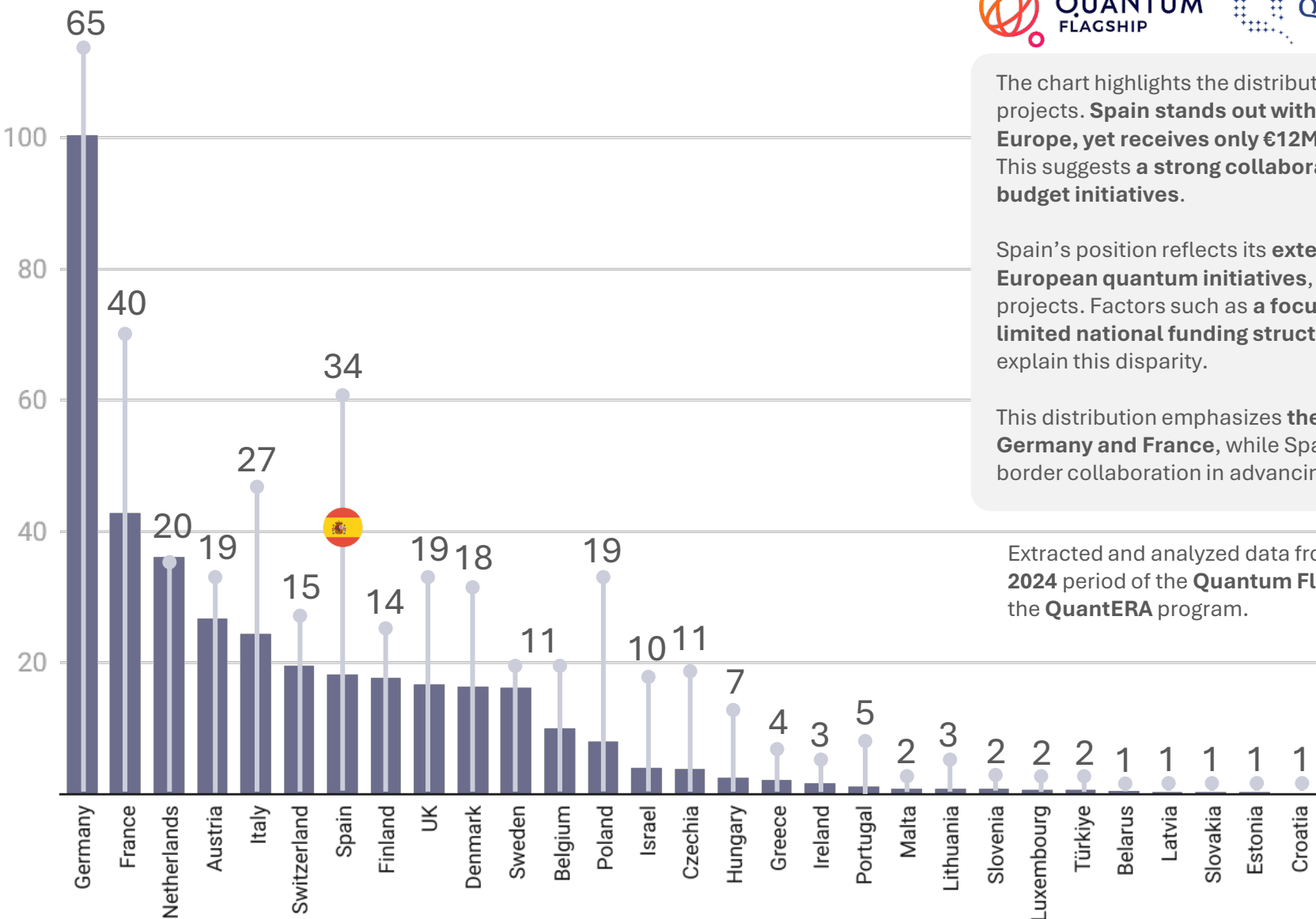
Quantum Landscape in Europe



QUANTUM
FLAGSHIP



QUANTERA



The chart highlights the distribution of European funding for quantum technology (QT) projects. **Spain stands out with 34 projects, one of the highest participations in Europe, yet receives only €12M**, significantly less than countries with fewer projects. This suggests a **strong collaborative role rather than leadership in large-scale, high-budget initiatives**.

Spain's position reflects its **extensive research network and active engagement in European quantum initiatives**, often contributing as a key partner in multi-national projects. Factors such as **a focus on research over infrastructure, a supportive but limited national funding structure, and high integration in international consortia** may explain this disparity.

This distribution emphasizes **the concentration of funding in leading countries like Germany and France**, while Spain's case highlights the strategic importance of cross-border collaboration in advancing Europe's quantum ecosystem.

Extracted and analyzed data from the 76 projects corresponding to the calls from the **2018-2024** period of the **Quantum Flagship** program and the projects from the **2023-2027** call of the **QuantERA** program.

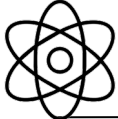


€ Millions accumulated from funding through participation in European projects



Number of participations in European projects funded



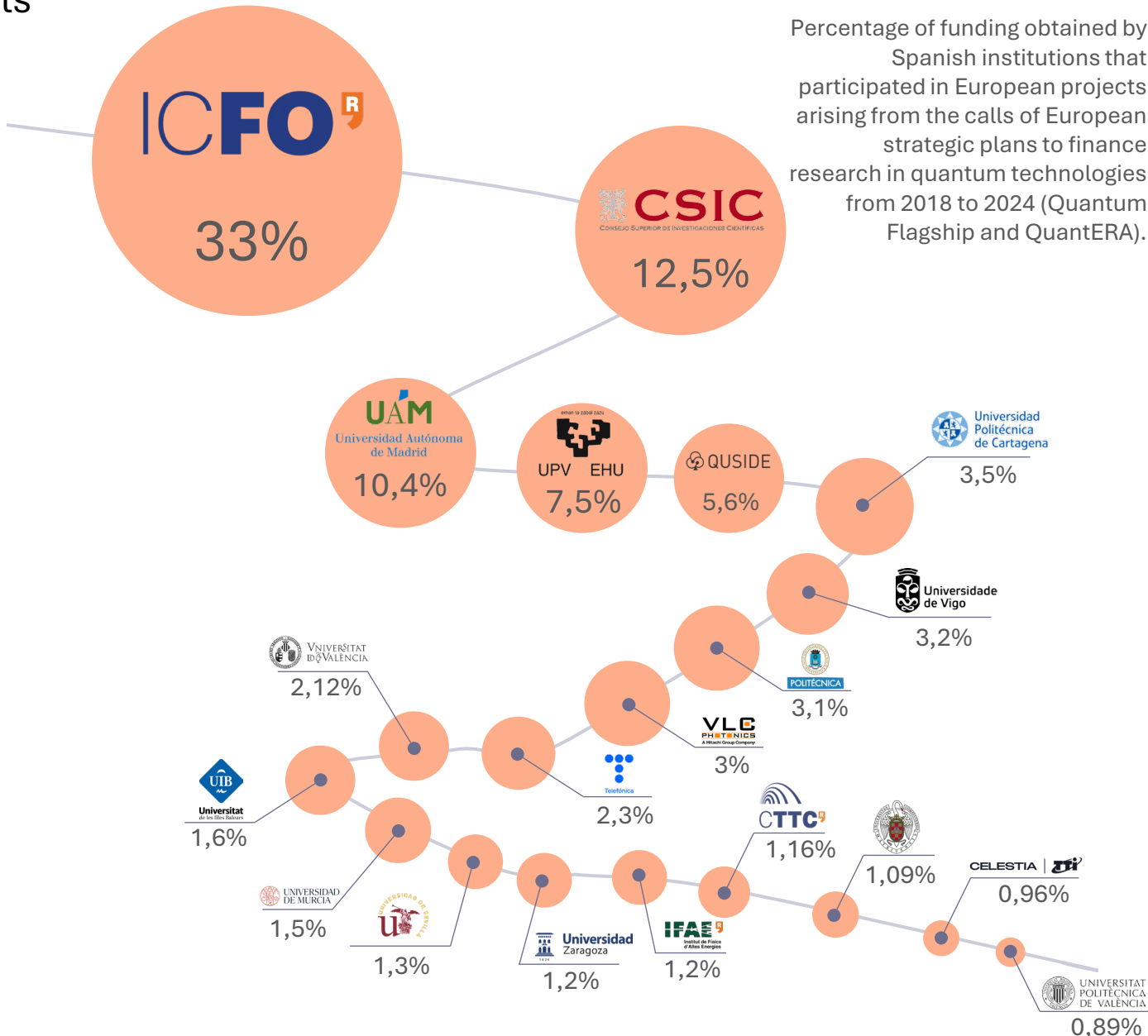


Quantum Landscape in Europe

Analysis of Spanish Participation in UE projects

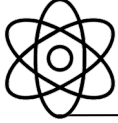


This slide highlights Spain's participation in European-funded quantum technology projects, securing €15,5M across 32 projects (2018–2024). ICFO leads with 33% of the funding, followed by CSIC (12,5%). Other contributors like UAM (10,4%), UPV/EHU (7,5%), and QUSIDE (5,6%) showcase the diversity of Spanish involvement, reflecting its strong role in advancing quantum innovation through public and private institutions. This analysis showcases Spain's robust engagement in cutting-edge quantum research through both public and private institutions. The strong representation of research centers and universities underlines Spain's potential to contribute significantly to quantum innovation in Europe.



Key Quantum
Centers and
Strategies:
Spain vs Europe





Key Quantum Centers and Strategies: Spain (1/2)



A leading Spanish technology center, CTIC promotes digital transformation and innovation via applied research in key areas like AI, big data, cybersecurity, and advanced computing, partnering with industry to develop solutions and enhance competitiveness.



2003

QC | Qsim



4

0/2

2

10/16,22

~€19,25M



DIPC is strengthening its quantum technology role through a medium-term strategy focused on advanced research, collaboration with leading institutions, and specialized training, aiming to advance quantum computing, communication, and sensing.



2000

QS | QC | QComms



5

0/5

4

38/47,42

~€20M



This is Spain's national supercomputing Centre. It leads the Quantum Spain project as head of the Spanish Supercomputing Network.



2005

QC



5

0/31

4

179/37,34

~€25M



i2CAT focuses on integrating quantum technologies into communication infrastructures and exploring new models of quantum-based secure communications.



2003

QC | QComms



5

0/5

1

155/15

~€17M



A leading photonics research institute, ICFO explores applications in quantum technologies, life sciences, and renewable energy, with a focus on advancing quantum photonics, communication, and computing.



2002

QC | QComms | QS



5

0/31

4

179/37,34

2

~€27M



ICN2, a leading nanoscience institute, studies nanomaterial properties and quantum behavior, focusing on quantum materials and their applications in computing and communications, using AI for device design.



2013

QS | QMet



8

1 5/31

8

331/37,43

~€25M



The Galician Supercomputing Centre drives scientific progress through research and high-performance computing. It leads the Galician Quantum Technologies Hub and has tendered for a quantum computer.



1993

QC | QComms



5

0/0

2

24/9,79

~€5M (Inversions €30M)



Data on CSIC institutes, their strategies, and participation in Quantum Technologies projects has been gathered. A specific map displaying these institutes can be found in the following section.

Localization Network of researchers

Sectors

- Telecommunications
- Logistics
- Energy
- Finance
- Computing
- Materials
- Chemicals
- Security
- Engineering
- Health

Active projects

Patents: Quantum focus/Total

Strategic interest in Quantum

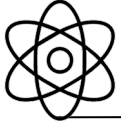
Nº research groups focused on QuanTech

Nº Research papers in QuanTech/Average Times Cited

Organization Budget (€)

Nº Spinoffs





Key Quantum Centers and Strategies: Spain (2/2)



AMETIC has established the Quantum Information, Computing, and Cybersecurity Working Group to promote the adoption and development of QT within the Spanish industry, aiming to position Spain as a leader in this emerging field.

2017

QC | QComms

1
0/0
7
1/--
~€2,8M



Catalonia's leading tech center specializes in quantum computing, focusing on machine learning, optimization, and secure communication. It collaborates with businesses, supporting R&D from concept to industrialization.

2015

QC | QComms

3
0/49
7
6/30,67
~€62M



DIPC is strengthening its quantum technology role through a medium-term strategy focused on advanced research, collaboration with leading institutions, and specialized training, aiming to advance quantum computing, communication, and sensing.

2000

QS
QC | QComms

5
0/5
4
38/47,42
~€20M



Based at the University of Vigo, focuses on secure quantum communication. Its strategy combines theory, experiments, and satellite applications, aiming to advance quantum networks and train new experts.

2023

QC | QComms

4
2/2
4
88/72,26
~€10M



Launching in 2025, this initiative fosters quantum research, startups, and industry collaboration in health, environment, and social services, aiming to position Madrid as a leader in quantum technologies.

2025

Localization Network of researchers

Sectors

- Telecommunications
- Logistics
- Energy
- Finance
- Computing
- Materials
- Chemicals
- Security
- Engineering
- Health

Active projects

Patents: Quantum focus/Total

Strategic interest in Quantum

N° research groups focused on QuanTech

N° Research papers in QuanTech/Average Times Cited

Organization Budget (€)

N° Spinoffs



Quantum Landscape in UE: Reference organizations



The QCS Hub, part of the UK National Quantum Technologies Programme, has focused on accelerating quantum computing development through an interdisciplinary approach. By integrating research in ion traps, superconducting circuits, diamond-based nodes, photonics, and silicon processors, the hub has advanced both hardware and software capabilities. Its strategy emphasized bridging academia and industry, fostering collaborations, supporting startups, and facilitating technology transfer to sectors like cybersecurity, AI, and energy. After concluding in 2024, its legacy continues through QCI3, reinforcing the UK's leadership in quantum innovation.

2019



The HQC at FZJ bridges fundamental research and quantum computing development, integrating six research areas and seven technology clusters. With €50M in funding, its state-of-the-art facility connects academia and industry, supporting the Quantum Flagship and advancing quantum technologies in Germany and Europe.

2020



It covers the entire spectrum of quantum computing research, from quantum materials research to prototype development.

(QT section) 2020

QS | QC | QComms

6

~25/328

>20

4.156/34,14

~€50M



Its goal is to establish a leading quantum technologies center, linking research with industry through strategic measures to transform the scientific and technological landscape.

2019

QSIm | QC | QMet | QComms

QS | QM

2

0/0

7

248/26

~€7M



The CESQ is a strategic initiative by the Université de Strasbourg and CNRS, aiming to advance quantum science and technology. CESQ focuses on quantum materials, quantum information, and quantum algorithms, fostering interdisciplinary collaboration across physics, chemistry, and biology. Integrated within ISIS and linked to EUCOR, it enhances Franco-German cooperation and supports startup creation and technology transfer. With cutting-edge facilities, CESQ is positioned as a key European hub for quantum research, innovation, and industrial applications.

2023



Exploring quantum mechanics from fundamentals to applications, including spacetime, information, sensing, optics, and many-body systems, to advance physics and unlock new technologies.

2010

QC | QComms | QS | QM | QF | ET

Basic research



>15

0/31

31

179/37,34

--

--

Interdisciplinary research center advancing quantum science and technology by fostering synergies between natural sciences and engineering. It unites researchers including the University of Stuttgart, the University of Ulm, and the Max Planck Institute, focusing on quantum optics, solid-state physics, and quantum information science. Recognized for scientific excellence, driving innovation from fundamental research to real-world applications.

2014



MQV advances quantum science and technology in Bavaria, focusing on developing quantum computers, transferring knowledge to industry, building international networks, and educating future quantum experts.

2022

QC

6

6/6

5

1.684/81,86

4

~€95M

Localization Network of researchers

Sectors

- Telecommunications
- Logistics
- Energy
- Finance
- Computing
- Materials
- Chemicals
- Security
- Engineering
- Health

Active projects

Patents: Quantum focus/Total

Strategic interest in Quantum

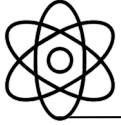
N° research groups focused on QuanTech

N° Research papers in QuanTech/Average Times Cited

Organization Budget (€)

N° Spinoffs





Key Quantum Centers and Strategies: Spain (1/4)



The **Barcelona Supercomputing Center (BSC)** leads the **Quantum Spain project**, overseeing the deployment of Spain's first quantum computer and its integration into the Spanish Supercomputing Network. Its strategy focuses on developing **advanced algorithms** and exploring applications in sectors such as energy, materials, and security to enhance the practical use of quantum computing.

BSC is actively engaged in **international collaborations**, including the "Future of Computing" initiative with IBM and European programs like **EuroHPC** and **Quantum Flagship**. It also promotes the training of specialized talent and the integration of quantum and classical computing to optimize computational capabilities.

Looking ahead, BSC aims to strengthen its role in **technology transfer** by expanding industrial applications and fostering partnerships with companies. The center also plans to scale up its quantum infrastructure and deepen its involvement in international networks to drive advancements in quantum computing.



The **Centro de Supercomputación de Galicia (CESGA)** focuses on advancing scientific research through **high-performance** computing and communications. It leads the Galician Quantum Technologies **Hub** and has recently initiated the construction of a quantum computer to expand its research capabilities.

Specializing in **quantum computing hardware and software**, CESGA participates in national and European initiatives like **Quantum Spain**, **NEASQC**, and **EuroHPC**. Its infrastructure includes a **Classical Quantum Algorithm Simulator**, a **Qmio Quantum Computer (20-100 qubits)**, and a High-Performance Computing System (HPC). Looking ahead, CESGA aims to strengthen **academic and industrial collaborations**, expand its quantum **infrastructure**, and attract specialized talent. Despite challenges such as **limited funding** and hardware **shortages**, it seeks to reinforce its role in the Galician Quantum Hub and foster **supercomputing-quantum synergies**.



The **Fundación CTIC** is a leading Spanish technology center focused on digital transformation and innovation through applied research in **artificial intelligence, big data, cybersecurity, and advanced computing**. It collaborates with industries to develop technological solutions and enhance competitiveness.

CTIC is active in **quantum computing and simulation**, developing infrastructures such as **ISAAC**, a **high-performance simulator of a 38-qubit quantum computer**, and leading industrial projects like **Alcatraz**, which applies quantum computing to logistics, molecular modeling, and cybersecurity. It also participates in networks like **ARQA** to promote innovation and technology transfer.

Looking ahead, CTIC aims to expand **industrial applications** of quantum computing, strengthen **collaborations**, and enhance **infrastructure**. Despite challenges such as **limited funding** and a **shortage of specialized personnel**, it leverages **strong industrial partnerships** and its **leading simulation capabilities** to advance quantum research and applications.



The **Donostia International Physics Center (DIPC)** is a research institution dedicated to **cutting-edge physics** and related disciplines, with a strong emphasis on **scientific collaboration and education**. It aims to bridge **fundamental research and technological applications** in quantum computing, communication, and sensing technologies.

DIPC is engaged in quantum **information theory and computing**, with a focus on quantum systems and technologies, **attosecond physics, and advanced materials**. It collaborates with international institutions and participates in initiatives such as **Basque Quantum** and **IKUR Quantum Talks**. Additionally, it has **priority access to IBM Quantum Systems** and plans to open a **new research facility in 2025**. Looking forward, DIPC seeks to expand research programs, **talent** development, and international partnerships.

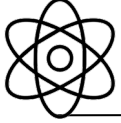


The **i2CAT** is a research and innovation center focused on **advanced internet technologies**, including **5G/6G, IoT, immersive technologies, and space communications**. It actively works on **quantum communications and quantum key distribution (QKD) for satellite networks** to enhance secure data transmission.

i2CAT integrates quantum technologies into communication infrastructures, exploring **quantum-secure communications and quantum internet architectures**. It participates in initiatives such as **Quantum Spain, QuantumCAT, and 6GSatNet**, collaborating with leading industry partners like **Telefónica and Orange**.

i2CAT aims to expand **quantum-secure networks**, strengthen collaborations, and support European quantum strategies, leveraging its **6G** expertise and institutional backing despite limited access to large-scale infrastructure.





Key Quantum Centers and Strategies: Spain (2/4)



The **Institute of Photonic Sciences (ICFO)** is a world-leading research center specializing in **photonics and quantum technologies**, with applications in **communications, computing, sensing, and cryptography**. It participates in major European and national programs, establishing itself as a key reference in photonic sciences.

ICFO focuses on **quantum photonics, communication, and computing**, developing **secure quantum systems, ultrafast quantum dynamics, and light-matter interactions**. It leads projects such as **CiViQ** (quantum communication protocols), **2D-SIPC** (quantum device integration in silicon technologies), and **QUIONE** (quantum-gas microscope for quantum simulation).

Looking ahead, ICFO aims to expand **quantum research and technology transfer**, strengthen **international collaborations**, and enhance **quantum infrastructure**. ICFO benefits from **cutting-edge facilities**, world-class expertise, and leadership in key quantum technology projects, supported by **significant funding** and a strong competitive position globally.



The **Eurecat** is Catalonia's leading technological center and a major private research organization in Southern Europe. Its **Quantum Computing research group**, within the **Digital Technologies department**, focuses on **quantum machine learning, optimization, and software development**, collaborating with industries from R&D to industrialization.

Eurecat integrates quantum technologies into **communication infrastructures** and explores **quantum-secure communications**. It is part of the **ARQA Network**, developing and testing quantum algorithms on **IBM and D-Wave systems** for industrial applications, and participates in projects like **QUORUM** to foster quantum innovation.

Looking ahead, Eurecat aims to **expand quantum computing capabilities**, strengthen **industry collaborations**, and advance **quantum algorithms for real-world applications**. While facing funding and competition challenges, its **strong industrial ties, interdisciplinary expertise**, and leadership in quantum projects solidify its role in applied quantum research.



The **Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)** is a non-profit research institution specializing in **telecommunications**, conducting both fundamental and applied research in areas such as **mobile, satellite, and space communications**, as well as **software and simulation tools**.

CTTC is engaged in **quantum secure communications and quantum key distribution systems**, contributing to technology transfer and industrial innovation. It actively participates in **QuantumCAT** and the **Catalonia Quantum Academy** to support research, education, and the deployment of quantum technologies.

Looking forward, CTTC aims to expand collaborative projects and strengthen **regional quantum technology initiatives**. While it faces challenges such as **limited funding and a shortage of specialized personnel**, it benefits from **strong partnerships** with leading research institutions, reinforcing its role in advancing quantum communications and education.



The **Catalan Institute of Nanoscience and Nanotechnology (ICN2)** is a leading research center focused on **nanoscience and quantum materials**, exploring their technological applications in **quantum computing, communication, and sensing**. It examines the **quantum behavior of matter** and develops **nanoengineered materials** for optimized device performance.

ICN2 is engaged in **multivariable quantum and neuromorphic technologies**, leveraging **artificial intelligence** to design novel quantum materials. It participates in initiatives such as the **Quantum Flagship, Graphene Flagship**, and regional programs like the **Future Quantum Internet Research Programme in Catalonia**.

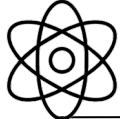
ICN2 benefits from **strong expertise, international partnerships, and leadership in key quantum technology projects**, supported by **significant funding and a competitive global position**.



The **AMETIC** represents Spain's **digital technology industry**. In 2017, it launched the **Quantum Information, Computing, and Cybersecurity Working Group** to promote quantum technology adoption and development.

In 2022, AMETIC published "*La España Cuántica 2022*", analyzing the **economic impact of quantum technologies** and featuring contributions from major companies like **Airbus, Banco Santander, BBVA, and Iberdrola**. It also participates in **European initiatives**, including the **Quantum Industry Consortium (QuIC)** and the **EU Quantum Technology Flagship Advisory Board**. Looking ahead, AMETIC seeks to boost **quantum adoption, enhance industry collaboration**, and develop **specialized infrastructure and talent**. Despite **funding and infrastructure challenges**, its **strong industry network and European partnerships** position it as a key player in Spain's quantum ecosystem.





Key Quantum Centers and Strategies: Spain (3/4)



The **IKUR 2030 Strategy**, led by the **Basque Government's Department of Science, Universities, and Innovation**, aims to position **Euskadi as an international hub for science and technology**. It focuses on **quantum technologies, neurosciences, neutrinos, supercomputing, and AI**, with an additional **€100 million investment over ten years** to strengthen the region's research ecosystem, attract international talent, and foster collaboration among **technology centers, universities, and industry**.

Aligned with this vision, the **IBM-Euskadi Quantum Computational Center** in Donostia will host Europe's **first IBM Quantum System Two**, featuring a **156-qubit processor** for advanced quantum computing applications in **biotechnology and cybersecurity**. This initiative, part of **BasQ** and **IKUR 2030**, enhances Euskadi's role in quantum technology, attracting talent and investment.

IKUR also promotes cutting-edge infrastructure, research excellence, and a strong scientific community, accelerating knowledge transfer and industrial competitiveness to establish Euskadi as a global innovation leader.



Bizkaia Quantum Advanced Industries (BIQAIN) is an initiative by the **Bizkaia Provincial Council** to establish the region as a leader in **quantum technology**. Launched in **2021**, it integrates **universities, technology centers, global corporations, startups, and public institutions** to drive **applied research, technology development, and innovation in QC**. Its headquarters, located in the **María Goyri building in Leioa's technology park**, will host **UPV/EHU's quantum labs** and **Tecnalia's quantum infrastructure**.

Bizkaia has access to **twelve quantum platforms** from **D-Wave, Fujitsu, IBM**, and partners with **AWS, Microsoft, and Telefónica**. BIQAIN supports companies at different stages, providing access to **quantum technology and expert consulting**, while also fostering **education and workforce training**. The number of quantum startups in the region has grown from **one in 2021 to fifteen today**, many of which will be based at BIQAIN's headquarters.

As part of the **BasQ strategy**, BIQAIN strengthens Bizkaia's position as an **innovation hub for quantum computing**, bridging supply and demand to accelerate industry adoption.



TECNALIA is Spain's largest applied research and technology development center, recognized as a European leader. Founded in **2001**, it is based in the **Bizkaia Science and Technology Park** and integrates **AZTI-Tecnalia, NEIKER-Tecnalia, and TECNALIA Research & Innovation**. Its quantum technology efforts focus on **three key areas: Quantum Computing and Simulation**, where it develops hybrid quantum-classical solutions for optimization and machine learning using cloud-based platforms; **Quantum Communications and Cybersecurity**, where it advances **Quantum Key Distribution (QKD)** and post-quantum cryptography for industrial security; and **Quantum Sensing and Metrology**, leveraging nitrogen-vacancy centers for high-precision detection, magnetic measurement, and imaging applications. TECNALIA collaborates with **QCentroid** to facilitate quantum adoption, partners with **Erhardt Serikat** to optimize logistics, and leads regional initiatives positioning **Gipuzkoa and Bizkaia** as European quantum hubs.



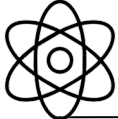
The **Galician Institute of High Energy Physics (IGFAE)**, a joint research center of the **University of Santiago de Compostela (USC)** and the **Xunta de Galicia**, was established in **1999** and is based in **Santiago de Compostela**. Its mission is to promote research in **high-energy physics, particle and nuclear physics**, as well as related fields like astrophysics, medical physics, and instrumentation. IGFAE collaborates with major international facilities, including **CERN, GSI/FAIR, the Pierre Auger Observatory, and LIGO**. In **2016**, it was accredited as a **María de Maeztu Unit of Excellence**, joining **SOMMa**, Spain's top research centers alliance. IGFAE has shown interest in **QC**, organizing training programs with the **Galician Supercomputing Center (CESGA)**, including a 2020 course on **quantum algorithms and circuits**. In 2024, it co-organized the **"Salto Cuántico"** outreach program, featuring quantum-inspired art and film. It also joined **Quantum Spain**, supporting the national quantum ecosystem initiative led by **BSC**.



The **Quantum Computing Cluster of Madrid** aims to **promote research, innovation, and startups** in **quantum computing**, particularly in **healthcare, environment, and social services**. Launching in **2025** in Boadilla del Monte, it seeks to position Madrid as a **quantum technology hub** through **technology transfer and industry collaboration**.

While partners and infrastructure remain undisclosed, the cluster prioritizes **quantum algorithms, industrial partnerships, and startup development**. However, concerns exist over **funding and execution**, as previous clusters in Madrid have faced delays and financial challenges. Ensuring adequate financing and implementation will be key to its success.





Key Quantum Centers and Strategies: Spain (4/4)



The **Institute for High Energy Physics (IFAE)**, founded by the Generalitat de Catalunya and UAB, explores **fundamental physics** in both experimental and theoretical areas. Its research **spans particle physics**, high-energy astrophysics, cosmology, neutrino physics, gravitational waves, medical physics, and **QC**. It also has a technical division supporting advanced instrumentation development.

As a member of BIST and a CERCA center, IFAE receives funding from MICINN, ERC, FEDER, AGAUR, and "la Caixa" Foundation, strengthening its scientific impact.

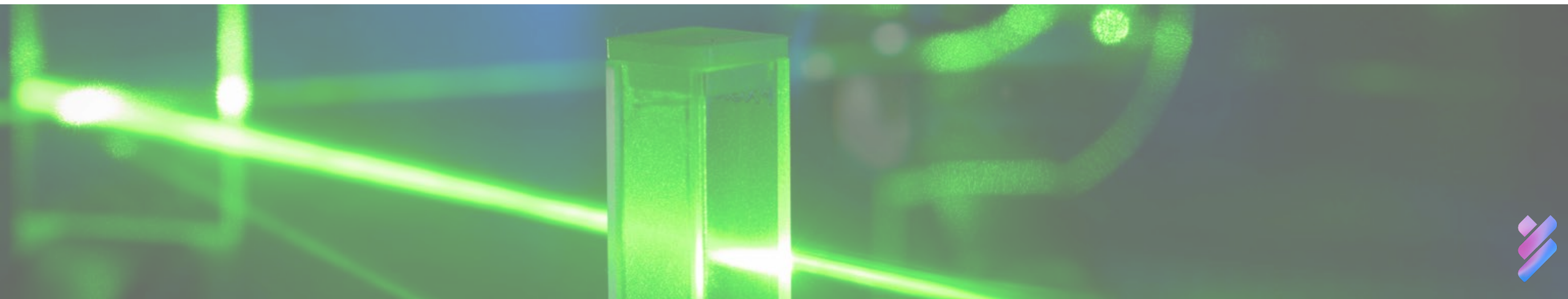
The Quantum Computing Technologies (QCT) group leads national and **international collaborations** on **superconducting qubits**. It has coordinated projects like FET Open AVaQus (2020-2024) on **quantum annealing**, Quanterra SiUCs (2020-2024) on **superinductors**, and ICRQ, studying **cosmic radiation's** interaction with qubits. As Spain's top lab in **superconducting qubit** development, IFAE plays a crucial role in advancing QC in Southern Europe.

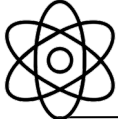


The **IMDEA Nanoscience Institute** is a **non-profit foundation** established between **2006 and 2007** through a collaboration between the **Community of Madrid** and the **Spanish Ministry of Education and Science**. It focuses on **cutting-edge research in nanoscience, nanotechnology, and molecular design**, fostering **innovation** and **industry collaboration**. Part of the International Excellence Campus (**UAM/CSIC**), the institute integrates **experts** in condensed matter physics, chemistry, computational modeling, spectroscopy, microscopy, surface sciences, and molecular biology. With over **50 regional and international projects**, it explores areas like polymer solar cells, OLEDs, biosensors, drug delivery, and nanomedicine. Its **quantum technology research** delves into **tunneling effects, topological states, and atomic-scale magnetism**. Key achievements include discovering **discrete energy levels without confinement, molecular Kondo effects, and novel spectroscopic techniques**, contributing to **QC, optoelectronics, and spintronics**.



The **Vigo Quantum Communication Center (VQCC)**, based at the University of Vigo, is a key player in the field of secure quantum communication. Its mission is to become a center of excellence, attracting top researchers in physics, engineering, mathematics, and computer science. The VQCC combines theoretical and experimental work across areas such as quantum communication technologies, cybersecurity, satellite applications, and foundational theory. It also promotes the training of new experts through advanced education programs and collaboration with academia and industry. Although independent, the VQCC works closely with **CESGA** within Galicia's quantum ecosystem, with CESGA focusing on quantum and high-performance computing and the VQCC specializing in secure quantum transmission. Led by Marcos Curty, the center is gaining international recognition for its contributions to quantum communication security.





Key Quantum Centers and Strategies: European institutions and strategies (1/4)



The Munich Center for Quantum Science and Technology (**MCQST**), established in **2019**, is a **Cluster of Excellence** uniting over **500 scientists** from disciplines such as **physics, mathematics, computer science, and material science**. It covers all areas of **Quantum Science and Technology (QST)**, from fundamental research to applications.

MCQST aims to build a **world-leading QST center**, addressing key scientific and technological challenges while fostering **industry collaborations** with partners like **IBM Watson, the University of Waterloo, and the National University of Singapore**. Its research spans **quantum computing, communication, metrology, simulation, and quantum matter**, developing next-generation quantum technologies.

Looking ahead, MCQST focuses on **multidisciplinary research, industrial partnerships, and education** to train future quantum scientists and engineers. While facing global competition and rapid technological evolution, its **expertise, collaborations, and leadership in key quantum projects** ensure its continued prominence in the field.



The HZA is a leading German research network advancing quantum technologies. Established in **1995**, with a dedicated quantum focus since **2020**, it integrates expertise from **physics, computing, materials science, and engineering** to develop **quantum computing, communication, sensing, and simulation** solutions. Its quantum research spans **computing**, developing prototypes and real-world applications; **communication**, securing quantum-based information transmission; **sensing**, creating highly sensitive measurement devices; **materials and fundamental science**, investigating new quantum states; and **simulation**, modeling complex physical phenomena. The **Helmholtz Quantum Center (HQC)** at **Forschungszentrum Jülich** serves as a hub for quantum research and computer prototyping. HZA collaborates with **industry leaders such as Volkswagen, Airbus, BMW, and Bosch**, alongside academic and research institutions. With a **€50 million investment** and contributions from **Forschungszentrum Jülich, KIT, and HZB**, it plays a key role in Europe's **quantum research and industrial applications**.



The **MQV** is a leading Bavarian research network advancing **quantum science and technologies**. Established in **2021**, it brings together institutions like **BAdW, Fraunhofer, FAU, DLR, LMU, MPG, and TUM** to develop **quantum computers** and transfer knowledge to industry. Its mission includes fostering **international collaboration** and building a strong **quantum ecosystem** in Bavaria.

MQV focuses on multiple **quantum computing platforms**, including **neutral-atom, superconducting, and trapped-ion** qubits, covering the entire quantum computing stack from hardware to applications. Supported by Bavaria's **Hightech Agenda**, it has secured **€380 million (2022–2026)**.

Collaborating with **Infineon, DATEV, Airbus, BMW, and Roche**, MQV ensures industrial relevance, while also fostering **education and outreach** to train the next generation of quantum experts. With **70+ principal investigators and 400 researchers**, it plays a crucial role in shaping the global quantum landscape and bridging the gap between fundamental research and real-world applications.

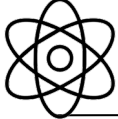


The **VCQ** is a prominent European research hub dedicated to advancing quantum physics and its technological applications. Established in **2010**, VCQ unites 31 research groups from the **University of Vienna, TU Wien, the Austrian Academy of Sciences, and the Institute of Science and Technology Austria**. VCQ's research encompasses a wide array of quantum science fields, including foundational quantum mechanics, quantum information, quantum sensing and devices, quantum optics, hybrid and many-body quantum systems, and quantum aspects of spacetime. This multidisciplinary approach fosters both theoretical and experimental investigations, aiming to push the boundaries of quantum knowledge and explore its transformative potential. Through **collaboration**, VCQ advances research and education, deepening quantum understanding and developing technologies that harness quantum effects for **practical use**.



The **Forschungszentrum Jülich**, designed to cover the entire **QC research spectrum**, from **quantum materials to prototype development**. Its structure integrates **six research areas** and **seven technology clusters**, bridging **fundamental research with quantum hardware and software development**. HQC's **state-of-the-art building**, directly connected to the **Helmholtz Nano Facility** and other **Forschungszentrum institutes**, will host two new institutes dedicated to **quantum control and computing**, as well as the **JARA Institute for Quantum Information**, part of the **Jülich Aachen Research Alliance**. Additionally, **Quantum Flagship** facilities from **Forschungszentrum Jülich** will be relocated to this center. With nearly **€50 million in funding from the Helmholtz Association**, HQC was launched in **2020** and is expected to be fully operational by **2025**, providing access to **regional universities, industry partners, and researchers across Germany and Europe**.





Key Quantum Centers and Strategies: European institutions and strategies (2/4)

IQST

The **Center for Integrated Quantum Science and Technology (IQST)**, founded in **2014**, is an **interdisciplinary research center** focused on developing **innovative quantum technologies** based on fundamental **quantum physics**. Its main goal is to foster collaboration between **natural sciences and engineering** to advance both **the understanding and application of quantum science**.

IQST brings together **physicists, chemists, engineers, mathematicians, and life scientists** working in **cutting-edge facilities** at the University of Stuttgart, University of Ulm, Karlsruhe Institute of Technology, and the Max Planck Institute for Solid State Research, alongside other universities in Baden-Württemberg. This **interdisciplinary network** covers **solid-state physics, quantum optics, quantum theory, quantum materials engineering, and quantum information science**. Recognized for scientific excellence, IQST boasts an **award-winning research team** working on projects from **fundamental principles to technological applications**. Additionally, it is a **member of Quantum Alliance**, a consortium of **German excellence clusters and research centers** dedicated to quantum science and technology.



The HZA is a leading German research network advancing quantum technologies. Established in **1995**, with a dedicated quantum focus since **2020**, it integrates expertise from **physics, computing, materials science, and engineering** to develop **quantum computing, communication, sensing, and simulation** solutions. Its quantum research spans **computing**, developing prototypes and real-world applications; **communication**, securing quantum-based information transmission; **sensing**, creating highly sensitive measurement devices; **materials and fundamental science**, investigating new quantum states; and **simulation**, modeling complex physical phenomena. The **Helmholtz Quantum Center (HQC)** at **Forschungszentrum Jülich** serves as a hub for quantum research and computer prototyping. HZA collaborates with **industry leaders such as Volkswagen, Airbus, BMW, and Bosch**, alongside academic and research institutions. With a **€50 million investment** and contributions from **Forschungszentrum Jülich, KIT, and HZB**, it plays a key role in Europe's **quantum research and industrial applications**.



The **Quantum Computing and Simulation Hub (QCS Hub)**, founded in **2019** under the **UK National Quantum Technologies Programme**, brought together **17 leading universities** to tackle the **most complex challenges in quantum computing**. Its strategy integrated **hardware, software, and industrial applications**, advancing **ion-trap processors, superconducting circuits, diamond qubits, photonics, silicon processors, and quantum verification**. This **comprehensive approach** positioned the **UK as a global leader in quantum computing**.

QCS Hub served as a **bridge between academia and industry**, fostering **collaborations and knowledge transfer**. It played a crucial role in **training, startup support, and outreach**, promoting **real-world quantum adoption** in sectors like **energy, artificial intelligence, and cybersecurity**. After completing its cycle in **2024**, it transitioned into **QCi3**, continuing its **legacy of quantum advancements** and further reinforcing the **UK's strategic role in global quantum innovation**.

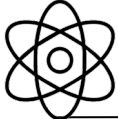


Quantum Valley Lower Saxony (QVLS) is a German initiative uniting **scientists, industry leaders, and policymakers** to advance **quantum technologies** and position **Lower Saxony as a global competitor**. It fosters **long-term collaborations, knowledge transfer, and workforce training**, ensuring the **integration of quantum innovations** into startups and established companies. Supported by the **Lower Saxony Ministry of Science and the Volkswagen Foundation**, QVLS strengthens **quantum R&D efforts**. A key initiative is **QuantumFrontiers**, an **Excellence Cluster** pushing metrology limits using **light and matter** to overcome quantum constraints. It develops **quantum devices for space-based water monitoring, gravitational wave detection, and high-precision atomic clocks**. Integrating **nanosystem engineering with quantum physics**, QuantumFrontiers enhances **measurement sensitivity**, benefiting **quantum cryptography, high-precision currents, and nanometric microscopy**. This research expands metrology applications from **subatomic scales to cosmic phenomena**.



The **Center for Quantum Science and Engineering (CQSE)** in NRW is a joint initiative of the **Fraunhofer Institute for Laser Technology (ILT) and Forschungszentrum Jülich**, aiming to coordinate and advance **quantum technology research and development** in the Rhine region. It fosters a **high-growth innovation ecosystem**, collaborating closely with **academic institutions and industry partners** to accelerate **technology transfer** into the industrial sector. Supported by the **NRW Ministry of Culture and Science**, CQSE has received **€21 million** for quantum computing projects, including **EPIQ**, which develops a **trapped-ion quantum computer** in partnership with **eleQtron and the Jülich Supercomputing Centre**. The CQSE network includes **over 70 companies, universities, and research institutes**, collectively shaping **NRW's quantum roadmap**. This collaboration ensures **resource optimization and policy frameworks** to establish NRW as a leading hub for **quantum technologies**.





Key Quantum Centers and Strategies: European institutions and strategies (3/4)



The **Q.Link.X network**, funded by Germany's **Federal Ministry of Education and Research (BMBF)**, aims to develop a **high-security quantum network** across Germany. It focuses on **interconnecting quantum nodes** via **Quantum Key Distribution (QKD)** and developing **quantum repeaters** to extend transmission distances while maintaining security. The project integrates quantum and classical communication infrastructure, ensuring compatibility with existing optical networks.

With **24 partners**, including **Fraunhofer HHI**, Q.Link.X advances **multiplexed quantum communication** and real-world demonstrations. It also supports **technology transfer** through industry collaboration and an advisory board. Additionally, it promotes **workforce training** to strengthen Germany's leadership in quantum technologies. By creating a solid **quantum ICT foundation**, Q.Link.X lays the groundwork for future **secure quantum communication systems**, bridging academia and industry to drive technological progress.



The **Quantum Alliance** is a growing consortium advancing **digital twin technologies**, making them accessible to various industries. It provides a **collaborative forum** and develops **standards** to simplify and reduce the cost of adopting these technologies, particularly for building owners and operators. Beyond digital twins, Quantum Alliance is actively engaged in **quantum technologies**, including **computing, simulation, cryptography, imaging, sensing, and photonics**. In Germany, national strategies like "Quantum Technologies — From Basic Research to Market" and "Agenda Quantensysteme 2030" focus on quantum computing, simulation, communication, and sensing, reinforcing the country's position in the quantum race.

At the **European level**, initiatives such as the **Quantum Internet Alliance (QIA)** have led to breakthroughs like the **first operating system for quantum networks**, paving the way for a functional **Quantum Internet**.

These efforts highlight the global commitment to accelerating **quantum adoption**, fostering collaboration among research institutions, industry, and policymakers to integrate quantum innovations into key sectors, driving the transition toward **next-generation digital and quantum ecosystems**.



Quantum Delta NL (QDNL) is a **Dutch foundation** accelerating quantum technology development through a **nationwide network of five hubs** in Delft, Eindhoven, Leiden, Twente, and Amsterdam. It fosters **collaboration between academia, industry, and startups**, creating a **dynamic innovation ecosystem**. Launched in **2021**, it received a **€615 million investment** from the Dutch government over seven years, supporting projects like **Quantum Inspire** (Europe's first quantum computer), a **national quantum network**, and **quantum sensor applications**.

QDNL also established QDNL Participations, a **venture capital fund** to boost **early-stage quantum startups**, initially funded with **€15 million**. In **January 2025**, it secured a **€25 million first closing**, aiming to reach **€60 million** for **global quantum investments**.

With these efforts, QDNL seeks to position the Netherlands as a global quantum leader, driving research, commercialization, and technological breakthroughs, reinforcing its role in the future **quantum economy**.



The **Quantum Internet Alliance (QIA)** is a **European consortium** dedicated to **advancing secure quantum networks**. It develops infrastructure for a **Quantum Internet**, leveraging **Quantum Key Distribution (QKD)** to ensure data security and strengthen **Europe's digital sovereignty**. QIA fosters collaboration among research institutions, universities, and tech companies, ensuring that **scientific advances** translate into commercial applications and innovative **communication security solutions**.

Following a **phased strategy**, QIA progresses from controlled testing environments to establishing a pan-European infrastructure that enables secure quantum communication across borders. As part of the **EU's Quantum Flagship**, QIA plays a strategic role in consolidating Europe's leadership in quantum technologies. It also works on **global standards**, driving **quantum networking adoption** in **cloud computing, banking, defense, and telecommunications**. Additionally, QIA contributes to **training a skilled workforce**, ensuring long-term growth and competitiveness in **quantum communications**.

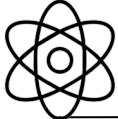


NATO's Quantum Technology Strategy, launched in **2023**, prepares the Alliance for **quantum advancements** by fostering **interoperability, quantum-secure cryptography**, and preventing **adversarial investments**. The **Transatlantic Quantum Community (TQC)** unites **government, industry, and academic experts** to drive **quantum innovation and security**.

The **TQC Industry Network** connects **quantum tech firms** with **NATO defense users**, organizing **events, matchmaking, and funding opportunities**. This initiative strengthens collaboration between key stakeholders, accelerating the **adoption of quantum solutions** in **defense, cybersecurity, and secure communications**.

Spain plays an **active role** in TQC, strengthening **public-private partnerships** and reinforcing its **commitment to quantum research and security**. By engaging in NATO's quantum strategy, Spain contributes to **advancing cutting-edge technologies**, improving **military communications**, and safeguarding **digital sovereignty** across the **Allied nations**.





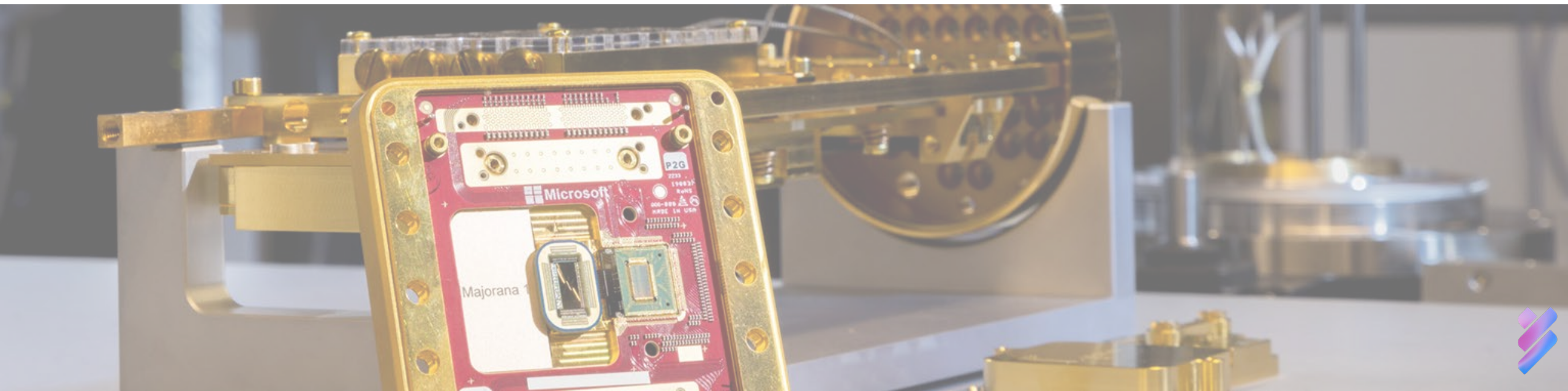
Key Quantum Centers and Strategies: European institutions and strategies (4/4)

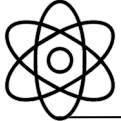


The **European Chips Act** is a key initiative by the European Union aimed at strengthening its **semiconductor ecosystem**, ensuring the **resilience** of the industry, and reducing dependence on external suppliers. With a projected investment of **€43 billion**, the EU aims to double its global semiconductor market share to **20% by 2030**, promoting the development of advanced technologies and fostering **technological sovereignty** in this strategic sector. The strategy focuses on improving **production capacity**, boosting **innovation** in chip design and manufacturing, and consolidating a network of **competence centers** to facilitate research and access to cutting-edge infrastructure. Additionally, **advanced pilot lines** are being established for the production of quantum chips and next-generation semiconductors, integrating these developments into the European digital ecosystem.

The Act also aims to ensure supply security through a **strong regulatory framework** and enhanced coordination among member states, allowing the EU to respond quickly to potential supply chain crises. Moreover, it promotes the development of **specialized talent** and the attraction of private investments to complement public efforts in creating a more competitive industry. Looking ahead, the EU plans to expand the European Chips Act to include **foundational and legacy semiconductors**, ensuring that Europe not only leads in innovation but also strengthens its presence in essential technologies across multiple industries.

A crucial element of this strategy is the establishment of the **Chips Joint Undertaking (Chips JU)**, a tripartite partnership involving the **European Union, participating member states, and key industry associations**. This entity aims to drive the development and adoption of advanced nanoelectronic chip technologies manufactured in Europe. With a total projected budget of nearly **€11 billion** until 2030, the Chips JU will manage **pre-commercial pilot lines**, develop a **cloud-based design platform**, support **quantum chip advancements**, and establish a **network of competence centers**. These efforts are designed to bridge the gap between research and production, facilitating the commercialization of innovative ideas and reinforcing the EU's **strategic autonomy** in the semiconductor sector. In summary, the **European Chips Act** and the **Chips Joint Undertaking** work together to position Europe as a **global leader** in the semiconductor industry, ensuring a **secure supply chain** and fostering **innovation** in critical technologies for the future.





Key Quantum Centers and Strategies:

cinn

Nanomaterials & Nanotechnology Research Center

2 **QC | QMat | QSim**
20 8 2 €2,97M

IFCA

Instituto de Física de Cantabria

1 **QS | QM**
5 1 QF | ET

CFM

Materials Physics Center
Centro de Física de Materiales

4 **QMat**
43 **QS | QM**
20 QF | ET
3 €3,7M

INMA

INSTITUTO DE NANOCIENCIA Y MATERIALES DE ARAGÓN

QC | QMat | QSim
QS | QM
QF | ET
3 30 3
15 3 €5,13M

ICN2

Institut Català de Nanociència i Nanotecnologia

ICMAB

INSTITUT DE CIÈNCIA DE MATERIALS DE BARCELONA

CNM

Centro Nacional de Microelectrónica IMB

5 **QMat**
40 **QS | QM**
19 1 €10,8M

IFISC

QC | QMat | QSim
QS | QM QF | ET
1 10 4
€0,68M

i3M

Instituto de Instrumentación para Imagen Molecular

IFIC

INSTITUT DE FÍSICA CORPORUSCULAR

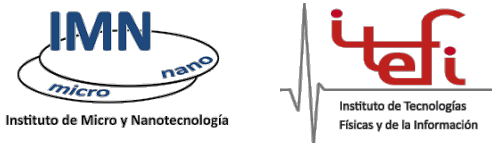
QC | QSim
QS
2 11 3
€1,12M

IMSE-CNM

Instituto de Microelectrónica de Sevilla

2 **QComms | QInfo**
2 2

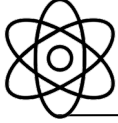
15 **QC | QMat | QSim**
132 **QComms | QInfo**
60 **QS | QM**
9 QF | ET
3
€19,95M



QTEP - CSIC

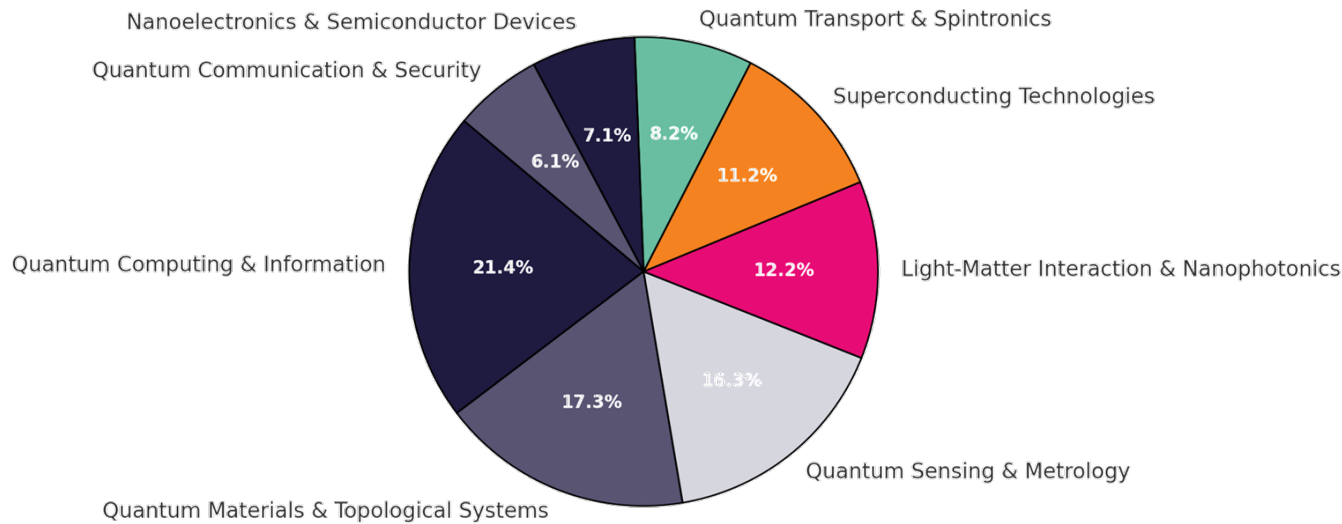


- Nº research groups focused on QuanTech
- Nº Research papers in QuanTech
- QT projects
- Patents: Quantum focus/Total
- Nº Spinoffs
- QT projects funding (€)



Key Quantum Centers and Strategies:

Distribution of major research areas in QT CSIC groups



Methodology

This analysis **extracted and normalized research terms** from CSIC quantum technology groups to identify major research areas. **Similar terms were grouped**, avoiding redundancy, and **categorized into broader themes** aligned with global quantum research. The **word cloud** highlights the most frequent terms, while the **pie chart** illustrates their relative distribution.

Key Insights

The **pie chart** illustrates the distribution of research areas within CSIC's quantum technology groups. **Quantum Computing & Information (21.4%)** stands out as the dominant field, driven by efforts in **quantum algorithms, error correction, and qubit architectures**, which are crucial for achieving scalable quantum advantage. **Quantum Materials & Topological Systems (17.3%)** follows closely, emphasizing the importance of **superconductors, topological insulators, and exotic materials** in developing next-generation quantum hardware. **Quantum Sensing & Metrology (16.3%)** is another key research area, focusing on **high-precision measurements, magnetometry, and quantum-enhanced detection**, with applications ranging from navigation to fundamental physics. The **word cloud** highlights **Light-Matter Interaction & Nanophotonics (12.2%)**, which plays a key role in **quantum communication and photonic computing**, utilizing optical platforms for **secure data transmission and quantum state manipulation**. **Superconducting Technologies (11.2%)** also holds a significant share, focusing on **superconducting qubits, resonators, and detectors**, essential for improving quantum coherence and circuit stability. These research trends suggest that **CSIC's strategy aligns with global priorities in quantum science and technology**. The dominance of **Quantum Computing & Information** reflects the worldwide effort to develop scalable quantum processors. **Quantum Materials research is essential**, as novel materials will shape the next generation of quantum devices.

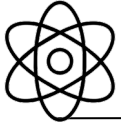
The relevance of **Quantum Sensing & Metrology** is tied to its immediate applications, already influencing areas like **geophysics, defense, and medical imaging**. The focus on **Light-Matter Interaction** suggests that photonic-based quantum technologies are gaining traction for **secure communication and scalable quantum networks**. Finally, **Superconducting Technologies remain crucial**, as superconducting circuits continue to be a leading platform for quantum computing and sensing. These findings reinforce CSIC's role as a key player in quantum research, contributing to both **fundamental breakthroughs and applied innovations** in the field.



Quantum
comercial
applications and
sectors

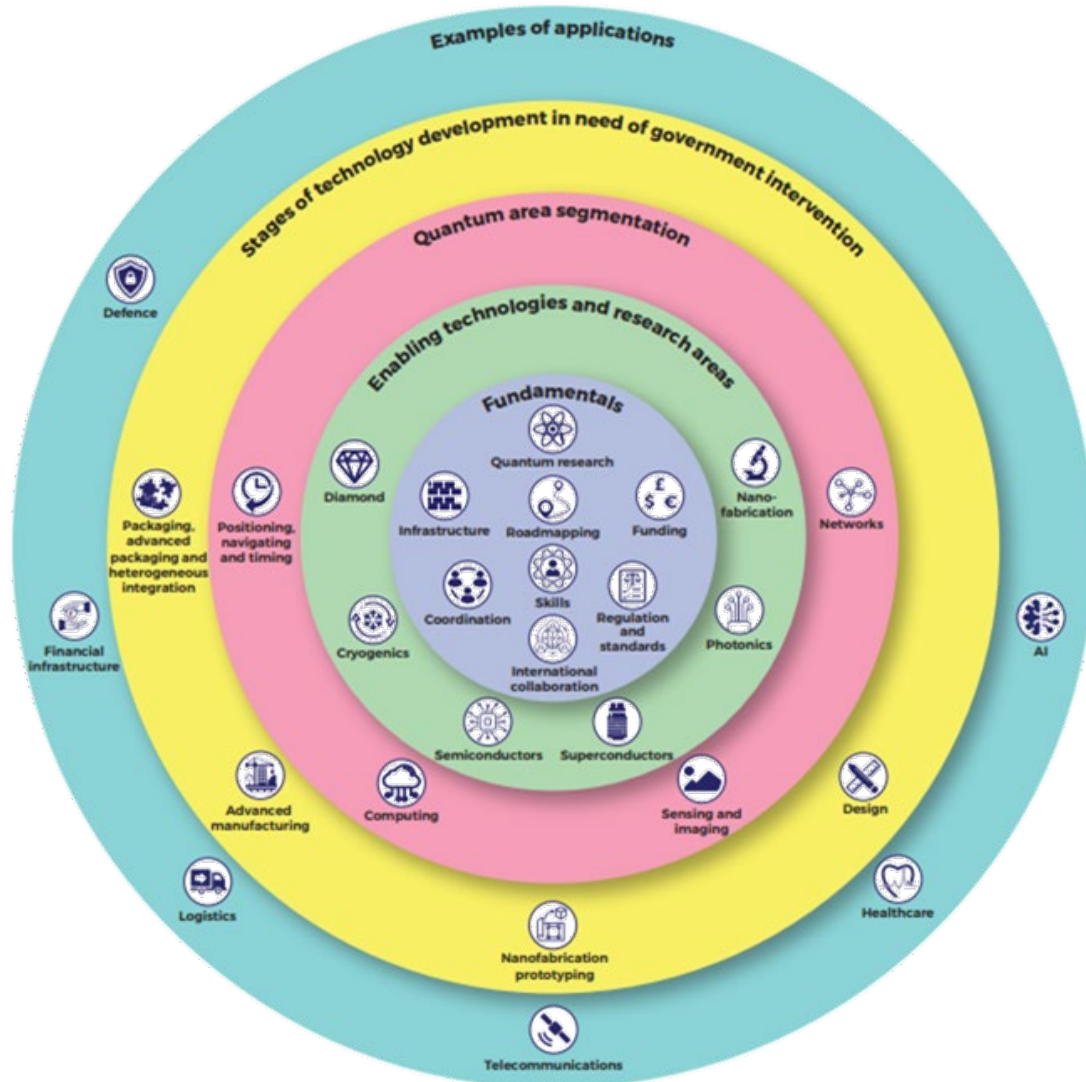
Summary





Main Focus Quantum Effort: Driving Innovation and Research

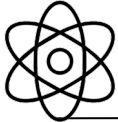
Simplified depiction of the key components of the quantum technology ecosystem and some of the main application areas



This graphic provides a comprehensive overview of the ecosystem surrounding quantum technologies, highlighting their foundational elements, enabling technologies, and diverse applications across industries.

- **Core Fundamentals:** At the center lies the foundation of quantum technologies, including quantum research, nanofabrication, infrastructure development, roadmapping, funding, and networks. These elements are essential to drive innovation and establish a robust quantum ecosystem. Key enablers such as cryogenics, photonics, semiconductors, and superconductors provide the technological backbone.
- **Enabling Technologies and Research Areas:** The second layer focuses on the critical areas supporting quantum advancements, such as advanced manufacturing, sensing and imaging, and design. These areas are essential to transition quantum research into practical, scalable solutions.
- **Quantum Area Segmentation:** The third layer identifies broad quantum-specific domains that require government intervention to facilitate development. These include positioning and timing technologies, logistics, nanofabrication, and heterogeneous integration.
- **Applications and Sectors:** The outermost layer showcases the broad spectrum of real-world applications for quantum technologies. These range from telecommunications, healthcare, and AI to defense, financial infrastructure, and advanced manufacturing. The inclusion of diverse sectors underscores the transformative potential of quantum technologies to revolutionize industries and societal functions.

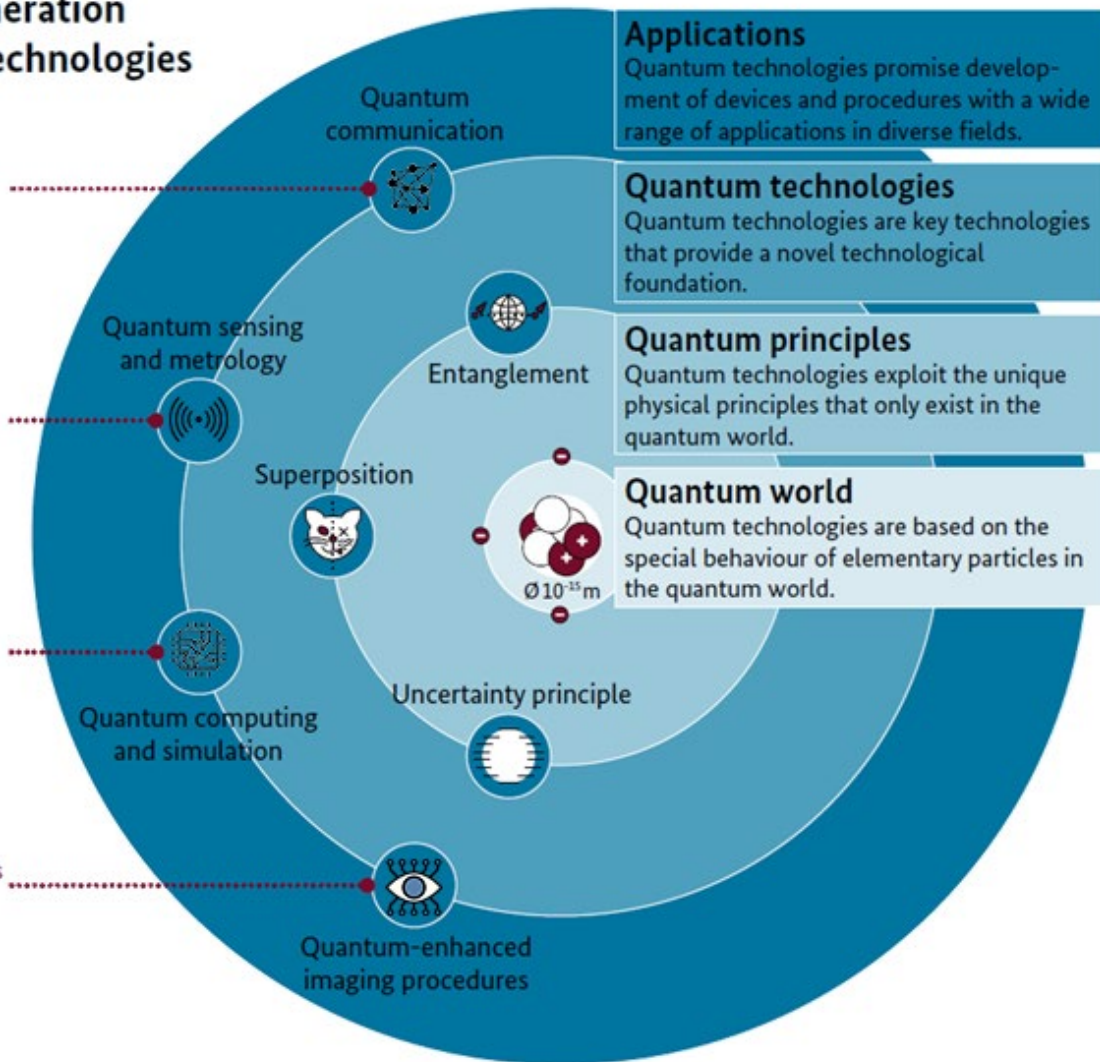




Main Focus Quantum Effort: Driving Innovation and Research

Second generation quantum technologies

- IT security
- Data security
- Encrypted data transfer
- Medical technology
- Navigation
- Satellite earth monitoring
- AI/Machine learning
- Pattern recognition
- Developing materials
- Automation
- Medical diagnosis
- Manufacturing semiconductors



This graphic delves into second-generation quantum technologies, building on the foundations laid by first-generation quantum advancements, as highlighted in the previous graphic. It emphasizes the evolution from fundamental principles of quantum physics to advanced applications across multiple sectors.

- **Quantum World and Principles:** The core of this graphic highlights the underlying quantum principles—such as superposition, entanglement, and the uncertainty principle—that serve as the basis for all quantum technologies. These unique properties, exclusive to the quantum domain, enable breakthroughs in how information is processed, transmitted, and analyzed.
- **Technological Domains:** The second layer illustrates how quantum principles give rise to four key technological areas:
 - Quantum Computing and Simulation (QC): Drives advancements in AI, material development, and pattern recognition, offering unparalleled computational power.
 - Quantum Communication (Qcomms): Enables secure IT and data systems, including encrypted data transfer.
 - Quantum Sensing and Metrology (QS): Revolutionizes medical diagnostics, navigation, and satellite earth monitoring through unparalleled precision.
 - Quantum-Enhanced Imaging Procedures: Enhances automation, medical imaging, and semiconductor manufacturing through superior imaging capabilities.
- **Applications:** The outermost layer demonstrates the diverse applications across industries, from IT security and healthcare to automation and advanced manufacturing, underscoring the transformative potential of quantum technologies.











Main Focus Quantum Applications & Sectors - Summary

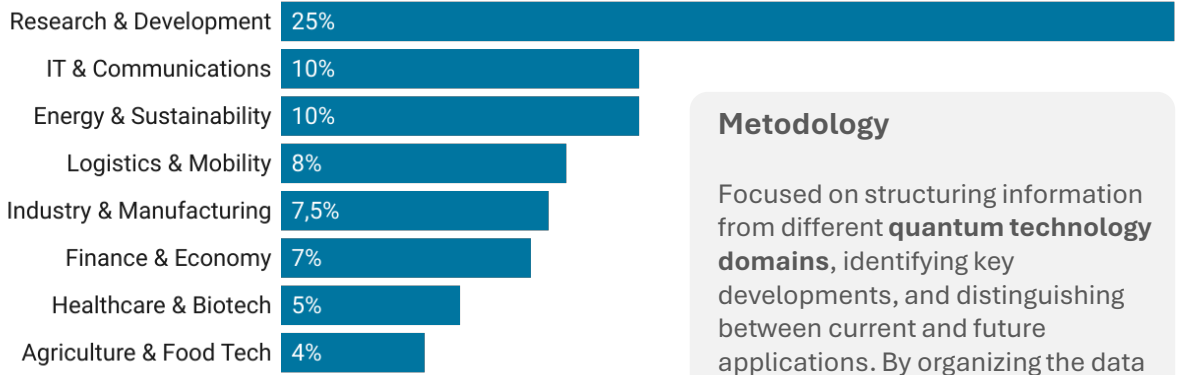
Core Domains		Area	Mature market	Developing markets
	hardware	 Superconducting <p>Optimization & Logistics, Material & Drug Discovery, Cybersecurity, Cloud-Based Quantum Computing</p>	<p>Fault-Tolerant Quantum Computing, Industrial & Energy Optimization, Quantum AI & Machine Learning, Advanced Quantum Simulations</p>	
		 Spin Qubits <p>Quantum Sensing, Scalable Quantum Computing</p>	<p>Advanced Quantum Computing, Quantum Networks</p>	
		 Trapped Ions <p>Quantum Computing Demonstrators, Industry Collaborations</p>	<p>Air Traffic Management, Scalable Quantum Processors</p>	
		 Neutral Atoms <p>Quantum Sensing, Scalable Quantum Computing</p>	<p>Advanced Quantum Computing, Quantum Networks</p>	
		 Photons <p>Quantum Communication, Cloud-Based Photonic Quantum Computing, Quantum Sensing & Metrology</p>	<p>Fault-Tolerant Quantum Computing, Quantum Internet, Next-Gen Quantum Cryptography</p>	
		 Nitrogen Vacancy Centres in Diamond <p>High-precision sensing, magnetometry, electrometry, temperature sensing, nanoscale imaging</p>	<p>Biomedical Applications, Navigation & Positioning, Non-Destructive Testing</p>	
		 Quantum Simulation hardware <p>Material Science & Chemistry, High-Energy Physics, Optimization & Logistics</p>	<p>Scalable Quantum Simulators, Hybrid HPC Integration, Industry-Specific Expansion</p>	
software	 Qubit control & error Correction <p>Control Systems, real-time decoders</p>	<p>Advanced Control Systems, Scalable Quantum Error Correction, Hybrid Classical-Quantum Architectures</p>		
	 Quantum Simulation software <p>Quantum Chemistry & Material Science, High-Energy Simulations, Financial & Risk Analysis</p>	<p>Industry-Specific Optimization, Hybrid Quantum-Classical Systems, Cloud-Based Quantum Simulations, AI-Assisted Quantum Modeling</p>		
	 Quantum Operating Systems & Algorithm <p>Quantum Hardware Optimization, Multi-Hardware Compatibility, Automated Quantum Control</p>	<p>Advanced Circuit Optimization, Distributed Programming, Standardization of Intermediate Representation, Hybrid Quantum-Classical Systems</p>		
	 Quantum APIs and Cloud Access <p>Quantum SDKs, Integration with HPC, Quantum Programming Support</p>	<p>Hybrid Quantum-Classical Workflows, European Autonomy in Quantum Cloud, Industry Adoption & Scalability</p>		
	 Quantum Algorithms <p>Quantum Optimization, Quantum Simulation, Quantum Machine Learning (QML)</p>	<p>Automated Algorithm Development, Integration with Classical Computing, New Applications in AI</p>		



Main Focus Quantum Applications & Sectors - Summary

Core Domains	Area	Mature market	Developing markets
QComms 	 Post-Quantum Cryptography (PQC)	Quantum Security, Hybrid Cryptography, Standardization & Compliance	IoT & Low-Power Devices, Blockchain & Cryptocurrencies, Cloud & AI Security, Space & Global Networks, Public Key Infrastructure (PKI) Evolution
	 Quantum Key Distribution (QKD)	Secure Communication Networks, Trusted Nodes & Network Expansion, Industrial Adoption & Standardization	Integration with PQC, Satellite & Global Quantum Networks, Cloud & AI Security, Quantum Internet & Entanglement-Based Communication, Public Key Infrastructure (PKI) Evolution
QS 	 Quantum Sensors	Quantum Healthcare & Imaging, Precision Timing & Frequency Standards, Geophysical & Infrastructure Monitoring, RF Sensing & Telecommunications, Industrial Adoption & Scalability	Quantum Navigation & Positioning, Advanced Telecommunications, Quantum Security & Defense, Aerospace & Space Exploration, Miniaturization & Portability, Quantum Metrology & Standardization
	 Quantum Imaging	Quantum Microscopy with NV Centers, Semiconductor & Metal Defect Detection, Advanced Biomedical Imaging, Scientific Instrumentation	Quantum-Enhanced Medical Imaging, Security & Surveillance, Environmental & Industrial Monitoring, Commercial Integration, Space & Telecommunications
Cross-Cutting Areas 	 Enabling Technologies	Cryogenics & Cooling Systems, Photonics & Lasers, Control Electronics, High-Precision Detectors	Miniaturized Cryogenic Systems, Integrated Photonics, Quantum-Optimized Electronics, Advanced Single-Photon Sources, Hybrid Quantum-Classical Systems

Sector distribution by Quantum Applications



Methodology

Focused on structuring information from different **quantum technology domains**, identifying key developments, and distinguishing between current and future applications. By organizing the data into **core domains and subdomains**, it became easier to spot trends and make meaningful comparisons.

Key Insights

One key conclusion is the **dominance of quantum computing**, particularly in hardware and software. The strong presence of **superconducting qubits, quantum algorithms, and cloud-based computing** suggests that industry investment is concentrated on making quantum processors scalable and commercially viable. Meanwhile, **quantum cryptography** is emerging as a crucial response to cybersecurity risks, with governments and private sectors pushing for standardization.

Quantum sensing and imaging show great potential in medical diagnostics, environmental monitoring, and defense. However, challenges in **miniaturization, commercialization, and cost efficiency** may slow their widespread adoption compared to computing and cryptography. Additionally, **enabling technologies** such as cryogenics, photonics, and control electronics remain critical bottlenecks, likely influencing the pace of overall quantum adoption.

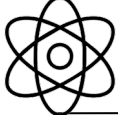
As expected, Quantum applications are **mainly concentrated in Research & Development**, highlighting the field's experimental and pre-commercial stage. **IT & Communications, Energy & Sustainability, and Industry & Manufacturing** show strong activity, signaling progress toward real-world implementation. In contrast, **Healthcare, Finance, and Agriculture**, though present, may need further technological advancements for widespread adoption. A key question is whether investment is balanced or overly focused on computing.



Quantum
comercial
applications and
sectors

Analysis





Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Superconducting

Superconducting circuits are one of the most advanced quantum computing technologies, used by companies like IBM and Google. These qubits rely on superconducting materials operating at extremely low temperatures to enable quantum computation.

Key Features & Challenges

- ✓ **Types of qubits:** Charge, flux, phase, and transmons (the most widely used due to their stability).
- ✓ **Challenges:** High error rates, scalability issues, and the need for ultra-low temperatures.
- ✓ **Solutions:** New designs like bosonic and "cat qubits" aim to improve error correction and reduce hardware overhead.

Future Outlook (2035)

- Achieving **logical qubits** with lower error rates.
- Advancing towards **fault-tolerant quantum computing**.
- Developing better materials and architectures for more stable qubits.
- Improve quality (fidelities) and scale (number) of the qubits using 3D architectures;
- Develop more efficient cryogenic units;
- Develop industrial-scale fabrication facilities;
- Research into materials, fabrication techniques and processing methods.

Superconducting qubits remain a leading approach in the race for **practical quantum advantage**.

Mature market

Although still in development, superconducting quantum computers are already being tested in key industries:

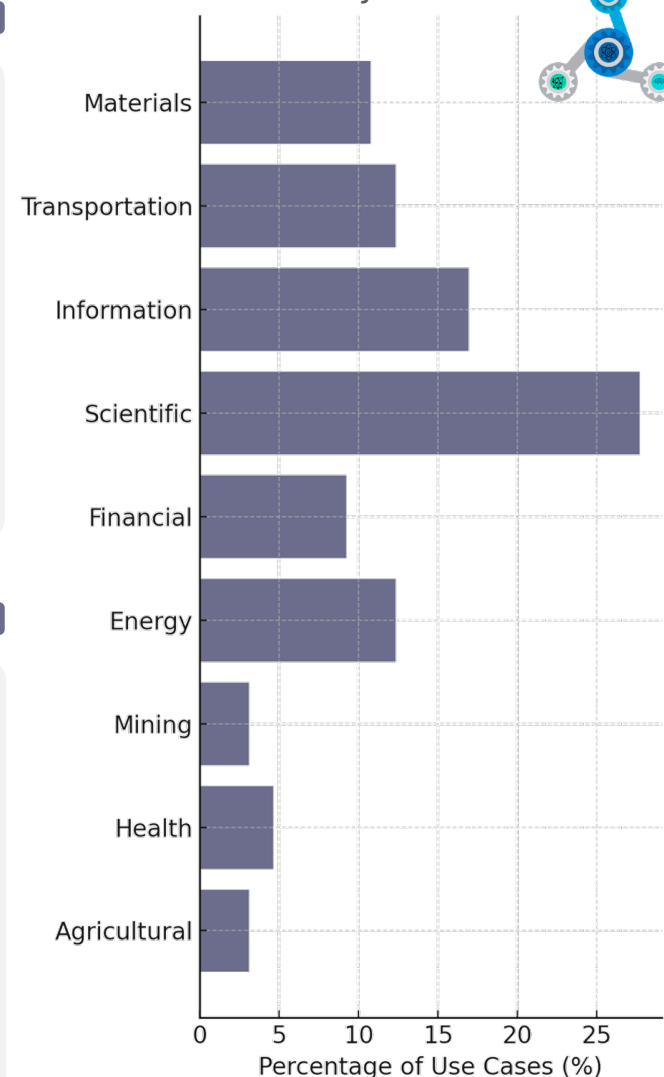
- 🚀 **Optimization & Logistics:** Improving traffic flow (Volkswagen) and optimizing financial portfolios (BBVA).
- 🚀 **Material & Drug Discovery:** Simulating materials for aerospace (Airbus, BASF) and accelerating pharmaceutical research.
- 🚀 **Cybersecurity:** Developing **post-quantum cryptography** solutions to counter future quantum threats.
- 🚀 **Cloud-Based Quantum Computing:** Companies like IBM and Google provide **Quantum Computing as a Service**, enabling businesses and researchers to experiment with quantum algorithms.

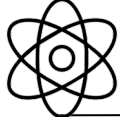
Developing markets

As superconducting technology advances in **error correction** and **scalability**, more powerful applications will emerge:

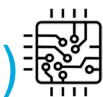
- 🚀 **Fault-Tolerant Quantum Computing:** Achieving **logical qubits** will enable reliable execution of complex quantum algorithms.
- 🚀 **Industrial & Energy Optimization:** Enhancing **manufacturing processes, power grids, and sustainable technologies**.
- 🚀 **Quantum AI & Machine Learning :** Accelerating AI models and boosting automation in various industries.
- 🚀 **Advanced Quantum Simulations:** Enabling breakthroughs in **chemistry, materials science, and fundamental physics**.

QC  Superconducting 
Use cases by sectors 





Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Spin Qubits

Spin qubits are an emerging quantum computing technology that utilizes the **spin of an electron or atomic nucleus** to store and manipulate quantum information. They are considered a promising approach due to their **compatibility with semiconductor technology**, allowing integration with existing microchip manufacturing processes.

Key Features & Challenges

- ✓ **Types of qubits:** Based on the spin of electrons trapped in quantum dots, controlled by electric and magnetic fields.
- ✓ **Advantages:** Long coherence times, low energy consumption, and seamless integration with silicon-based chips, enabling scalability.
- ✓ **Challenges:** Precise control of multiple qubits, complex readout mechanisms, and the need to improve two-qubit gate fidelities for error correction.

Future Outlook (2035)

- **Achieving scalable quantum processors** with spin qubits.
- Advancing towards **fault-tolerant quantum computing** by improving error correction.
- Developing **high-fidelity qubit control** with minimal noise interference.
- Exploring **hybrid architectures** that combine spin qubits with other quantum technologies.

Spin qubits are emerging as a **key contender in the future of quantum computing**, offering a scalable and energy-efficient pathway while benefiting from established semiconductor expertise.

Mature market

While spin qubits are primarily in the research and development phase, recent advancements indicate their potential in practical applications:

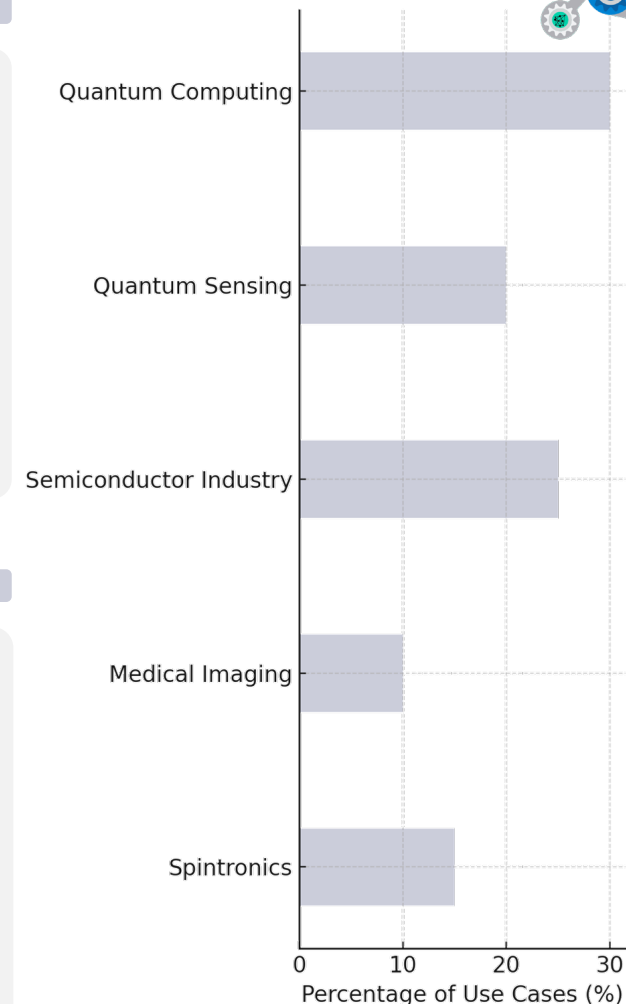
- 🔬 **Quantum sensing:** Spin qubits, particularly in diamond structures, are utilized in nanoscale quantum sensing, enabling high-precision measurements in materials science and biology.
- 🔬 **Scalable quantum computing:** Researchers have achieved over 99% fidelity in silicon spin qubits using CMOS technology, highlighting their viability for scalable quantum computing solutions.

Developing markets

As research progresses, spin qubits are anticipated to play a significant role in various sectors:

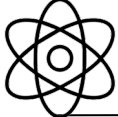
- 🚀 **Advanced Quantum computing:** The development of hole-spin qubits, which can be controlled up to 1000 times faster than electron-based qubits, suggests future applications in more efficient quantum computing systems.
- 🚀 **Quantum networks:** Innovations in spin-photon qubits could facilitate the connection of quantum nodes across remote networks, advancing the development of a quantum internet with enhanced security and data transmission capabilities.

QC  Spin Qubits
Use cases by sectors

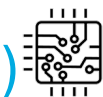


Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where spin qubits are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.





Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Trapped Ions



Trapped ion qubits are a well-established quantum computing technology that leverages **charged atomic particles (ions)** confined in electromagnetic fields to store and process quantum information. They are recognized for their **high fidelity and long coherence times**, making them a strong contender for fault-tolerant quantum computing.

Key Features & Challenges

- ✓ **Types of qubits:** Individual ions confined in vacuum traps and manipulated using laser or microwave fields.
- ✓ **Advantages:** High gate fidelities, long coherence times, and all-to-all qubit connectivity for efficient circuits.
- ✓ **Challenges:** Slow gate speeds, complex ion-trap setups, and the need for precise laser control.

Future Outlook (2035)

- **Achieving large-scale quantum processors** based on trapped ions.
- Advancing towards **fault-tolerant quantum computing** with improved error correction.
- Developing **scalable quantum networks** for distributed quantum computing.
- Enhancing **laser-based control systems** for efficient gate operations.

Trapped ions remain one of the most promising quantum computing technologies, offering **high precision and stability** while addressing scalability challenges.

Mature market

Trapped ion quantum computing is advancing towards practical applications, with several initiatives highlighting its current market presence:

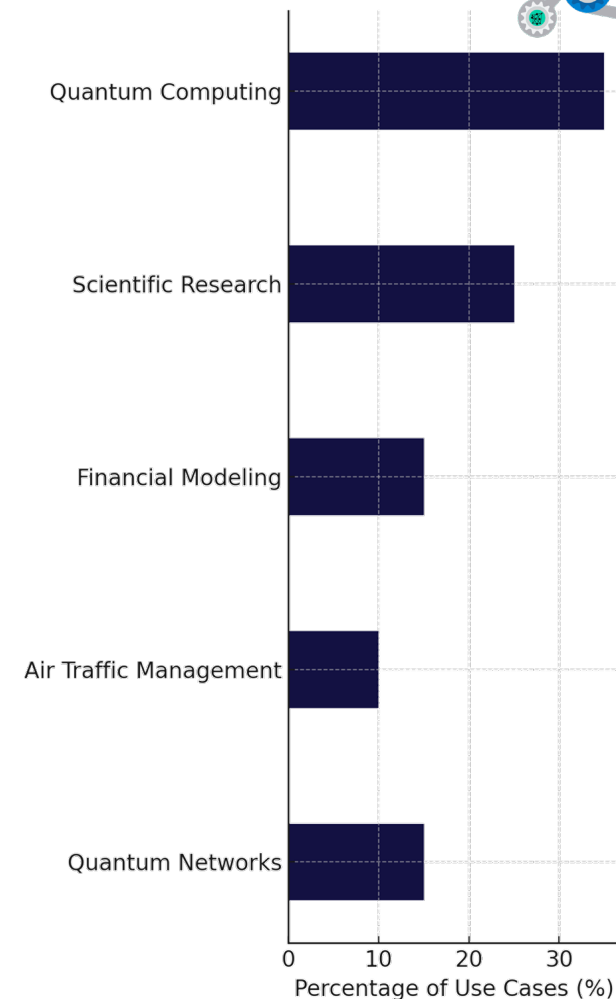
- ✦ **Quantum computing demonstrators:** In 2021, researchers from the University of Innsbruck presented a compact trapped-ion quantum computer that fits inside two 19-inch server racks, meeting quality standards for practical deployment.
- ✦ **Industry collaborations:** Companies like IonQ and Honeywell have developed trapped-ion quantum computers, making them accessible for research and commercial use.

Developing markets

As research progresses, trapped ion quantum computing is anticipated to impact various sectors:

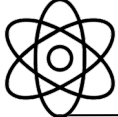
- 🚀 **Air traffic management (ATM):** Research is exploring how quantum computing, including trapped-ion systems, could be applied in ATM to optimize flight paths, enhance safety, and improve overall efficiency. euroquic.org
- 🚀 **Scalable Quantum processors:** Efforts are underway to develop scalable production infrastructures for trapped-ion quantum computing processors in Europe, transitioning from manual fabrication to automated manufacturing processes.

QC Trapped Ions
Use cases by sectors



Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where *Trapped Ions* are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.





Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Neutral Atoms

Neutral atom quantum computing is an emerging technology that utilizes **neutral atoms trapped in optical lattices or tweezers** to encode and process quantum information. It is gaining traction due to its **high scalability and flexible qubit connectivity**, making it a strong candidate for large-scale quantum systems.

Key Features & Challenges

- ✓ **Types of Qubits:** Based on neutral atoms manipulated with laser fields in optical traps.
- ✓ **Advantages:** High scalability potential, flexible qubit interactions, and compatibility with advanced quantum networking.
- ✓ **Challenges:** Precise control of atomic states, maintaining coherence in large systems, and improving gate fidelities for complex computations.

Future Outlook (2035)

- **Developing large-scale neutral atom quantum processors** with improved coherence and stability.
- Advancing towards **fault-tolerant quantum computing** by refining error correction techniques.
- Enhancing **quantum simulation capabilities** for material science and chemistry applications.
- Integrating **neutral atoms into quantum networks**, enabling distributed quantum computing.

Neutral atoms are emerging as a **scalable and flexible platform for quantum computing**, offering new opportunities in simulation, networking, and high-performance quantum computation.

Mature market

Neutral atom quantum computing is advancing towards practical applications, with several initiatives highlighting its current market presence:

- 🚀 **Quantum computing demonstrators:** In 2024, researchers demonstrated a 48-logical-qubit processor using neutral atoms, showcasing the modality's potential for scalable quantum computing.
- 🚀 **Industry collaborations:** Companies like QuEra Computing are developing neutral atom quantum computers, making them accessible for research and commercial use.

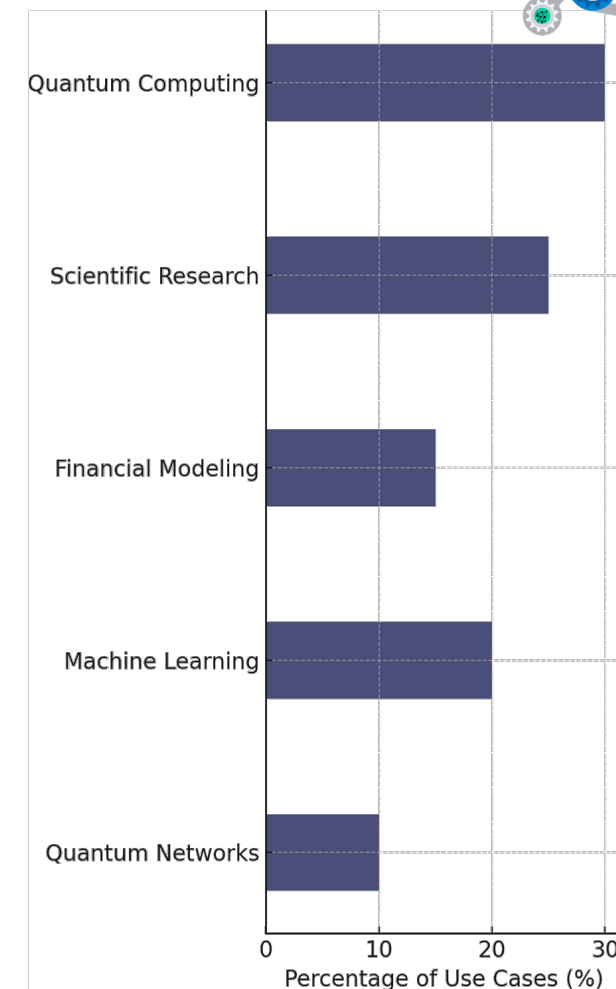
Developing markets

As research progresses, neutral atom quantum computing is anticipated to impact various sectors:

- 🚀 **Quantum Simulation:** Neutral atom processors operating in analog mode have enabled researchers to probe the entanglement frontier and advance scientific research, such as a 2021 study of quantum magnetism using approximately 200 qubits.
- 🚀 **Machine Learning:** Pasqal's neutral atom platform and DQC algorithm pave the way for quantum advantage in machine learning and solving differential equations.

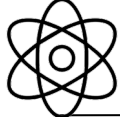
Neutral atom technology has the potential to **transform industries**, enabling **efficient and scalable** quantum computing in the near future.

QC  Neutral Atoms 
Use cases by sectors



Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where *Neutral Atoms* are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.





Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Photons

Photon-based quantum computing leverages **individual particles of light** to encode and process quantum information. It is a promising approach due to its **natural compatibility with optical communication networks** and potential for long-distance quantum communication.

Key Features & Challenges

- ✓ **Types of Qubits:** Based on single photons manipulated through beam splitters, phase shifters, and interferometers.
- ✓ **Advantages:** Room-temperature operation, low decoherence, and seamless integration with fiber-optic infrastructure.
- ✓ **Challenges:** Efficient generation and detection of single photons, scalability in complex circuits, and improving two-photon gate fidelities.

Future Outlook (2035)

- **Developing scalable photonic quantum processors** with higher qubit counts.
- Advancing towards **fault-tolerant quantum computing** by improving photonic error correction.
- Expanding **quantum communication networks** for secure data transfer and quantum cryptography.
- Enhancing **optical quantum simulation capabilities** for applications in materials science and optimization.

Photon-based quantum computing is emerging as a **key player in quantum communication and secure computing**, offering advantages in scalability, connectivity, and robustness against decoherence.

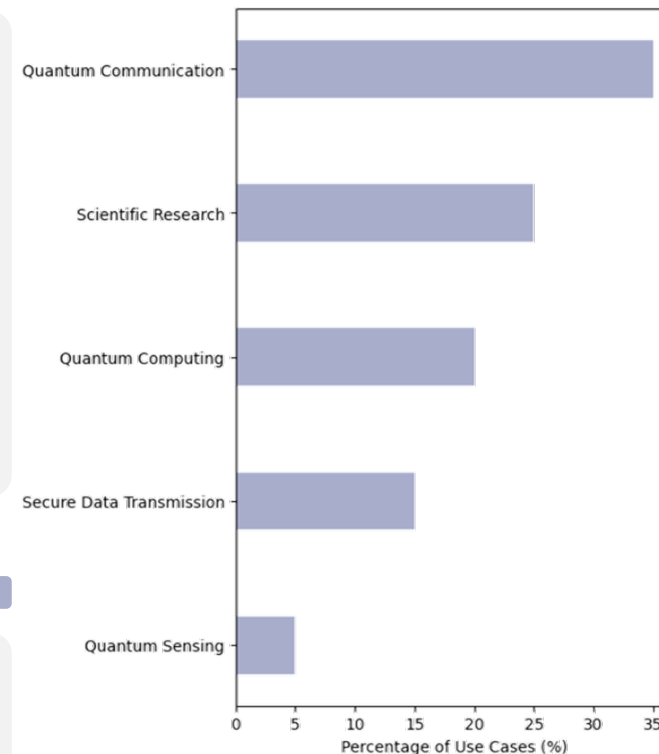
Mature market

- ◆ **Quantum Communication:** Photons are fundamental for **Quantum Key Distribution (QKD)**, ensuring **highly secure data transmission** over fiber-optic and satellite networks.
- ◆ **Cloud-Based Photonic Quantum Computing:** Companies like **Quandela and QuiX Quantum** offer access to **photonic quantum processors** via the cloud, supporting industry and research applications.
- ◆ **Quantum Sensing & Metrology:** Photonic technologies enable **ultra-precise measurements**, including **optical atomic clocks, LiDAR systems, and high-resolution imaging**.

Developing markets

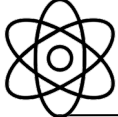
- 🚀 **Fault-Tolerant Quantum Computing:** Breakthroughs in **integrated photonics and single-photon sources** will drive the scalability of photonic quantum processors.
- 🚀 **Quantum Internet:** **Photonic entanglement** will enable large-scale **quantum networks**, connecting quantum computers across long distances.
- 🚀 **Next-Gen Quantum Cryptography:** Emerging **post-quantum security systems** will leverage photonic-based cryptographic methods for **unbreakable encryption**.

QC  Photons
Use cases by sectors 

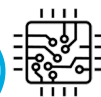


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Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Nitrogen Vacancy Centres in Diamond

NVCD centers in diamond are a promising quantum technology that **leverages atomic-scale defects** in diamond lattices to store and process quantum information. Their unique properties make them particularly suited for **quantum sensing, metrology, and secure communication applications**.

Key Features & Challenges

- ✓ **Types of Qubits:** Based on **electronic and nuclear spins** trapped within diamond defects.
- ✓ **Advantages:** High coherence times at room temperature, **strong spin-photon interactions**, compatibility with existing **photonic and electronic** technologies, and **high nanometric spatial resolution**.
- ✓ **Challenges:** Limited **scalability** for quantum computing, difficulty in precisely engineering NV defects, and improving **photoelectric readout** for more compact quantum sensors.

Future Outlook (2035)

- Advancing **quantum sensing applications** for **ultra-precise magnetic, electric, and pressure measurements**.
- Developing **NV-based quantum networks** for **secure communication and distributed quantum computing**.
- Enhancing **biomedical imaging and molecular spectroscopy** using NV centers for **high-resolution real-time diagnostics**.
- Exploring **hybrid architectures**, integrating NV centers with **superconducting and photonic quantum systems**, and improving **photoelectric readout** for **more compact quantum sensors**.



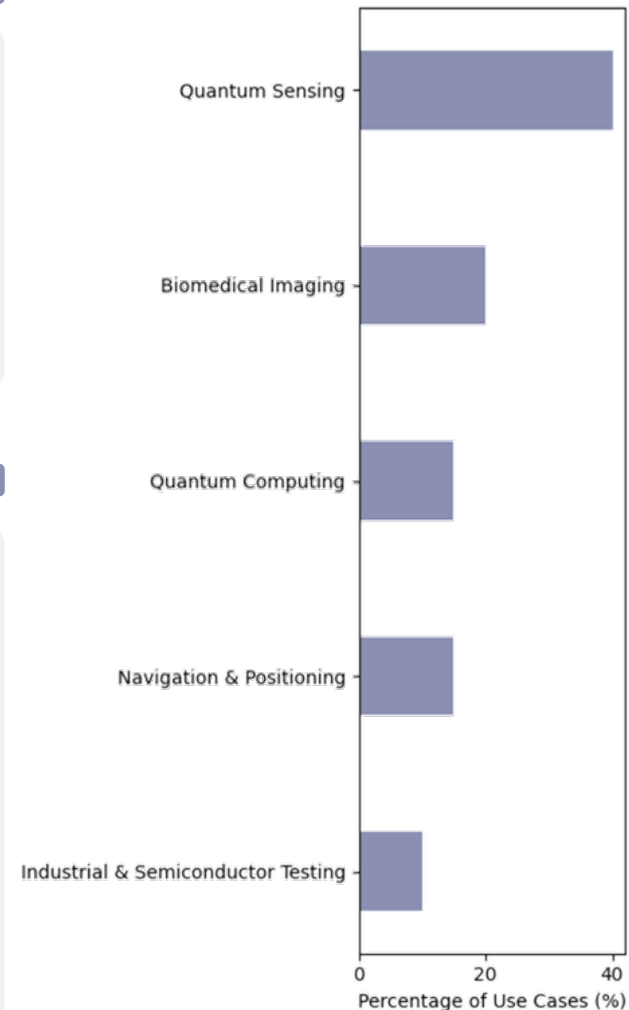
Mature market

- ◆ **Quantum Sensing:** NVCD centers are widely used for **ultra-precise quantum sensing**, including magnetometry, electrometry, **mechanical stress**, and temperature sensing. Their **room-temperature operation** makes them ideal for **biological and industrial applications**.
- ◆ **Quantum Microscopy:** NVCD-based **scanning microscopes** provide **nanoscale imaging** of magnetic fields, enabling breakthroughs in **materials science, superconductors, and high-pressure material characterization**.

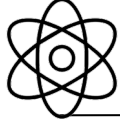
Developing markets

- 🚀 **Quantum Computing:** NVCD-based quantum **processors** are being explored for **scalable quantum computing**, leveraging **long coherence times**, photonic integration, and compatibility with **semiconductor and 2D materials**.
- 🚀 **Biomedical Applications:** Functionalized **nanodiamonds** with NVCD centers are being developed for **medical imaging, lab-on-a-chip diagnostics, and quantum-enhanced MRI**.
- 🚀 **Navigation & Positioning:** NVCD-based **quantum magnetometers** enhance **positioning systems**, offering high-precision inertial navigation solutions, particularly in **GNSS-denied environments**.
- 🚀 **Non-Destructive Testing:** NVCD centers enable advanced **defect detection** in semiconductor circuits, **aerospace components, metallic structures, and high-pressure superconducting materials**.

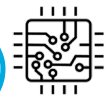
QC  Photons 
Use cases by sectors



Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where NVCD are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.



Main Focus Quantum Applications: Quantum Computing (QC-hardware)



Quantum Simulation hardware

Qsim-h enables efficient modeling of quantum systems, tackling problems beyond classical computing capabilities.

Key Features & Challenges

- ✓ **Superconducting Qubits:** Advances focus on extending coherence times, optimizing interconnectivity, and implementing tunable non-stoquastic couplings for more complex simulations.
- ✓ **Spin Qubits:** Research explores novel applications for quantum simulation, leveraging spin-based encoding for robust, scalable computations.
- ✓ **Trapped Ions:** Development aims at optimizing annealing protocols and expanding qubit connectivity for industrial simulations.
- ✓ **Neutral Atoms:** Demonstrated potential in quantum machine learning and complex graph-based simulations, with systems scaling towards 1000 qubits.

Future Outlook (2035)

- **Scalability & Performance:** Focus on enhancing qubit coherence, reducing errors, and minimizing encoding overhead.
- **Universal simulation hardware:** New architectures will support broader **quantum Hamiltonians**, enabling more diverse applications.
- **Hybrid Quantum-classical integration:** Quantum simulators will complement **HPC environments**, optimizing large-scale simulations.
- **Industry-specific applications:** Growth in **materials science, chemistry, and life sciences**, especially in **drug discovery and new material synthesis**.

Mature market

- 🔧 **Material Science & Chemistry:** Used for simulating molecular structures and material properties, aiding in drug discovery and new material synthesis.
- 🔧 **High-Energy Physics:** Supports complex simulations in particle physics, improving the understanding of quantum phenomena.
- 🔧 **Optimization & Logistics:** Applied in solving complex optimization problems in transportation, supply chains, and financial modeling.

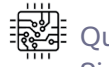
Developing markets

As Qsim-h advances, its impact is expected to grow across various sectors:

- 🚀 **Scalable Quantum simulators:** Efforts focus on enhancing qubit coherence, error correction, and computational efficiency for broader industrial applications.
- 🚀 **Hybrid HPC integration:** Quantum simulators will complement classical high-performance computing (HPC) to tackle large-scale scientific and engineering challenges.
- 🚀 **Industry-specific expansion:** Future applications include climate modeling, energy grid optimization, and precision medicine, expanding quantum simulation's role in real-world problem-solving.

Qsim-h will bridge theoretical quantum models with real-world applications, driving industrial innovation.

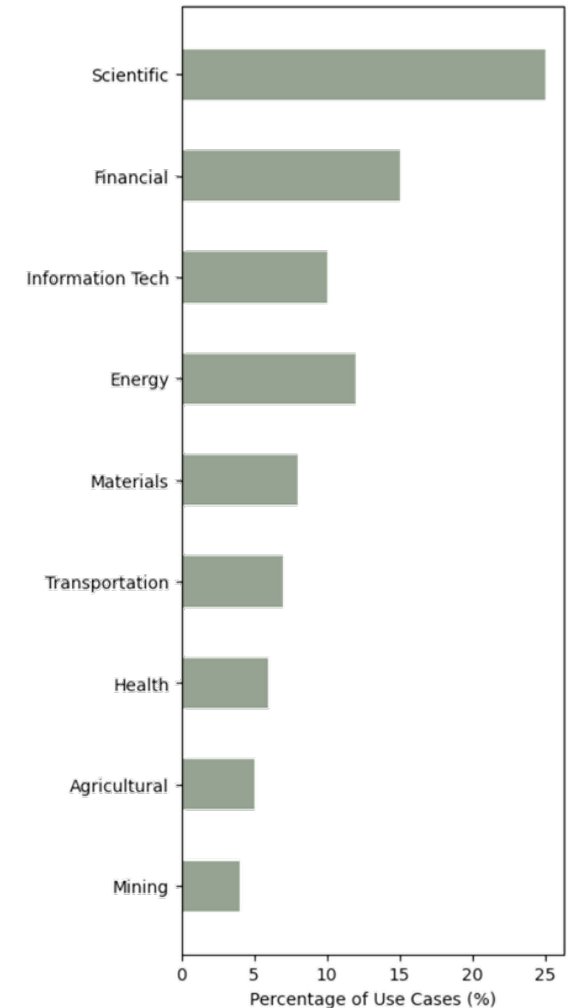
QC



Quantum Simulation

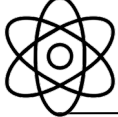


Use cases by sectors



Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where *Quantum Simulation hardware* are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.





Main Focus Quantum Applications: Quantum Computing (QC-hardware&software)



Qubit control & error correction

Essential for stabilizing and optimizing quantum computations, qubit control and error correction technologies ensure high-fidelity operations, reducing computational noise and extending qubit coherence times.

Key Features & Challenges

- ✓ **Qubit Control:** Encompasses optimized manipulation of individual qubits, precise signal routing, and integration of hardware/software solutions for managing large-scale quantum processors.
- ✓ **Error Correction:** Utilizes multiple physical qubits to encode information into a logical qubit, requiring rapid and efficient error detection and correction strategies.
- ✓ **Challenges:** Increasing the scalability of control systems, mitigating qubit noise, and reducing hardware-induced errors to achieve fault-tolerant quantum computing.

Future Outlook (2035)

- **Advancing error correction** methods to handle multiple logical qubits and reduce logical-to-physical qubit ratios.
- **Developing next-generation control electronics** with real-time feedback loops, minimizing latency and improving qubit fidelity.
- **Enhancing qubit interconnectivity** using photonic links and scalable network architectures.
- **Standardizing control protocols** to enable cross-platform integration, supporting the transition to large-scale, fault-tolerant quantum systems.

Qubit control & error correction will be **critical enablers** for scalable quantum computing, ensuring the long-term viability of quantum technologies in practical applications.



Mature market

Essential for scalable quantum computing :

- ✦ **Qubit Control Systems:** Companies such as Creotech, Qblox, and Zurich Instruments provide control hardware, while software solutions come from QUARTIQ, QuantrolOx, Riverlane, and Qruise. These technologies improve signal routing, qubit readout efficiency, and noise mitigation.
- ✦ **Quantum Error Correction (QEC):** Methods such as surface codes and bosonic codes are being implemented to reduce logical error rates, supported by real-time decoders like those developed by Riverlane.

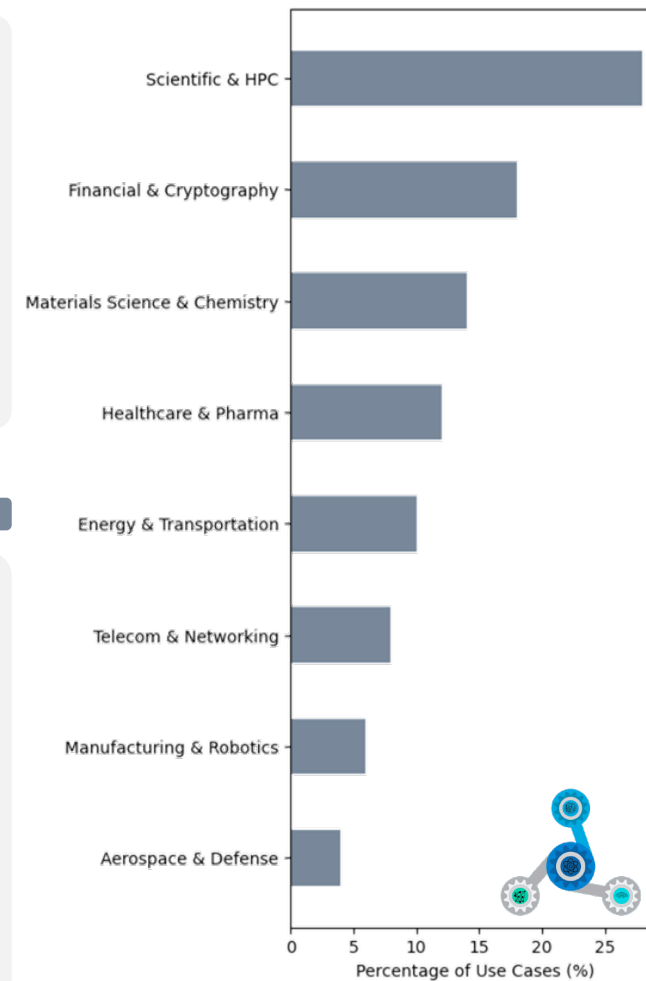
Developing markets

Advancements in qubit control & error correction will be key to more robust and scalable quantum systems:

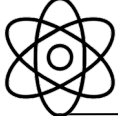
- ✦ **Advanced Control Systems:** The integration of application-specific integrated circuits (ASICs) for qubit control could provide lower latency and reduced crosstalk, essential for managing large-scale quantum processors.
- ✦ **Scalable Quantum Error Correction:** Future quantum processors will integrate sophisticated error correction codes, aiming to support over a trillion error-free quantum operations `BASE_PROSPECTIVA_QuIC-S....`
- ✦ **Hybrid Classical-Quantum Architectures:** Developing synergies between quantum control hardware and classical computing for efficient error handling and system calibration.

QC  Qubit control & error correction

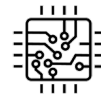
Use cases by sectors



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Main Focus Quantum Applications: Quantum Computing (QC-Software)



Quantum Simulation software

Essential for advancing **quantum research and industrial applications**, simulation software enables precise modeling of quantum systems beyond classical computing capabilities.

Key Features & Challenges

- ✓ **Simulation accuracy:** Enhances modeling of quantum behaviors in chemistry, material science, and physics.
- ✓ **Algorithm development:** Facilitates the testing and optimization of quantum algorithms in simulated environments.
- ✓ **Scalability:** Addresses computational challenges by integrating high-performance computing (HPC) with quantum methodologies.
- ✓ **Hardware-agnostic compatibility:** Ensures interoperability across various quantum computing architectures.

Future Outlook (2035)

- **Expanded industry adoption:** More sectors, including pharmaceuticals and nanotechnology, will integrate quantum simulation tools.
- **Hybrid integration:** Advancements in cloud-based quantum simulation will improve accessibility and usability.
- **Enhanced computational models:** Development of more efficient, noise-resilient algorithms for accurate simulations.
- **Automation & AI assistance:** Machine learning will refine simulation parameters, accelerating quantum research applications.

Quantum simulation software will **bridge the gap** between experimental quantum computing and real-world industrial applications, paving the way for innovation across multiple domains.



Mature market

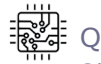
- **Quantum chemistry & material science:** Enables precise modeling of molecular interactions, accelerating **drug discovery** and the **development of novel materials**.
- **Physics & high-energy simulations:** Used to simulate **quantum states** in condensed matter physics and high-energy particle interactions.
- **Financial & risk analysis:** Emerging applications in **financial modeling**, where quantum simulations optimize risk assessments and portfolio management.

Developing markets

- **Industry-specific optimization:** Quantum simulations will drive innovations in **nanotechnology, biophysics, and climate modeling**.
- **Hybrid Quantum-classical systems:** Future developments will integrate **quantum simulators** with **HPC infrastructures**, improving computational efficiency.
- **Cloud-based Quantum simulations:** Increased access to **cloud quantum platforms** will democratize quantum-powered modeling for enterprises.
- **AI-assisted Quantum modeling:** Machine learning algorithms will refine quantum simulations, enhancing accuracy and usability across disciplines.

Quantum simulation software is positioned to **revolutionize computational research**, bridging the gap between theoretical quantum models and **real-world industrial applications**.

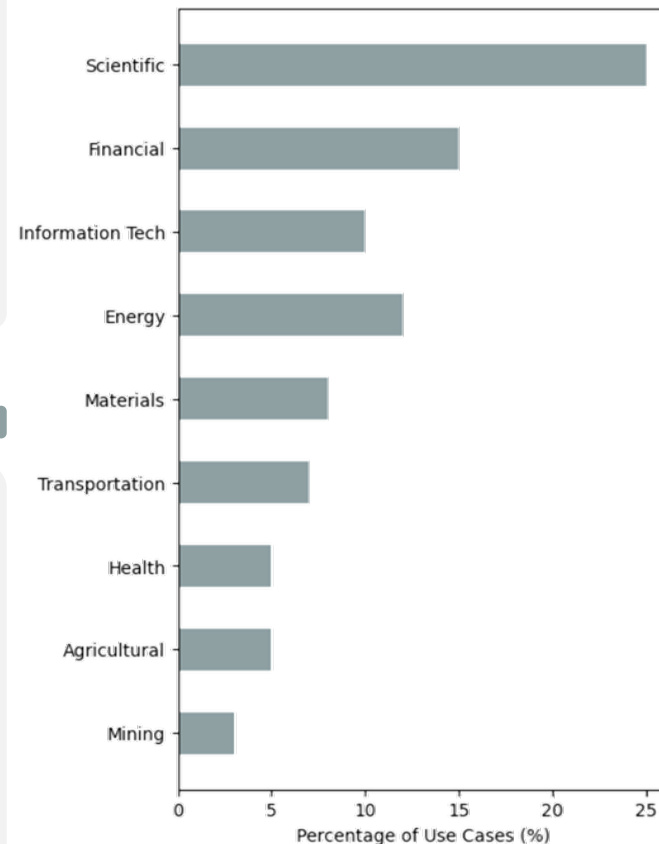
QC



Quantum Simulation

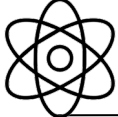


Use cases by sectors

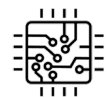



European Quantum Industry Consortium (QuIC). (2024). Strategic Industry Roadmap (SIR) 2024. NEASQC Project.

Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where NVCD are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.



Main Focus Quantum Applications: Quantum Computing (QC-Software)



QC  Quantum Operating Systems & Algorithm



Quantum Operating Systems & Algorithm

Essential for bridging the gap between **quantum hardware and practical applications**. They provide the necessary **software infrastructure** to efficiently execute quantum programs across different quantum computing platforms.

Key Features & Challenges




- ✓ **Quantum Operating Systems:** Manage resource allocation, qubit mapping, and error correction across various quantum architectures.
- ✓ **Algorithm Compilers:** Translate high-level quantum algorithms into hardware-optimized instructions, ensuring compatibility across different quantum processors.
- ✓ **Challenges:** Standardization across quantum platforms, optimizing performance for diverse quantum hardware, and minimizing computational overhead.

Future Outlook (2035)






- **Developing cross-platform quantum operating systems** to ensure interoperability between different quantum hardware providers.
- Advancing **high-efficiency quantum compilers** that optimize quantum circuits, reducing gate depth and execution time.
- Enabling **hybrid quantum-classical workflows**, allowing seamless integration between quantum and conventional computing systems.
- Enhancing **error mitigation techniques** within quantum software stacks for improved algorithm performance.

Quantum operating systems and compilers are **key enablers for scalable quantum computing**, ensuring that QT transition from experimental research to real-world applications.

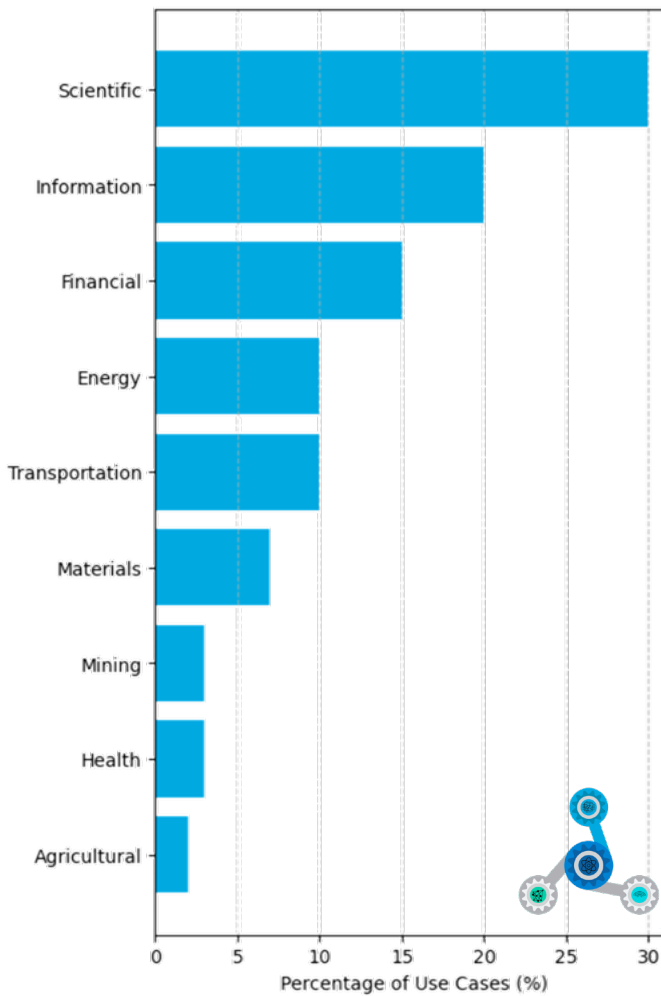
Mature market

-  **Quantum hardware optimization:** Efficient management of quantum hardware resources through quantum operating systems helps reduce hardware requirements and execution times.
-  **Multi-hardware compatibility:** Quantum compilers enable the translation of high-level algorithms into hardware-specific instructions for different quantum platforms.
-  **Automated quantum control:** The implementation of compilers with automatic optimization capabilities facilitates algorithm execution with lower latency and fewer errors.

Developing markets

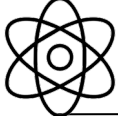
-  **Advanced quantum circuit optimization:** Compilers with automatic optimization capabilities are being developed, incorporating AI and ML techniques to improve code quality and scalability.
-  **Distributed programming across multiple platforms:** Quantum OS advances enable distributed execution across hardware, enhancing qubit interoperability.
-  **Standardization of intermediate representation (IR):** Efforts focus on an intermediate language for efficient, flexible quantum algorithm translation across architectures.
-  **Integration with error correction systems:** Next-generation compilers will incorporate
-  **Hybrid quantum-classical systems:** Research integrates quantum and classical hardware to optimize high-performance computing workloads.

Use cases by sectors

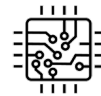


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Main Focus Quantum Applications: Quantum Computing (QC-Software)



Quantum APIs and Cloud Access



Quantum APIs enable seamless interaction between users and quantum computing platforms, providing cloud-based access to quantum simulators and hardware. These interfaces facilitate the execution of quantum algorithms, supporting both problem-specific computations and direct control of quantum circuits.

Key Features & Challenges

- ✓ **Flexible Execution:** Supports both parameterized problem-solving and low-level pulse control.
- ✓ **Hybrid Infrastructure:** Available as on-premises installations or cloud-based solutions integrated with HPC systems.
- ✓ **Interoperability Issues:** Many current solutions remain hardware-specific, limiting cross-platform compatibility.

Future Outlook (2035)

- **Expanding European quantum simulators on cloud platforms** to enhance accessibility.
- **Seamless integration with HPC infrastructures** for hybrid quantum-classical workflows.
- **Development of unified APIs and SDKs** to standardize quantum access across different providers.

Quantum cloud access will be essential in **democratizing** quantum computing, fostering interoperability, and ensuring **Europe's technological sovereignty**. It plays a **key role** in seamlessly integrating quantum computing into classical and **hybrid** infrastructures.



Mature market

- 🚀 **Quantum SDKs:** General-purpose software development kits enable the implementation of quantum algorithms, primarily developed by US companies, which raises concerns about European technological sovereignty.
- 🚀 **Integration with HPC:** Efforts are being made to integrate quantum computing with high-performance computing (HPC) systems, enhancing computational capabilities.
- 🚀 **Quantum Programming Support:** APIs facilitate interoperability and provide predefined subroutines to streamline quantum software development.

Developing markets

As the field advances, Quantum APIs and cloud access are expected to play a more significant role in various sectors:

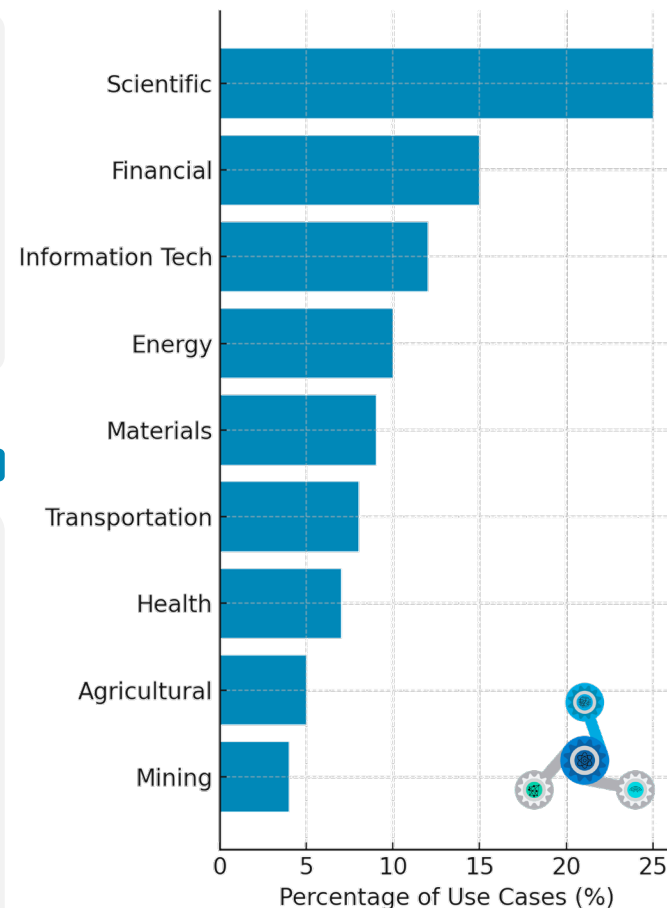
- 🚀 **Hybrid Quantum-Classical Workflows:** Future advancements will focus on fully integrating hybrid algorithms within cloud infrastructures, optimizing workflows for real-world applications.
- 🚀 **European Autonomy in Quantum Cloud:** Strengthening European quantum cloud solutions to reduce dependency on non-EU providers and ensure compliance with data protection regulations.
- 🚀 **Industry Adoption & Scalability:** Large-scale industries will need robust quantum cloud solutions to seamlessly transition quantum computing from research to production.

QC



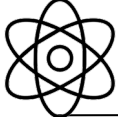
Quantum APIs and Cloud Access

Use cases by sectors

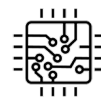


European Quantum Industry Consortium (QuIC). (2024). *Strategic Industry Roadmap (SIR) 2024*. QuIC.

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Main Focus Quantum Applications: Quantum Computing (QC-Software)



Quantum Algorithms

Quantum algorithms leverage quantum physics principles like superposition, entanglement, and interference to outperform classical computing for certain tasks. Their development is key to unlocking quantum advantage in practical applications.

Key Features & Challenges

- ✓ **Algorithm Libraries:** Collections of quantum algorithms make QC more accessible, enabling broader programming applications.
- ✓ **Optimization & Performance:** Over half of the known 100+ quantum algorithms offer super-polynomial speed-ups compared to classical methods.
- ✓ **Industry Applications:** Companies are developing specialized algorithms for fields like finance, engineering, energy, and cybersecurity.
- ✓ **Challenges:** Efficient quantum manipulation and integration into business applications remain hurdles for widespread adoption.

Future Outlook (2035)

- **Expanding Quantum Applications:** Development of industry-specific algorithms in finance, aerospace, and materials science.
- **Automated Compilation:** Platforms enabling automatic quantum gate generation from high-level inputs.
- **Quantum-Inspired Methods:** Classical systems adopting quantum principles for enhanced optimization.
- **Industry Collaboration:** Strengthening partnerships to accelerate real-world quantum adoption.

Mature market

- ❖ **Quantum Optimization:** Companies like Multiverse Computing are applying quantum algorithms in finance, manufacturing, and energy, enhancing efficiency and solving complex problems.
- ❖ **Quantum Simulation:** Quantum algorithms are used in quantum chemistry and material design, enabling more accurate molecular modeling.
- ❖ **Quantum Machine Learning (QML):** Companies and research centers are exploring its potential in complex data analysis, with applications in cybersecurity and healthcare.

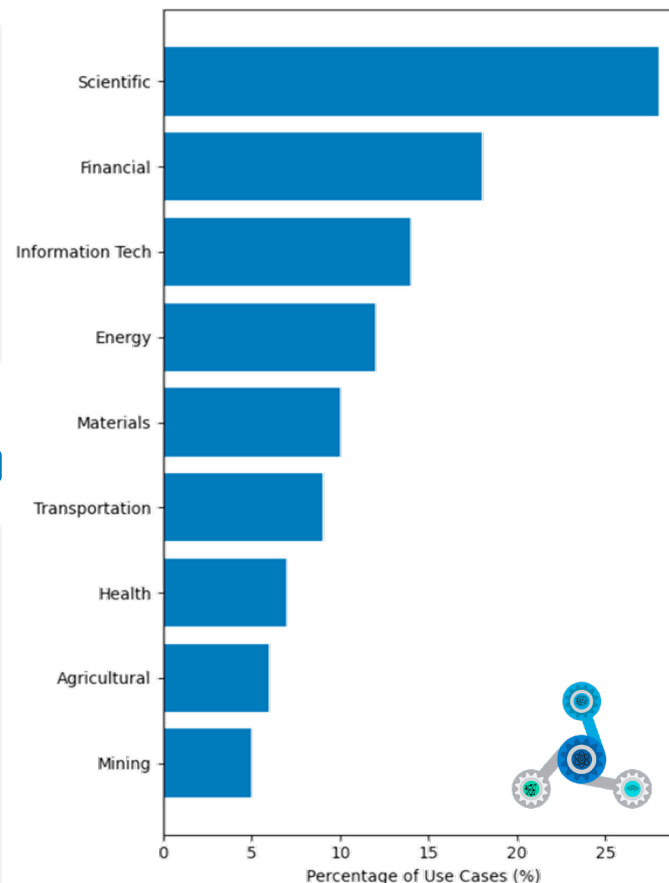
Developing markets

As quantum algorithms advance, their impact will expand into new areas:

- 🚀 **Automated Algorithm Development:** Platforms are being developed to automatically generate quantum gate sequences from high-level specifications, simplifying quantum programming.
- 🚀 **Integration with Classical Computing Infrastructure:** Quantum algorithms are expected to work alongside classical computing in hybrid systems, optimizing workloads in data centers and cloud computing.
- 🚀 **New Applications in Artificial Intelligence:** Combining AI with quantum computing could accelerate the development of advanced algorithms for pattern recognition, natural language processing, and decision-making.

QC  Quantum Algorithms

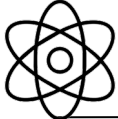
Use cases by sectors



European Quantum Industry Consortium (QuIC). (2024). *Strategic Industry Roadmap (SIR) 2024*. QuIC.

Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where Quantum Algorithms are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.





Main Focus Quantum Applications: Quantum Communications: (QComms)



Post-Quantum Cryptography (PQC)

PQC is a quantum-era cybersecurity solution that replaces cryptographic algorithms with quantum-safe versions resistant to quantum attacks.

Key Features & Challenges

- ✓ **PQC algorithms:** Based on highly **complex mathematical** problems that remain difficult to solve even with quantum computing. Standardization is underway, led by the NIST* PQC process.
- ✓ **Optimization & performance:** PQC can ready be deployed in many systems but still faces efficiency and speed challenges compared to classical cryptographic algorithms.
- ✓ **Industry applications:** PQC is being integrated into sectors such as **finance, government, defense,** and **telecommunications,** ensuring data protection against quantum threats.
- ✓ **Challenges:** While PQC is a promising solution, there is always the risk that future quantum algorithms could compromise its security. Additionally, transitioning from current systems requires a **global and coordinated** implementation.

Future Outlook (2035)

- **Expanding applications:** Integration of PQC into security protocols for **networks, IoT, and critical** systems.
- **Automation & standards:** Advances in **certification and standardization** to facilitate widespread adoption.
- **Hybridization with QKD:** Combining **Quantum Key Distribution (QKD)** and PQC for more robust security systems.
- **Industry collaboration:** Growing cooperation between governments, tech companies, and academia for the development of **hybrid cryptographic** solutions.

*NIST stands for National Institute of Standards and Technology, a U.S. government agency that develops and promotes measurement standards, including cryptographic standards like Post-Quantum Cryptography (PQC)

Mature market

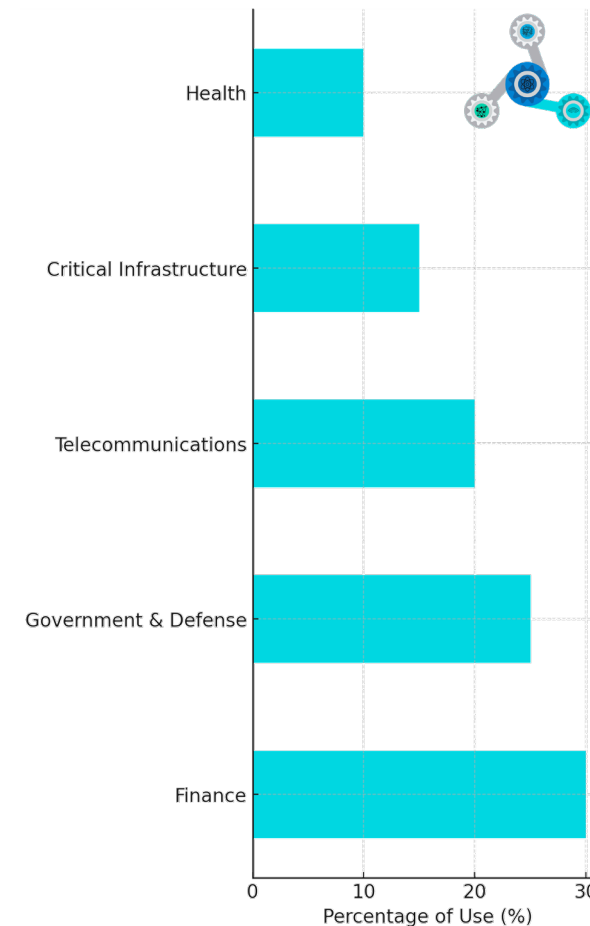
- 🌐 **Quantum security:** PQC is being adopted in **finance, government, and telecom** to protect data from quantum threats.
- 🌐 **Hybrid cryptography:** Integrating PQC with QKD for enhanced **secure communications and critical infrastructure.**
- 🌐 **Standardization & compliance:** Efforts are underway to **align PQC with global cybersecurity standards** for widespread adoption.

Developing markets

- 🚀 **IoT & low-power devices:** Development of **energy-efficient** PQC for **IoT, smart cities, and edge computing,** ensuring secure communications in **resource-limited** environments.
- 🚀 **Blockchain & cryptocurrencies:** Post-quantum cryptography will **secure transactions** and prevent quantum-based **attacks in decentralized finance (DeFi)** and **digital asset** management.
- 🚀 **Cloud & AI security:** Hybrid **PQC + QKD models** will strengthen **confidential** computing, AI-driven encryption, and **privacy-preserving** machine learning in the cloud.
- 🚀 **Space & global networks:** Quantum-secure **satellite** communications will ensure **resilient data** exchange in **space, defense,** and global **telecom networks,** integrating PQC with QKD.
- 🚀 **Public Key Infrastructure (PKI) evolution:** Next-gen **PKI** will incorporate PQC for **secure authentication, digital identity** protection, and **regulatory** compliance.

QComms  PQC

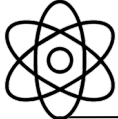
Use cases by sectors



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Main Focus Quantum Applications: Quantum Communications: (QComms)



Quantum Key Distribution (QKD)



QKD enables secure key exchange using quantum mechanics, ensuring security based on physical laws rather than computational assumptions.

Key Features & Challenges

- ✓ **Secure key exchange:** QKD ensures identical and private keys between two remote sites, preventing eavesdropping by quantum or classical adversaries.
- ✓ **Integration with classical networks:** QKD is being combined with classical cryptographic systems, enhancing security in government, finance, and defense.
- ✓ **Quantum networks:** The development of Trusted Nodes (TNs) and quantum repeaters will enable large-scale QKD networks, overcoming fiber optic limitations.
- ✓ **Challenges:** High deployment costs, specialized hardware, and limited interoperability hinder widespread QKD adoption, while fiber-based links are restricted to ~150 km, requiring Trusted Nodes for long-distance scalability.

Future Outlook (2035)

- **Expanding QKD applications:** Integration with PQC will create a hybrid security approach for long-term quantum resilience.
- **Quantum Internet & Satellite QKD:** The emergence of space-based QKD and entanglement-based communications will enable global quantum networks.
- **Automated Key Management:** Development of software-defined quantum networks to streamline key distribution across multi-node QKD architectures.
- **Standardization & Certification:** Efforts by ETSI, ITU, and ISO aim to establish universal standards for QKD security compliance and network interoperability.

Mature market

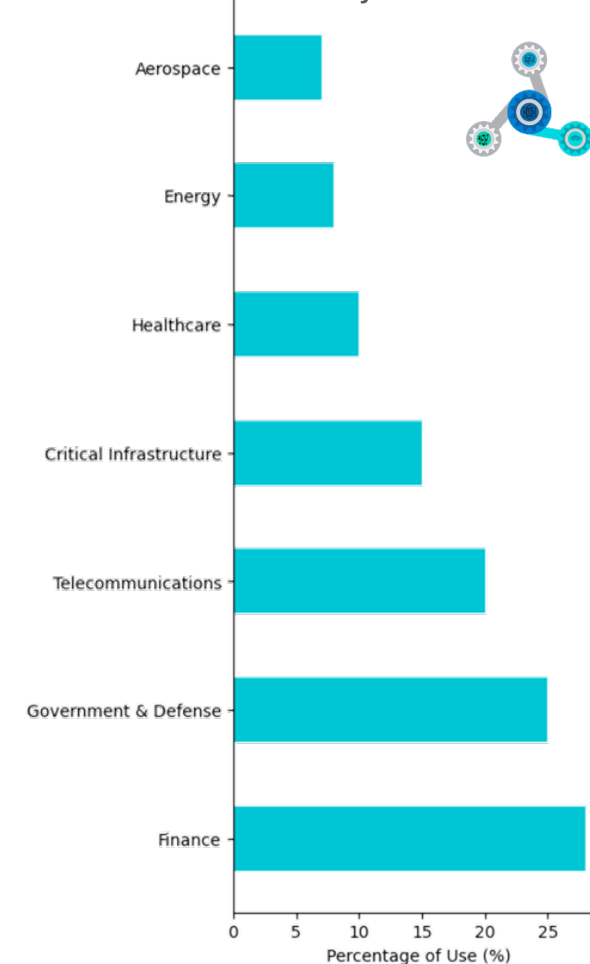
- 🌐 **Secure communication networks:** QKD is already deployed in government, financial, and defense sectors to protect highly sensitive data through quantum-safe encryption.
- 🌐 **Trusted nodes & network expansion:** Terrestrial QKD using Trusted Nodes (TNs) enables secure long-distance communication, especially in metropolitan networks.
- 🌐 **Industrial adoption & standardization:** QKD hardware is increasingly commercialized, with data center-compatible systems and efforts by ETSI, ITU, and ISO for global standards.

Developing markets

- 🚀 **Integration with PQC:** Combining QKD with PQC strengthens **multi-layered security** architectures to future-proof cryptographic frameworks.
- 🚀 **Satellite & global Quantum networks:** Space-based QKD initiatives like the European SAGA program aim to provide secure global key exchange, complementing terrestrial QKD.
- 🚀 **Cloud & AI security:** QKD can **enhance confidential computing**, enabling quantum-secure AI-driven encryption and privacy-preserving cloud infrastructure.
- 🚀 **Quantum Internet & entanglement-based communication:** Future quantum repeaters and entanglement networks will allow secure communication over vast distances, forming the backbone of a quantum internet.
- 🚀 **Public Key Infrastructure (PKI) evolution:** Next-gen PKI frameworks will integrate QKD for secure authentication, digital identity protection, and regulatory compliance.

QComms  QKD

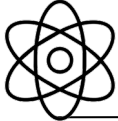
Use cases by sectors



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Main Focus Quantum Applications: Quantum Sensing and Metrology (QS)



Quantum Sensors

QS leverage quantum phenomena for highly precise measurements, outperforming classical sensors in healthcare and geophysics.

Key Features & Challenges

- ✓ **High-precision measurements:** Quantum sensors offer extreme sensitivity for gravitational-wave detection, atomic clocks, and medical diagnostics.
- ✓ **Diverse sensor platforms:** Gas-based and solid-state sensors, like cold atoms for gravimetry and diamond NV centers for magnetometry, enhance measurement accuracy.
- ✓ **Industrial adoption & scalability:** While some technologies (e.g., atomic clocks, quantum gravimeters) are commercialized, others require further development and miniaturization.
- ✓ **Challenges:** Quantum sensors are noise-sensitive, needing shielding from magnetic and thermal fluctuations. Industry adoption requires balancing performance, cost, and reliability, while cryogenics or complex setups limit portability.

Future Outlook (2035)

- **Quantum Healthcare & Bioimaging:** NV-center magnetometry will enhance early disease detection and enable non-invasive diagnostics for neurological and cardiovascular conditions.
- **Next-Gen Navigation & Positioning:** Cold-atom interferometers will provide GPS-independent navigation and precise positioning in GNSS-denied environments.
- **Quantum-Enhanced Telecommunications:** Optical atomic clocks and frequency standards will improve network synchronization and enable secure QComms.
- **Space & Earth Monitoring:** Quantum gravimeters and magnetometers will transform geophysics, climate monitoring, and space exploration, detecting subtle gravitational and electromagnetic variations.
- **Standardization & Commercialization:** Quantum metrology will define SI units, with global standardization efforts driving widespread adoption.



Mature market

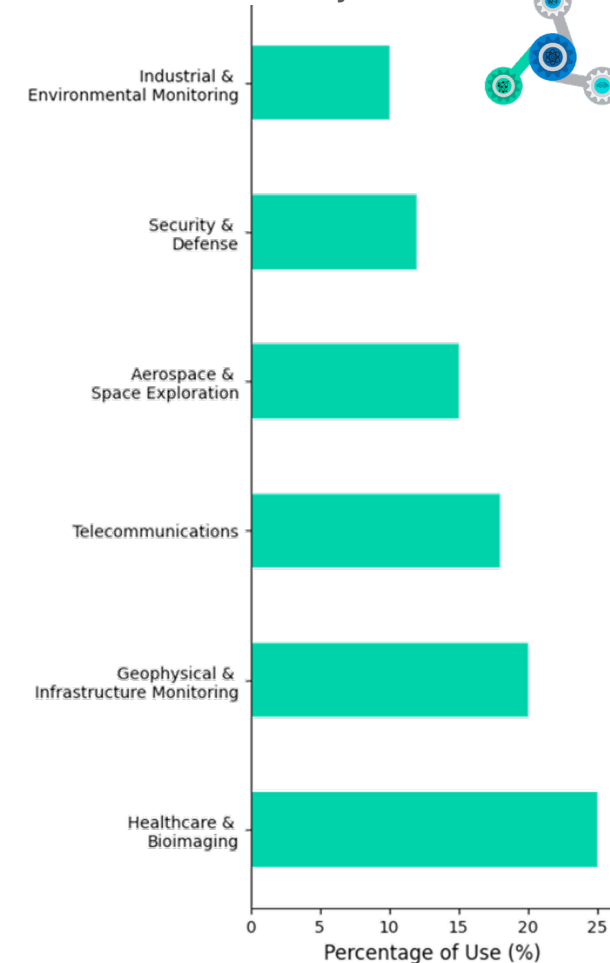
- Quantum Healthcare & Imaging:** NV-center sensors enable non-invasive diagnostics for neurological and cardiovascular diseases, improving early detection.
- Precision Timing & Frequency Standards:** Chip-scale atomic clocks enhance network synchronization, financial transactions, and GPS-free navigation.
- Geophysical & Infrastructure Monitoring:** Quantum gravimeters and magnetometers improve earthquake prediction, underground mapping, and mineral exploration.
- RF Sensing & Telecommunications:** Rydberg atom sensors provide broadband spectrum monitoring for secure, interference-free communications.
- Industrial Adoption & Scalability:** While some sensors (atomic clocks, NV magnetometers) are commercialized, others require miniaturization and standardization.

Developing markets

- Quantum Navigation & Positioning:** Cold-atom interferometers and optical atomic clocks will enable GPS-free navigation for autonomous vehicles and space missions.
- Advanced Telecommunications:** Optical atomic clocks will enhance data transmission and cyber resilience in quantum-secured networks.
- Quantum Security & Defense:** Quantum sensors will strengthen threat detection, secure communications, and radar systems.
- Aerospace & Space Exploration:** Quantum sensors will advance satellite navigation, gravitational mapping, and deep-space communication.
- Miniaturization & Portability:** Room-temperature quantum sensors will lead to compact, cost-effective commercial applications.
- Quantum Metrology & Standardization:** Quantum-enhanced measurement standards will redefine SI units, ensuring global precision.

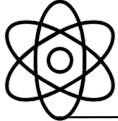
QS QKD

Use cases by sectors



European Quantum Industry Consortium (QuIC). (2024). *Strategic Industry Roadmap (SIR) 2024*. QuIC.

Note: The distribution of use cases in this chart is based on a qualitative estimation derived from industry trends, research publications, and expert insights. It does not represent an exact statistical analysis but provides an indicative perspective on where Quantum Sensing and Metrology are expected to have significant applications. Future empirical studies and industry reports will be necessary to refine these projections.



Main Focus Quantum Applications: Quantum Sensing and Metrology (QS)



Quantum Imaging (Qi)

Quantum imaging leverages entanglement and superposition to surpass classical methods, enhancing resolution, sensitivity, and noise reduction for advances in biomedical diagnostics, security, and environmental monitoring.

Key Features & Challenges

- ✓ **High-Resolution Imaging:** Quantum-enhanced techniques, like ghost imaging and quantum microscopy, surpass classical imaging in precision, allowing for non-invasive biological and material inspections.
- ✓ **Advanced Photon Detection:** Single-photon detectors and quantum-enhanced sensors enable extreme low-light imaging, crucial for astronomy, medical imaging, and deep-space exploration.
- ✓ **Medical & Biological Applications:** Quantum imaging supports enhanced contrast and early disease detection, improving MRI precision and fluorescence microscopy.
- ✓ **Challenges:** Commercialization faces obstacles such as the need for ultra-sensitive detectors, quantum noise control, and integration with classical imaging systems. Additionally, quantum sources remain expensive and require further miniaturization

Future Outlook (2035)

- **Quantum-Enhanced Medical Imaging:** Expanding applications in early cancer detection and functional brain imaging through ultra-sensitive quantum sensors.
- **Security & Surveillance:** Quantum illumination techniques could revolutionize radar and night-vision systems by enhancing detection capabilities in low-visibility conditions.
- **Environmental & Industrial Monitoring:** Improved detection of pollutants, subsurface imaging for archaeology, and enhanced non-destructive testing in materials science.
- **Commercial Integration:** Ongoing research aims to reduce costs and improve the scalability of quantum imaging devices for widespread industrial and medical use.

Mature market

- ✘ **Quantum Microscopy with NV Centers:** Companies like **Qnami** and **QZabre** offer scanning microscopes for **quantum materials** and **superconductor characterization**.
- ✘ **Semiconductor & Metal Defect Detection:** NV-center sensors inspect **microelectronic circuits**, **material fatigue**, and **corrosion** in aerospace & energy industries.
- ✘ **Advanced Biomedical Imaging:** Quantum sensors enable **lung imaging**, **magnetocardiography**, and real-time heart monitoring, with Bosch among key players.
- ✘ **Scientific Instrumentation:** High-resolution NV microscopes for **material science**, functioning under extreme temperatures.

Developing markets

Medical & Biotechnology

- › **Nanoscale biomolecule** spectroscopy for real-time cell metabolism analysis.
- › **Neural imaging** for advanced **brain activity monitoring**.
- › **Rapid diagnostics** using NV nanodiamonds for pathogen detection.

Industry & Security

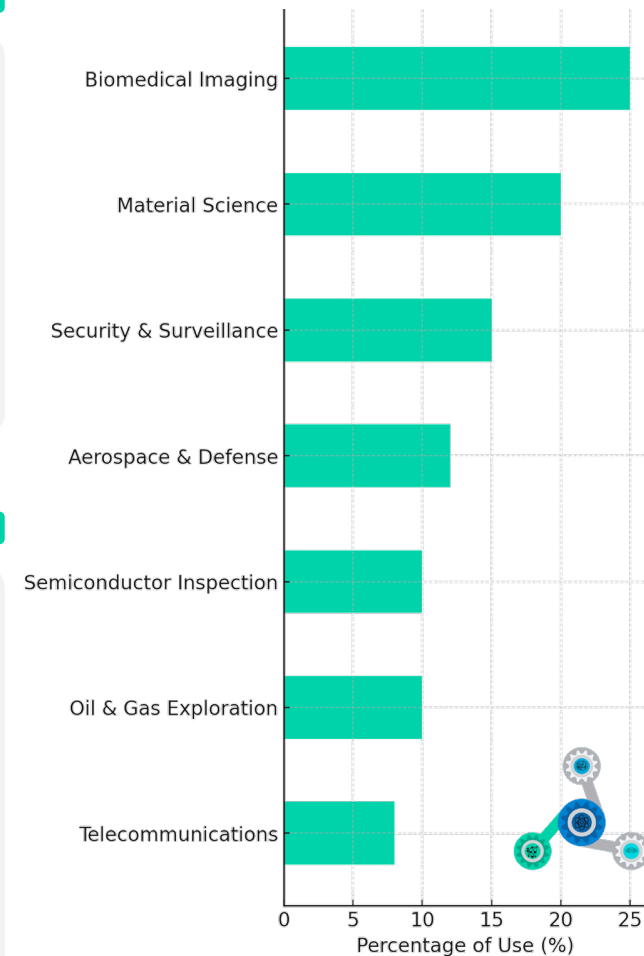
- › Quantum **LiDAR & Radar** for **navigation, surveillance, and interference-resistant sensing**.
- › Structural **inspection** in aerospace & energy with NV-based material fatigue detection.
- › Quantum **gravimetry** for underground resource exploration.

Space & Telecommunications

- › Quantum sensors in **satellites** for **Earth observation, secure communications, and navigation**.
- › **Electromagnetic signal detection** using Rydberg atoms for applications in **5G & RF**.



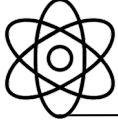
Use cases by sectors



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Main Focus Quantum Applications: Cross-Cutting Areas



Enabling Technologies (ET)

Quantum ET underpin the development and scaling of quantum applications in computing, communication, and sensing, providing key components for quantum state control.

Key Features & Challenges

- ✓ **Core Technologies:** Enabling technologies include cryogenics, vacuum environments, laser sources, optical detectors, integrated photonics, and control electronics, all essential for quantum computing, communication, and sensing.
- ✓ **European Leadership:** Europe has been a key supplier of enabling technologies for decades, benefiting from strong collaboration between industry and institutional research centers.
- ✓ **Challenges:** Many critical enabling technologies are not yet available in Europe, creating risks of dependency. Gaps exist in cryogenics, photonics, and control electronics.
- ✓ **Industrial Adoption:** The development of enabling technologies must keep pace with the growing quantum market to achieve quantum advantage.

Future Outlook (2035)

- **Cryogenics & Vacuum Systems:** Advances in cooling solutions will enable stable environments for superconducting qubits, quantum sensors, and photonic systems.
- **Photonics & Optical Components:** Improved integrated photonics, high-efficiency lasers, and low-loss optical modulators will enhance quantum communication and metrology.
- **Control Electronics & Scalability:** Next-generation electronics will support thousands of qubits, integrating cryogenic and room-temperature controls.
- **Standardization & Commercialization:** Efforts to establish industry-wide standards and supply chains will drive the mass adoption of quantum technologies.

Mature market

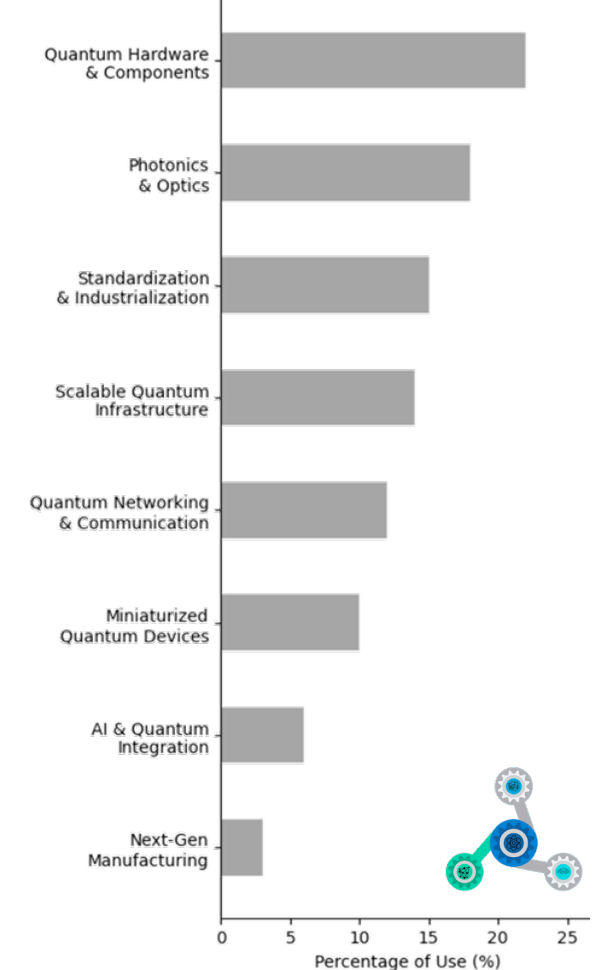
- 🚀 **Cryogenics & Cooling Systems:** Essential for quantum computing and sensing, maintaining low-temperature environments for superconducting qubits and precision sensors.
- 🚀 **Photonics & Lasers:** Used in quantum communication and computing, enabling secure quantum networks and optical quantum computing.
- 🚀 **Control Electronics:** Advanced control systems regulate quantum state manipulation in quantum computers and communication networks.
- 🚀 **High-Precision Detectors:** Key for quantum metrology, improving measurements in scientific and industrial applications.

Developing markets

- 🚀 **Miniaturized Cryogenic Systems:** Developing portable cryogenic solutions to support scalable and mobile quantum technologies.
- 🚀 **Integrated Photonics:** Enabling compact, efficient quantum computing and communication with chip-scale solutions.
- 🚀 **Quantum-Optimized Electronics:** AI-driven and error-corrected control systems to enhance quantum system stability.
- 🚀 **Advanced Single-Photon Sources:** Improving the efficiency and reliability of quantum cryptography and communication networks.
- 🚀 **Hybrid Quantum-Classical Systems:** Enhancing performance in AI, high-performance computing, and cybersecurity through quantum-enhanced processing.

Cross-Cutting Areas ET

Use cases by sectors



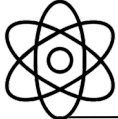
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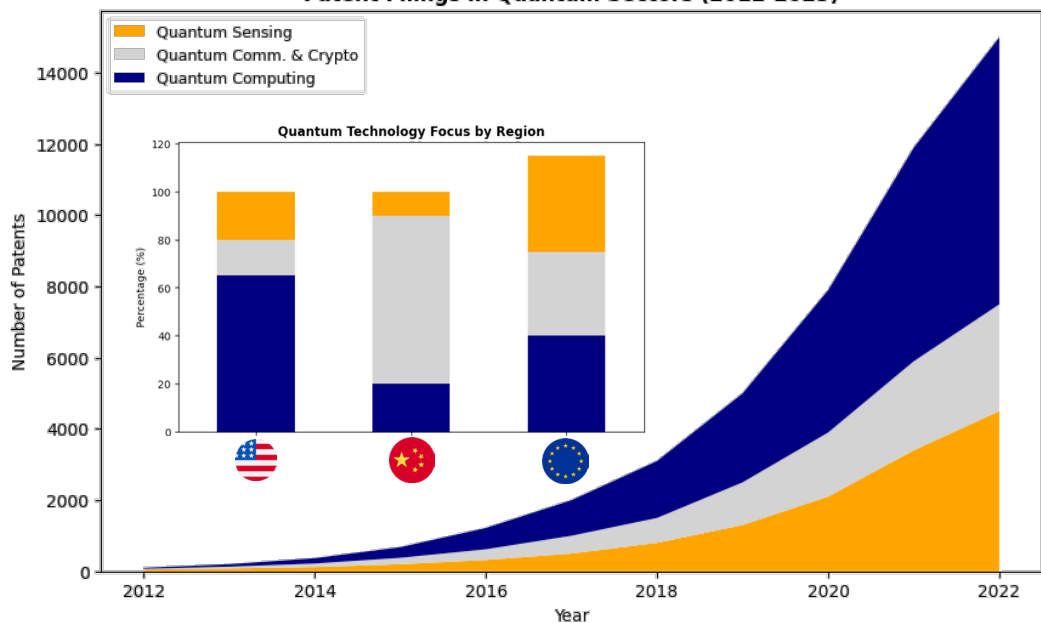
Global technology progress





Quantum analysis patents

Patent Filings in Quantum Sectors (2012-2023)

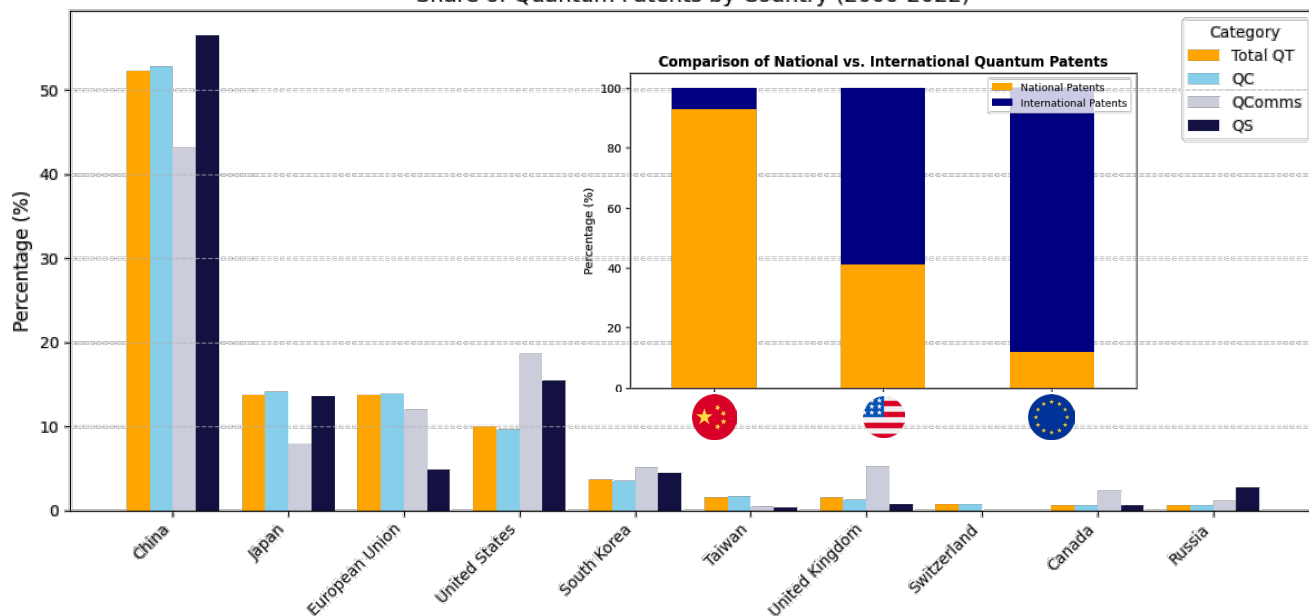


The patent landscape in quantum technologies highlights **significant advancements** over the past decade. The graph on the left showcases a **steady increase** in patent filings across key quantum sectors: **Quantum Sensing, Quantum Communication & Cryptography, and Quantum Computing**. This reflects the **growing global interest** in translating quantum research into commercial products:

- **35% annual increase in Quantum patents** between 2016 and 2021, with **50% growth in Quantum computing**.
- **Quantum Computing** has experienced the most significant expansion, driven by companies like **IBM, Google, Microsoft, and emerging startups in the U.S. and Europe**.
- **Quantum Sensing** continues steady growth, with key applications in **biomedicine, navigation, and advanced materials**.
- **Quantum Communication & Cryptography** has seen a notable increase due to investments in **Quantum networks and post-quantum security**, led by **China and Europe**.

The graph clearly shows a **sustained growth trend**, indicating that Quantum innovation is rapidly transitioning **from research to commercial applications**.

Share of Quantum Patents by Country (2000-2022)



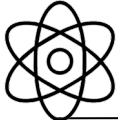
The chart emphasizes the **dominance of Chinese companies**, which account for **52,3% of QT patents filed between 2000 and 2022**, driven by **strong government policies supporting R&D**.

Japan and the EU follow with **13,8% each**, while the **U.S. holds 10%**. However, if we consider **only international patent families**, the landscape shifts:

- **The U.S. leads with 48%** of international patents.
- **Europe follows with 22%**.
- **China drops to 11%**, indicating a focus on domestic protection rather than global expansion.
- **Stronger patent strategies** are shaping global Quantum leadership, with increasing investments in **IP protection and commercialization**.

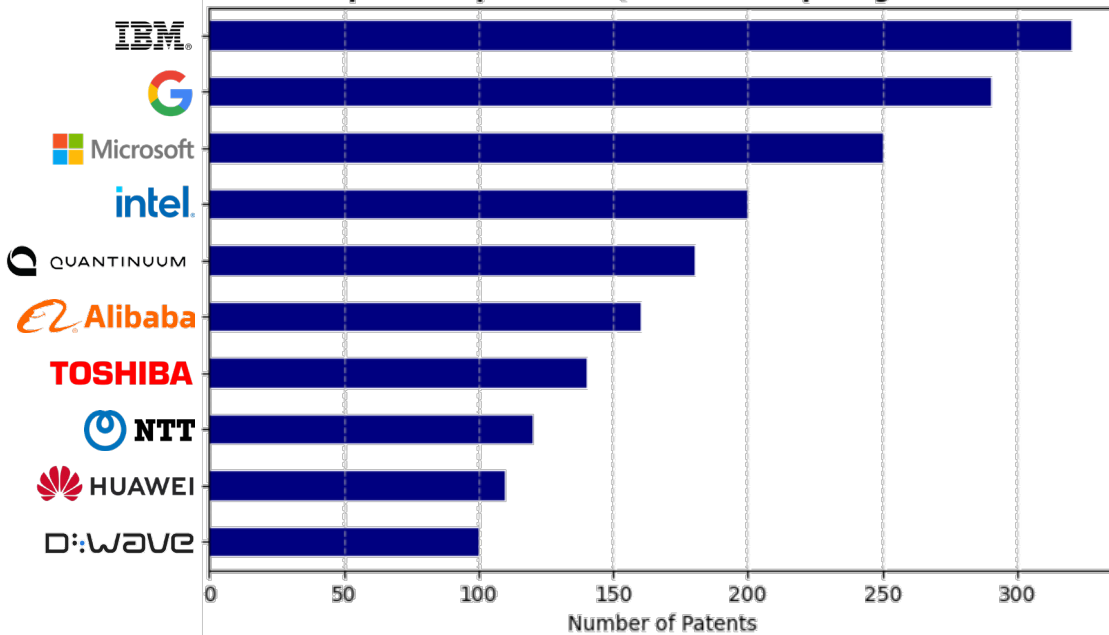
Quantum patents signal a maturing industry, with quantum computing driving the next wave of technological breakthroughs.





Quantum analysis patents

Top 10 Companies in Quantum Computing Patents

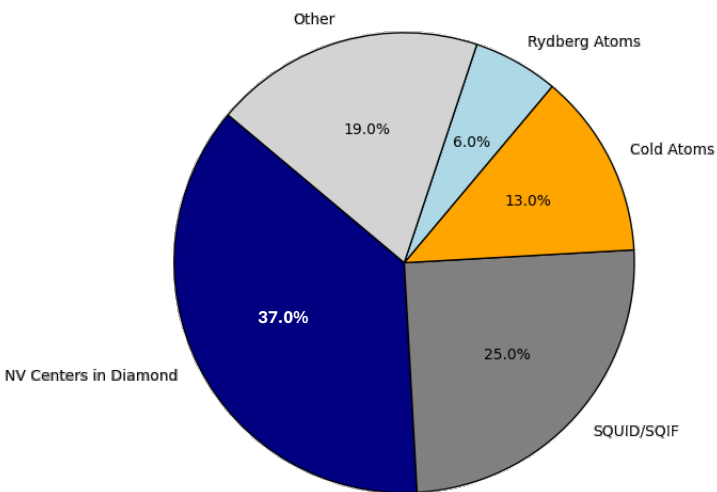


The Quantum computing patent landscape is dominated by a few key players, with IBM, Google, and Microsoft leading the race. These companies have consistently invested in Quantum research, filing hundreds of patents that shape the future of the industry. Intel, Quantinuum, and Alibaba follow closely, demonstrating a growing interest from both Western and Asian markets.

- **IBM leads global patent filings**, leveraging its advancements in superconducting qubits and cloud-based quantum computing.
- **Google and Microsoft focus on fault-tolerant quantum computing**, with breakthroughs in Quantum error correction and hybrid architectures.
- **Intel and Quantinuum expand hardware and software capabilities**, reinforcing their position in quantum development.
- **Asian companies (Alibaba, Huawei, Toshiba, NTT)** are increasingly active, securing patents in quantum algorithms, security, and chip design.

Key takeaway: Quantum computing is consolidating around key players shaping the industry through aggressive patent strategies. U.S. and Chinese firms dominate the global race, while Europe seeks to stay competitive.

Quantum Sensing Patent Distribution by Technology



Key Insights on Quantum Sensing Patents

- **NVCD (37%)** dominate, driving advances in magnetometry, biomedical imaging, and quantum communication.
- **SQUID/SQIF (25%)** are crucial for ultra-sensitive magnetic detection, used in MRI and geophysics.
- **Cold atoms (13%)** support quantum inertial navigation and fundamental physics.
- **Rydberg atoms (6%)** are emerging in Quantum metrology and electric field sensing.
- **Other technologies (19%)** include hybrid and photonic-based sensors.

Export Control:

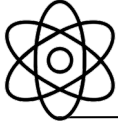
Ongoing discussions on Quantum technology export restrictions could impact trade, talent acquisition, and startup investments, especially for SMEs. The European Quantum Industry Consortium seeks to shape regulations and best practices.

Road to 2035:

Europe must strengthen its position in IP and patents:

- Collaboration with the EPO aims to improve patentability and train startups.
- **Standard Essential Patents** are monitored to prevent access barriers.
- **European firms hold only 31% of quantum patents in Europe**, while the U.S. dominates with 52%, posing a strategic risk.
- Increasing patent filings in key areas is crucial for Europe's long-term Quantum competitiveness.





Quantum analysis patents (text maning analysis)

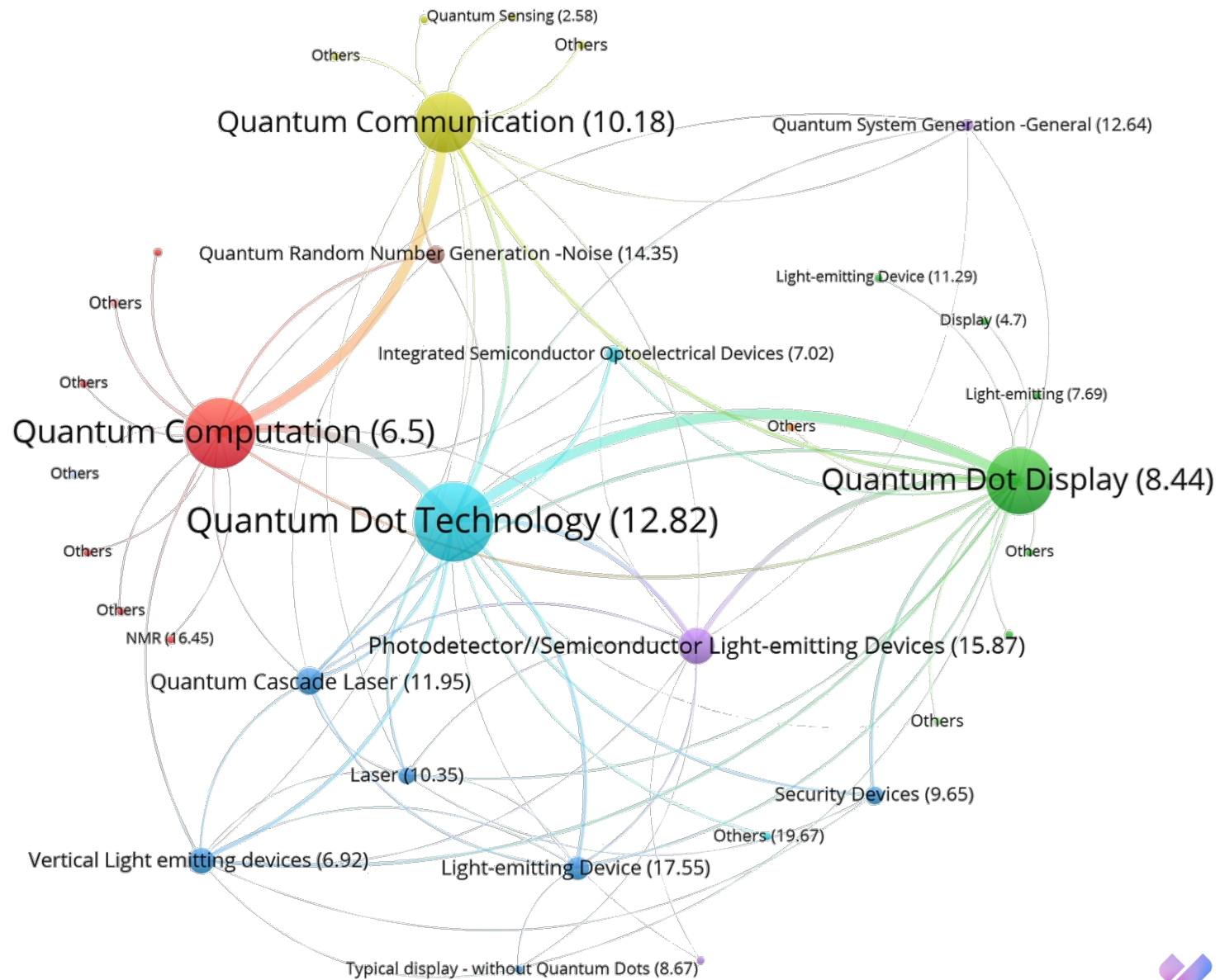
The figure provided illustrates a network analysis of patent activity in the field of QT, highlighting significant technological clusters and their interconnections through citation relationships. The visualization clearly identifies four major patent clusters, which dominate the quantum innovation landscape:

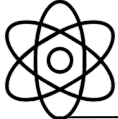
- **Quantum Dot Technology (12,82%):** Central node connecting multiple quantum fields, with applications from efficient LEDs to advanced quantum computing using coherence and entanglement.
- **Quantum Communication (10,18%):** Involves advanced cryptographic systems, quantum key distribution, and teleportation for secure data transmission.
- **Quantum Computation (6,5%):** Young, rapidly growing field characterized by high innovation, complexity, and potential for transformative computing breakthroughs.
- **Quantum Dot Display (8,44%):** Closely tied to Quantum Dot Technology, showing strong market potential in next-generation high-performance displays.

Patents are interconnected by citations, indicating knowledge spillovers, with universities like the University of California and MIT bridging technological clusters and industry (Samsung, D-Wave, Toshiba).

The analysis suggests that patent activity reflects both technological maturity and market potential. Quantum Dot Display appears commercially viable, while Quantum Computation sees intense competition, particularly among global players, including U.S. defense agencies. This highlights quantum computation’s strategic role in security and defense.

The patent network reveals regional disparities: North America (IBM, D-Wave) leads second quantum revolution patents (computation, communication), while Asia (Samsung, Toshiba, Panasonic) dominates first revolution applications (Quantum Dots, displays). This reflects differences in national priorities, industrial strengths, and technological investments.





Quantum analysis patents in Spain

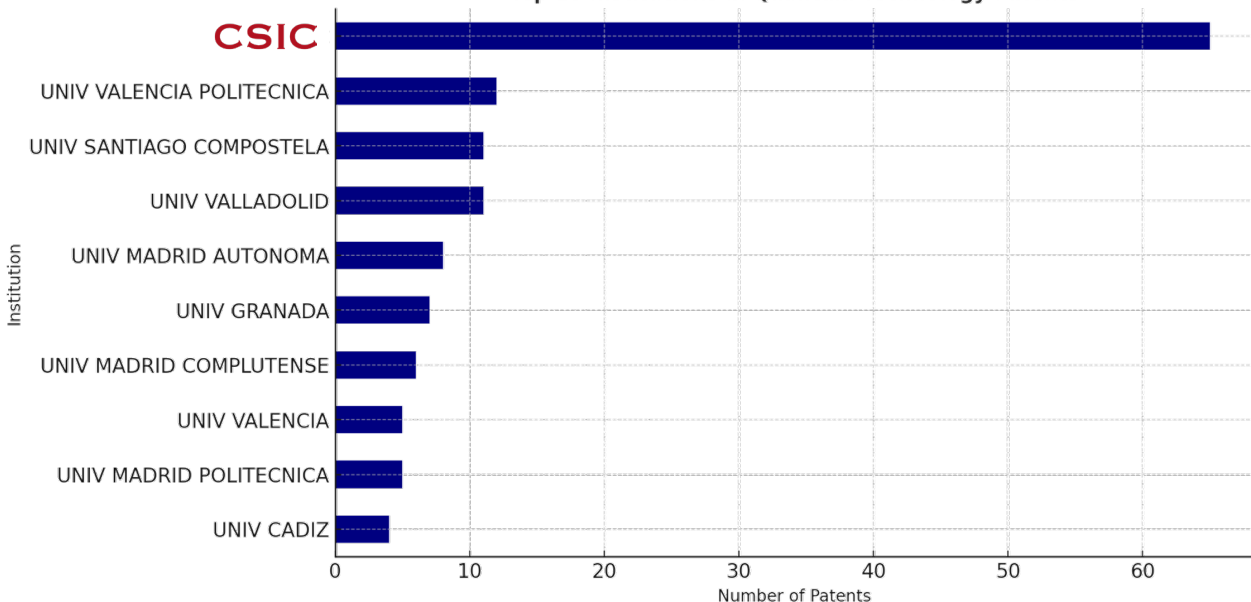
Main Insights on Quantum Patents in Spain

The landscape of quantum technology patents in Spain has shown steady growth over the years, with a peak between 2012 and 2015. The majority of patents are in **quantum sensing**, followed by **quantum communication & cryptography** and **quantum computing**.

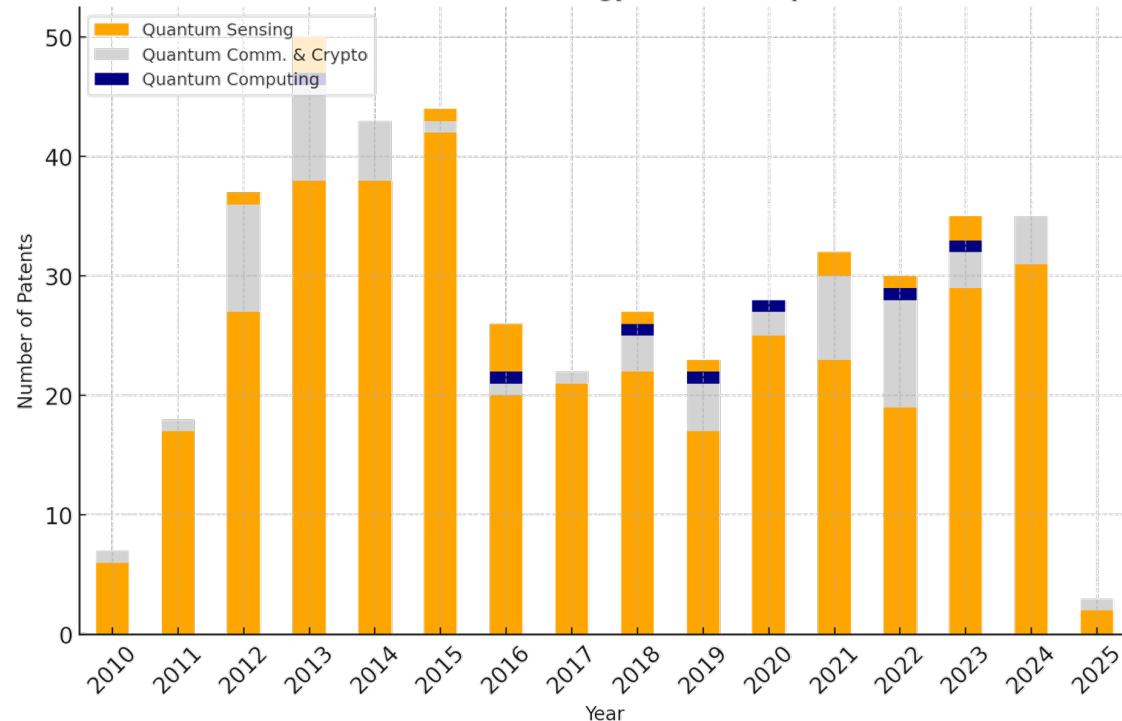
- **Quantum sensing** leads in patent filings, reflecting Spain's strong research base in metrology and precision measurement applications.
- **Quantum communication & cryptography** has seen increasing interest, aligning with global efforts in secure quantum networks.
- **Quantum computing** patents remain a smaller fraction, yet growing, as Spain contributes to global advancements in superconducting qubits and quantum algorithms.

Despite fluctuations, recent years show a renewed interest in quantum technology patents, suggesting an ongoing commitment to research and innovation in the field.

Top 10 Institutions in Quantum Technology Patents



Evolution of Quantum Technology Patents in Spain (2010-2025)



Top Patent Holders in Spain

An analysis of patent applicants reveals that **CSIC** is the dominant institution in Spain's QT patents. Other leading contributors include major universities such as **UPV, USC, and UVa**.

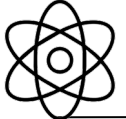
- CSIC's leadership highlights its pivotal role in national research and technology transfer.
- Universities are key players, showcasing Spain's strong academic involvement in quantum sciences.
- Unlike the global trend, corporate involvement remains limited, with patents largely concentrated in the public research sector.

Spain's innovation is academia-driven, with potential for greater industry involvement to commercialize research.



Quantum
technology
startups &
investment
landscape





Quantum technology companies analysis (statistics review)

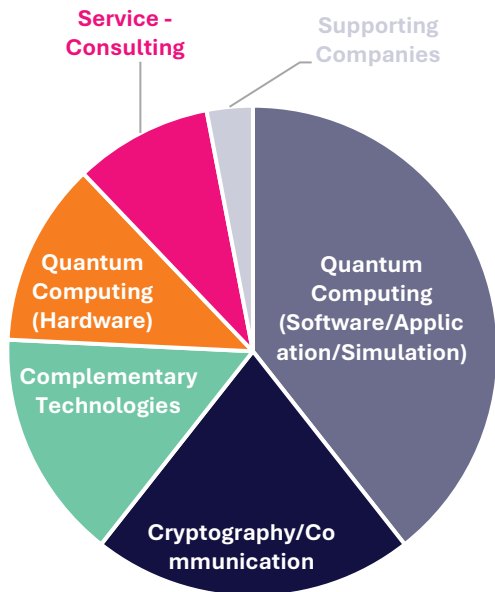


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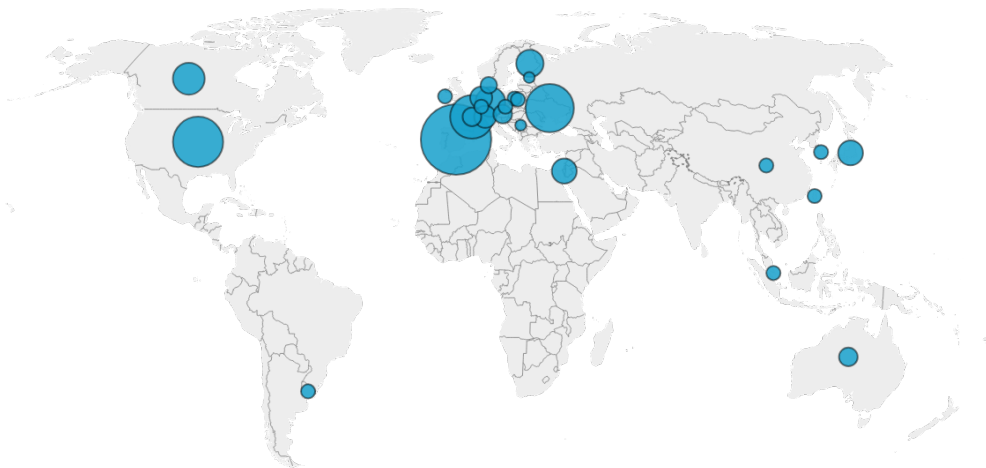
Detected companies

27

Venture Capital

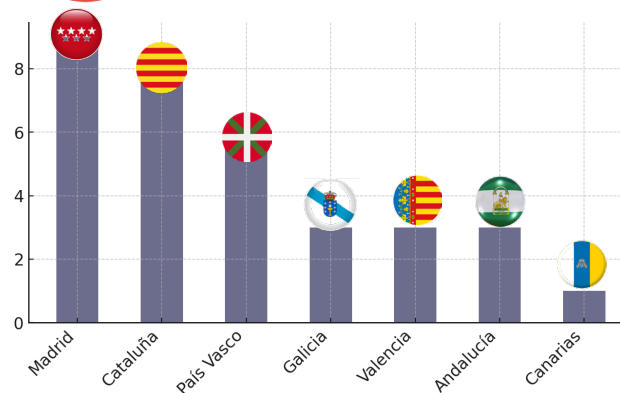


Geographical distribution of analyzed companies



33

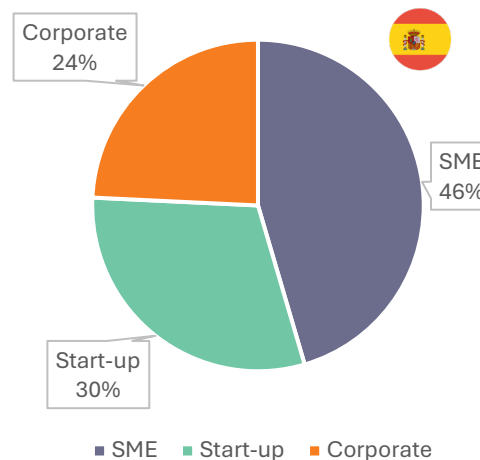
Detected Spanish companies

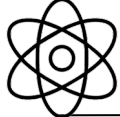


A total of 33 Spanish companies have been analyzed: 11 are located in Madrid (35%), 8 in Catalonia (24%), 6 in the Basque Country (18%), 3 in Galicia, Valencia and Andalusia, and 1 the Canary Islands.

Type companies analyzed: 46% are SMEs, meaning businesses with up to 300 employees. Another 30% are startups, mostly spin-offs from research centers or universities, founded after 2017 and/or with fewer than 150 employees.

Of the 13 Spanish companies developing Software/Applications, 6 (over 50%) apply it to FinTech. Additionally, all but one of the software-focused companies are SMEs or startups. In contrast, 4 out of the 7 Spanish companies dedicated to hardware are large enterprises.





Quantum technology companies analysis (Detected and analyzed company ecosystem)



Quantum Hardware (1/2)

Superconducting Circuits

ALICE & BOB IQM bleximo ILMANJARO ATLANTIC QUANTUM SPINQ Nord Quantique

BLUE FORS seeqc QCI QUANTWARE 本源量子 OXFORD INSTRUMENTS

CELESTIA | TTI IBM Quantum QUANTROL OX Lytid rigetti ANYON | EeroQ Zurich Instruments

Diamonds

QUANTUM BRILLIANCE DUST IDENTITY SBOQuantum

elements six™ NVISION DE BEERS GROUP LIGHTSYNQ

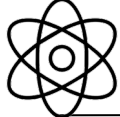
Photonic Quantum Computing

cea leti ORCA Computing BraneCell Optalysys CSIC g2-Zero VLG PHOTONICS iPRONICS photonic QBLOX XANADU Infleqtion QUANTUM SOURCE aegiq weling

QUANDELA Q.ANT SCINTIL Photonics Orange Quantum Systems DAS Photonics PsiQuantum QUIX QUANTUM

QUANTOPTICON LIGEN TEC Sparrow Quantum Pixel Photonics Advanced Fusion Technology Co., Ltd. PHASE SPACE COMPUTING Quside KETS





Quantum technology companies analysis (Detected and analyzed company ecosystem)



Quantum Hardware (2/2)

Neutral atoms



PASQAL



Trapped ions



Silicon, Carbon, & Helium



Quantum Software & Algorithms (1/2)

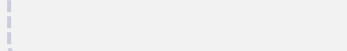
Developer & Tools | Machine learning & AI

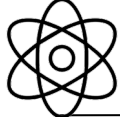


Cryptography/Communication



Q. Sensing

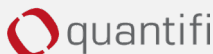




Quantum Software & Algorithms (2/2)



Algorithm development

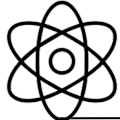


Interface & Error correction | Simulation & Modeling



Simulation solutions for quantum devices





Quantum Applications



Chemical & materials simulation

QU & CO
 NANO GAP
 LEIDEN CRYOGENICS BV
Leader in Low Temperature Techniques
 GOOD CHEMISTRY COMPANY
 QSIMULATE
 HQS QUANTUM SIMULATIONS
 BOSONQ PSI
 QUNASY
 Quemix



Drug discovery

Qubit PHARMACEUTICALS
 rahko
 KUANO
 APEXQUBIT
 ProteinQure Librarian
 QUNOVA COMPUTING
 kvantify
 CSIC
 Nanological
 menten.AI
 POLARIS qb
 algorithmiq



Fintech

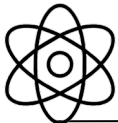
JoS QUANTUM
 CQC CAMBRIDGE QUANTUM COMPUTING
 BBVA Data & Analytics
 QDT QUANTUM DATA TECHNOLOGIES
 QUANTFI



Optimization & Logistics

D:wave The Quantum Computing Company™
 KIPU QUANTUM
 Entropica Labs
 SolidStateAI
 SAVANT X
 LightSolver
 ayesa
 QUBIT ENGINEERING





Quantum technology companies analysis (Detected and analyzed company ecosystem)

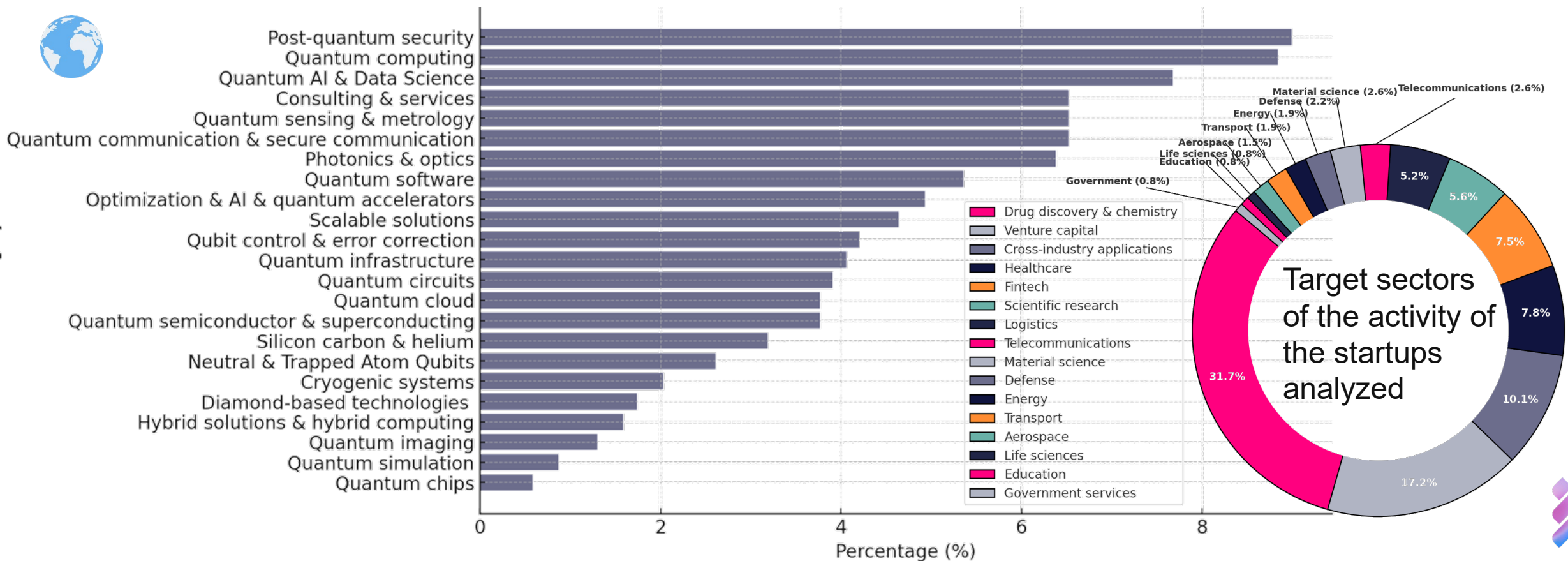
This analysis is based on a **database of companies and startups** in quantum technologies and related fields. The first step involved a **detailed study of their activity descriptions**, extracting **keywords (Tags)** that reflect the technologies, approaches, and solutions each company develops.

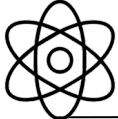
Next, the **frequency of each term** in the "Tags" column was quantified. To improve accuracy, an **advanced normalization process** was applied, grouping similar terms and unifying variations to avoid redundancies.

After normalization, the terms were classified into **technological categories**, grouping related concepts based on their applications or underlying principles. These categories help structure the data and highlight key technological trends.

A **graphical representation** was then created, showing the **most frequent categories** as a **percentage of total occurrences**.

This study provides a **quantitative overview of the key topics** emerging in the business landscape, identifying **leading innovation areas** and detecting **emerging trends** in the quantum industry and its technological ecosystem.





Quantum technology companies analysis (Analysis of Trends in Quantum Companies)

Key Quantum Technologies

The analysis of quantum companies and startups reveals key technological patterns that define their areas of focus.

- **Most relevant technologies and their impact**

The distribution of technological categories shows that many companies are working on **quantum computing, post-quantum security, and quantum artificial intelligence**. Post-quantum security is the most frequent category, which makes sense considering the urgency to develop **cryptographic solutions resistant to quantum computing advancements**. Companies are anticipating a scenario where current encryption algorithms could become vulnerable, which explains the strong focus on **post-quantum cryptography and advanced cybersecurity applications**.

On the other hand, the significant presence of **quantum computing and its infrastructure** confirms that many companies are dedicated to **developing quantum hardware and software**, tackling challenges such as **scalability and error correction**. The emergence of technologies like **superconducting circuits, modular architectures, and hybrid solutions** indicates that the industry is seeking commercial viability and greater stability in quantum systems.

Another key area is the role of **artificial intelligence applied to quantum computing**, which appears not only as a strong category but also as a crucial factor in application development. **Quantum Machine Learning (QML)** has great potential in areas where traditional AI models are limited, such as **complex optimization and large-scale data analysis**.

Additionally, technologies such as **quantum sensing and quantum optics** show significant representation, suggesting an active market for applications in metrology, quantum imaging, and telecommunications. **This opens opportunities in sectors that depend on extreme precision measurements, such as biomedicine, space exploration, and material detection.**

Key Quantum Sectors

Strategic sectors where these companies are focusing their efforts have been identified.

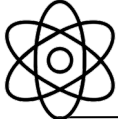
- **Sectors most affected by Quantum Technology**

The analysis of the target sectors for quantum startups makes it clear that **biotechnology and chemistry are top priorities**. The **"Drug Discovery & Chemistry"** category leads with 31.1%, confirming that **quantum simulation of molecules and chemical reactions** is one of the most promising applications. This makes sense, as quantum computing can **accelerate the identification of new drugs and advanced materials**, significantly reducing the time and cost of development in the pharmaceutical industry.

Another highly represented sector is **"Venture Capital"**, reflecting strong investor interest in quantum technologies. The industry is still in a development phase where the commercial viability of many technologies remains unproven, but **the high level of startup funding suggests strong expectations for disruption across multiple sectors**.

The notable presence of sectors like **"Cross-Industry Applications," "Healthcare," "Scientific Research," and "Logistics"** suggests that quantum computing is not confined to a single niche but has **cross-sector demand**. **From optimizing logistics networks to enhancing biomedical detection, the potential applications of these technologies are expanding across various industries.**





Quantum technology companies analysis (Analysis of Trends in Quantum Companies)

✔ Most active and developed technologies:

- **Quantum computing and post-quantum security:** Hardware based on **superconductors, error correction, and post-quantum cryptography.**
- **Quantum sensing & metrology:** Quantum sensors for biomedical, geological, and security applications.
- **Quantum AI & Data Science:** Machine learning applications in quantum environments, advanced optimization, and big data analysis.

🚀 Emerging technologies with growth potential:

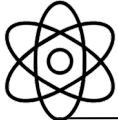
- **Quantum networking and secure communication:** Development of **quantum memories, quantum interconnects, and secure data transmission.**
- **Hybrid quantum computing:** Integration of quantum-classical systems to improve computational performance in the near term.
- **Quantum simulation for drug and material discovery:** More companies are investing in **using quantum computing to accelerate research in advanced materials, batteries, and new pharmaceuticals.**

Where Is the Quantum Industry Heading?

The quantum ecosystem is advancing **on multiple fronts simultaneously**. On one side, there is a **clear effort in quantum infrastructure, error correction, and software** to make quantum computing more accessible. At the same time, **more immediate applications, such as post-quantum security and material simulation, are already attracting strong investment and commercial activity.**

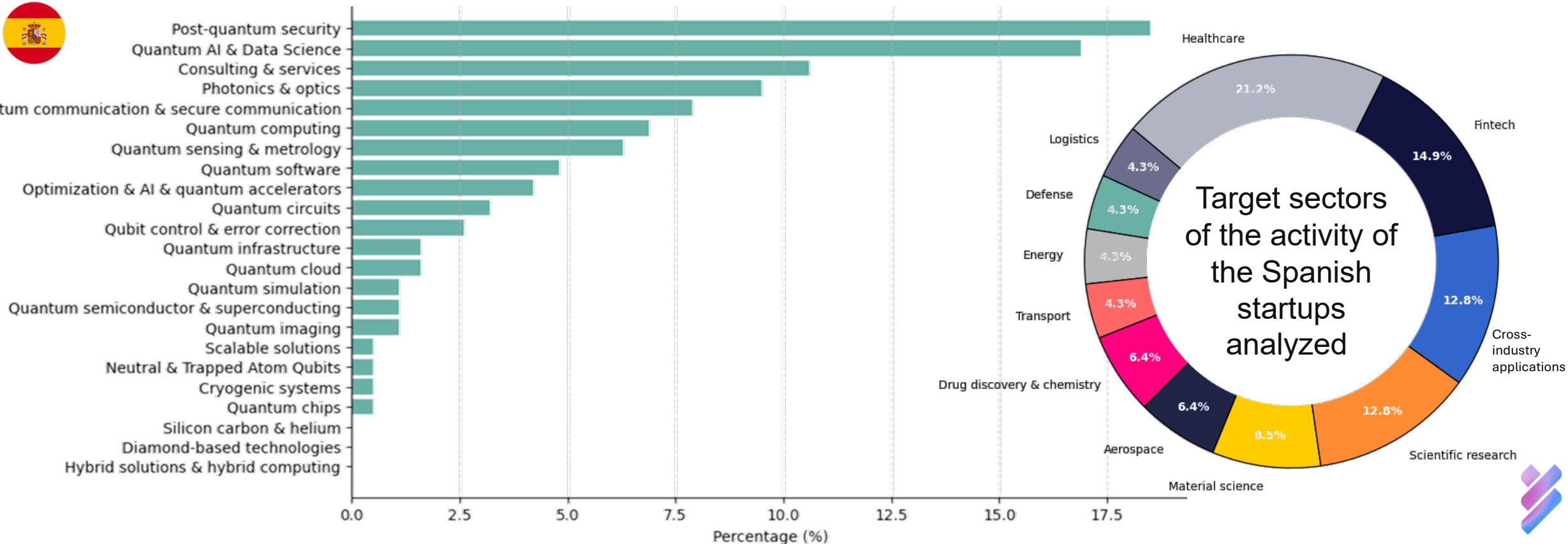
Although technical challenges remain, the increasing **diversification in application sectors** suggests that **quantum technology is transitioning from research to industrial adoption**. In the coming years, we could see a rise in commercial applications, especially in fields like **computational chemistry, industrial optimization, and secure communications.**

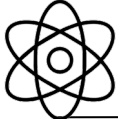




Quantum technology companies analysis (Comparison of the Global vs. Spanish Quantum Ecosystem)

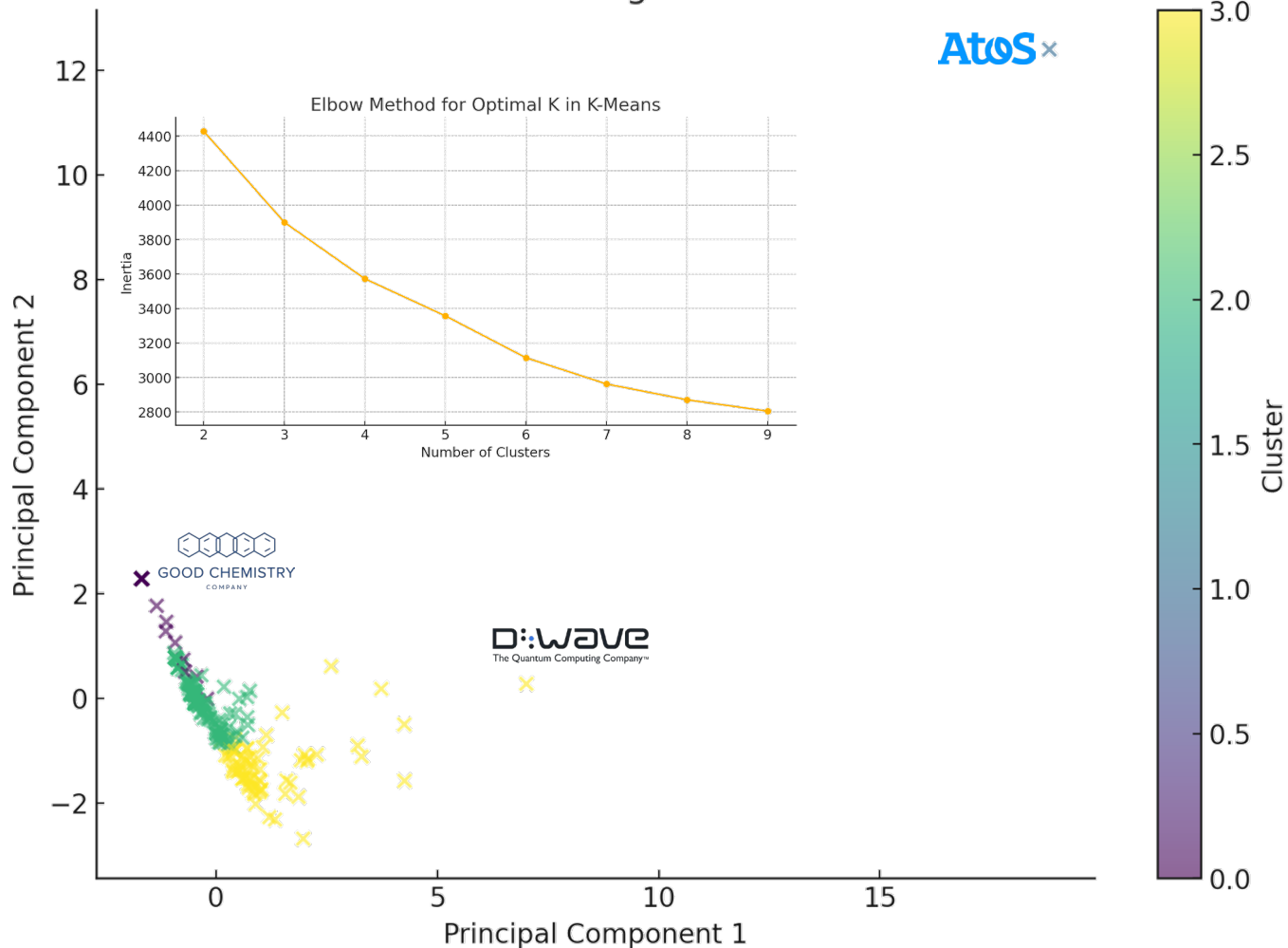
The analysis of the quantum ecosystem in Spain aligns with global trends, highlighting **post-quantum security, quantum AI, and quantum communication** as key areas. However, there are differences in technological and sectoral priorities. In Spain, the focus on **Quantum AI & Data Science** is more pronounced, suggesting greater interest in **data analysis and optimization** applications. **Photonics & Optics** and **Quantum Communication** also have a strong presence, likely driven by specialized research centers. In contrast, **Quantum Computing and Quantum Simulation** have a lower relative weight, indicating less activity in quantum hardware and a greater emphasis on software and industrial applications. At the sectoral level, **Healthcare (21.2%)** leads in Spain, whereas the global analysis prioritized **Drug Discovery & Chemistry**. This suggests that Spain is more focused on **digital health and diagnostics**, while globally, there is greater interest in **chemical and pharmaceutical simulations**. Additionally, **Scientific Research and Material Science** are well-represented in Spain, reinforcing strong ties to academia and R&D centers. The lower presence of **Venture Capital** suggests less private investment compared to other countries, potentially slowing the commercialization of quantum technologies. However, the strong presence of **Cross-Industry Applications and Quantum Communication** indicates that Spain is focusing on **logistics, telecommunications, and healthcare**, leveraging its research strengths to drive innovation with industrial impact.





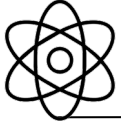
Quantum technology companies analysis (Clustering pattern analysis)

K-Means Clustering Visualization



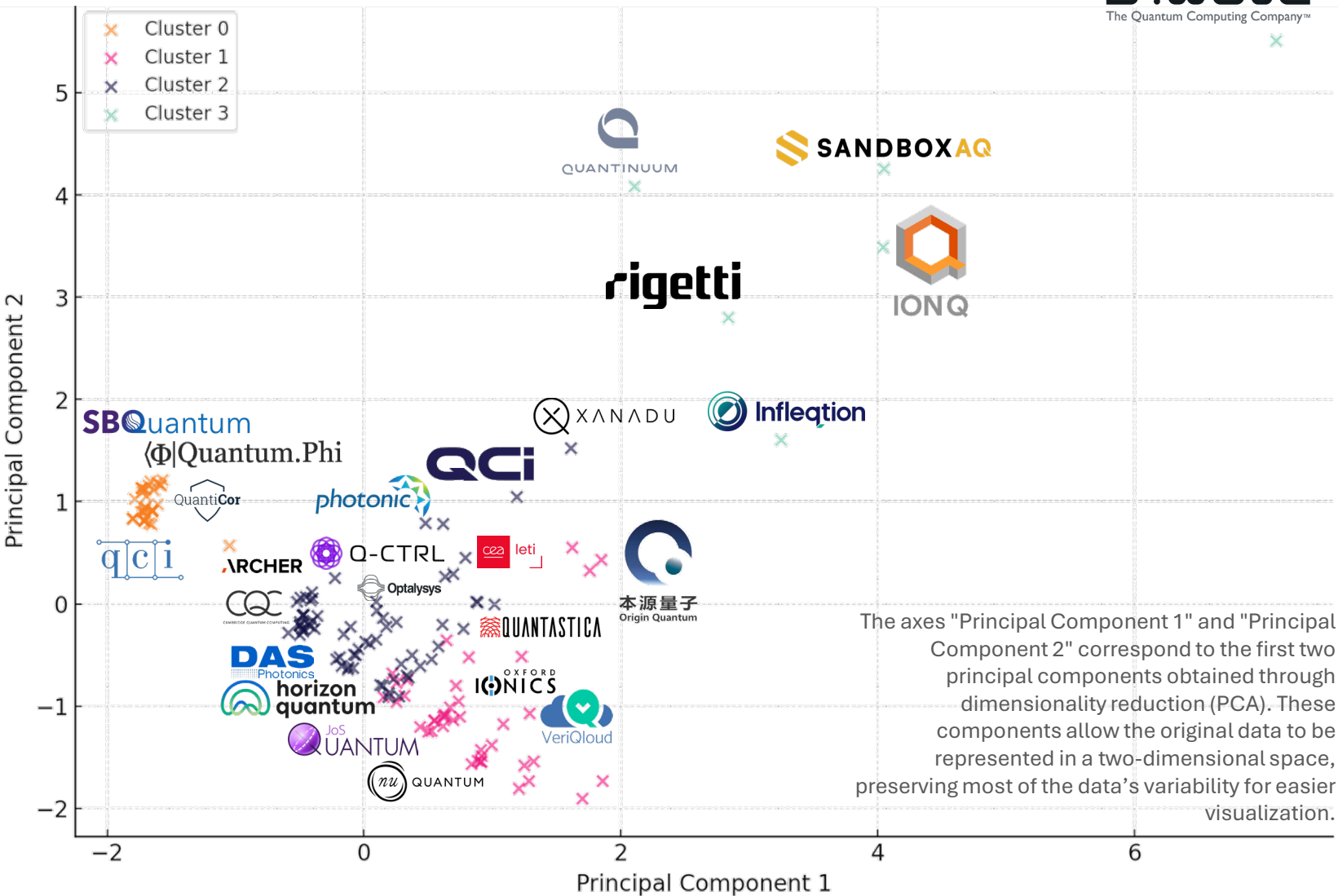
To analyze the quantum technology business ecosystem at both national and international levels, data from 182 companies and 27 venture capital firms specializing in this technology have been collected. The study aims **to identify emerging trends**, detect development **and innovation opportunities** in the **productive system**, and **highlight research areas** that require greater support. Various data processing and analysis techniques have been applied, including data cleaning and standardization, categorical variable encoding, and the use of **clustering algorithms** such as **K-Means** and **hierarchical clustering** to group companies with similar characteristics. The cluster evaluation was conducted using the elbow method and silhouette score to determine the optimal number of groups, complemented by Principal Component Analysis (PCA) for better visualization. Additionally, the regional distribution of companies in Spain was analyzed, identifying technological specializations in autonomous communities such as quantum photonics in the Basque Country and quantum optimization in Catalonia. On a global scale, the development of the quantum industry in Europe, America, and Asia-Oceania was compared, highlighting specialization areas such as quantum security in Switzerland and quantum hardware in the United States. This analysis aims to provide a clearer understanding of the current **quantum ecosystem**, enabling insights into **company positioning**, areas of specialization, and **investment and innovation** opportunities.





Quantum technology companies analysis (Clustering pattern analysis)

K-Means Clustering Visualization



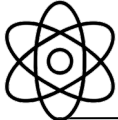
The axes "Principal Component 1" and "Principal Component 2" correspond to the first two principal components obtained through dimensionality reduction (PCA). These components allow the original data to be represented in a two-dimensional space, preserving most of the data's variability for easier visualization.

Clustering Analysis

The clustering analysis using the K-Means algorithm has identified four distinct groups of companies based on factors such as operational status, funding received, number of investors, and registered patents. The application of Principal Component Analysis (PCA) has facilitated the visualization of these groups, revealing significant patterns in their distribution.

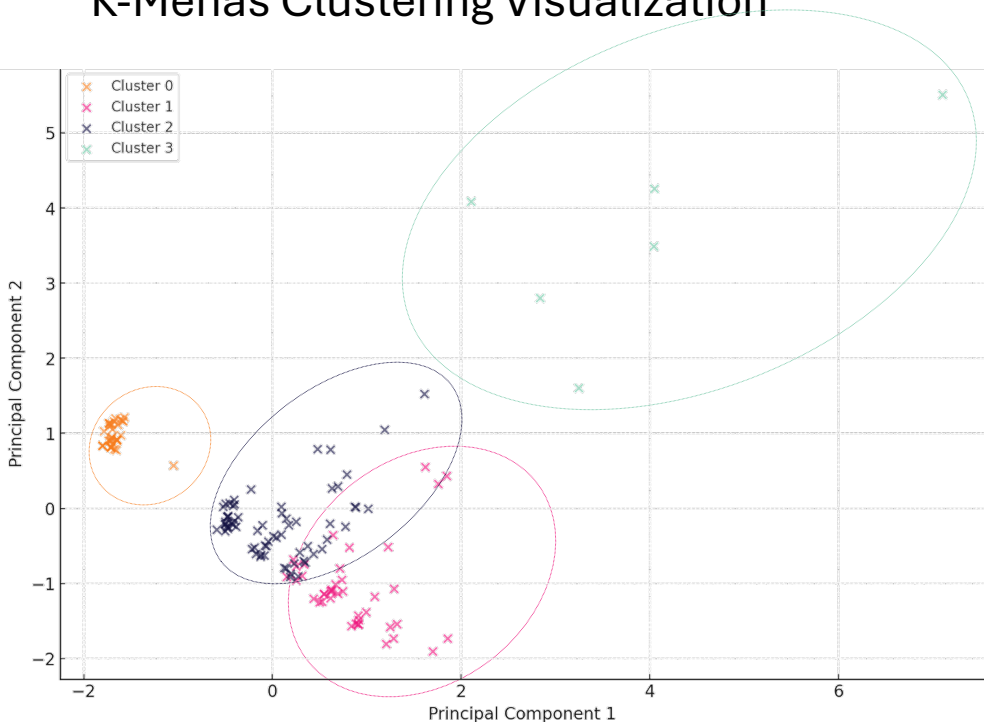
ATOS stands out in its cluster with exceptionally high values in key metrics: total funding of \$2.054M, 451 granted patents (well above the cluster average), and IT spending of \$1,970M. These extreme values suggest that ATOS operates on a much larger scale and has significantly greater resources than its peers, explaining its unique position in the clustering analysis. The analysis is conducted again, removing this outlier to better observe the patterns of the rest of the business ecosystem.





Quantum technology companies analysis (Clustering pattern analysis)

K-Menas Clustering Visualization



Identified Patterns

- There is a clear progression from emerging companies (**Cluster 0**) to industry leaders (**Cluster 3**), marked by the **number of patents, IT investment, and funding levels**.
- Software and algorithm-based companies (**Cluster 0** and **Cluster 1**) tend to require less initial investment compared to hardware-based companies (**Cluster 2** and **Cluster 3**), explaining their lower funding levels.
- **Cluster 3** exhibits a high degree of dispersion, suggesting that while companies in this group share leadership in the sector, they have different technological approaches.

QuantumTech follows a maturation cycle, where startups begin with software, advance into specialized hardware, and consolidate with funding and patents. Disruptive technologies require high investment and long development before widespread adoption.

Clustering Analysis

The clustering analysis of *QuantumTech* companies has identified four distinct clusters, each with common characteristics that reflect differences in their innovative activity, funding, and technological focus.

Cluster 0: Emerging companies with low investment levels.

- Companies primarily focused on **software and quantum computing applications**.
- Low number of patents and lower R&D investment.
- Mostly early-stage startups with growth potential but without strong financial backing.

Cluster 1: Companies specialized in applied quantum technologies.

- Greater presence of companies working on **specific areas of quantum computing**, such as algorithms and optimization.
- Moderate funding and patent levels, indicating they are in an expansion and consolidation phase.
- Many of these companies are developing technologies with practical applications in sectors like cryptography, simulation, and optimization.

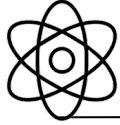
Cluster 2: Companies more advanced in quantum hardware.

- Companies with a higher number of **granted patents** and increased R&D investment.
- Mainly working on **superconducting circuits, trapped ions, and other advanced quantum infrastructures**.
- Strong financial backing, suggesting significant investments or development contracts.

Cluster 3: Highly established companies leading the industry.

- Companies with the **highest funding, most patents, and high IT spending**.
- Includes firms like **D-Wave, SandboxAQ, Quantinuum, IONQ, and Rigetti Computing**, which are leaders in quantum computing with commercial products and corporate partnerships.
- Their separation in feature space suggests they have reached a level of maturity and technological differentiation that sets them apart from the rest.





Quantum technology companies analysis (Clustering pattern analysis)

Cluster 0. Emerging Companies in Quantum Software and Photonics

This cluster includes young companies with **low investment and few patents**. These companies focus on developing **early applications of quantum computing and quantum photonics technologies**, exploring use cases in **simulation, optimization, and basic software applications**.

This group of companies specializes in **quantum software, silicon-based quantum hardware, photonic quantum computing, and complementary technologies** such as **Terahertz and infrared quantum technologies**.



Evolution Pattern in the QuantumTech Industry

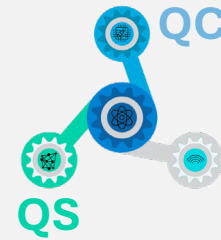
The results show a **maturation cycle in the sector**, where **emerging companies** start with **quantum software and photonics (Cluster 0)**, evolve into **more specialized applications in optimization and data analysis (Cluster 1)**, advance into **quantum hardware and simulators (Cluster 2)**, and finally reach a level of **technological consolidation with complete commercial solutions (Cluster 3)**.

This analysis reflects how different **areas of innovation are distributed along the industry's development process**, with **software and optimization dominating the early stages**, while **hardware and fully developed platforms characterize more established companies**.

Cluster 2. Developers of Quantum Hardware and Simulators

The companies in this group show **higher investment and technological development focused on quantum hardware**. These companies are building **platforms for quantum simulation, hybrid infrastructures, and advanced quantum hardware systems**.

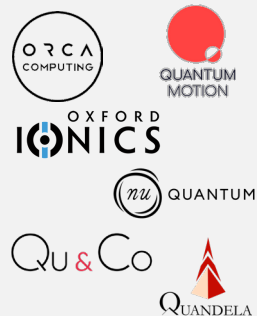
Many of these companies are in a **consolidation phase** and seek to offer **industrial solutions by integrating quantum simulators and technological services**. The companies in this **cluster** are primarily focused on **quantum hardware**.



Cluster 1. Specialists in Optimization and Applied Quantum Software

The companies in this group have a **more specialized approach to quantum software**, with practical applications in various industries. Many of these companies work on **quantum optimization** for sectors such as **pharmaceuticals (drug discovery), data analysis, and solving computational problems**.

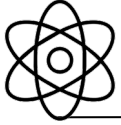
This cluster represents an **intermediate step between emerging companies and those with greater technological consolidation**.



Cluster 3. Industry Leaders with Advanced Technologies

This cluster includes well-established companies **with the highest R&D investment and intellectual property, driving innovation in the quantum sector**. They have successfully **commercialized mature quantum technologies** and built **strategic alliances** with major corporations and research institutions, **reinforcing their industry leadership**. **Cluster 3 specializes in superconducting and trapped-ion quantum hardware, with a strong presence in quantum sensing and cryptography**. Their **scalable solutions ensure long-term advancements in quantum computing and secure communications**.





Quantum technology companies analysis (Clustering pattern analysis)

Key Trends and Innovations in the Quantum Business Ecosystem

The development of quantum technologies is driving innovation across multiple industries. The main emerging trends include:

1. Quantum Computing and Simulation

Quantum computing is at the core of the ecosystem, enabling complex simulations, industrial optimization, and advanced analytics in fields like chemistry, pharmaceuticals, and finance. Companies like Cambridge Quantum Computing lead in quantum algorithms for simulation and cryptography.

2. Quantum Artificial Intelligence (AI)

The integration of AI with quantum computing is accelerating machine learning and real-time data processing, with applications in pattern recognition and optimization.

3. Photonic Technologies and Hybrid Systems

Photonic quantum computing, which uses light particles (photons) to process and transmit information, is advancing. Companies like Quandela are developing hybrid systems that blend quantum and classical computing.

4. Applications in Chemistry and Materials Science

Quantum simulations are revolutionizing molecular modeling, expediting drug discovery and the development of advanced materials. Companies like HQS Quantum Simulations and Phasecraft focus on these areas.

5. Quantum Security and Cryptography

The rise of quantum computing necessitates new security solutions. Post-quantum cryptography and quantum random number generators (e.g., Quside) are crucial for protecting sensitive data.

6. Quantum Optimization and Finance

Quantum algorithms are enhancing investment portfolio optimization, risk management, and fraud detection, improving financial efficiency. Companies like IQM Quantum Computers are leading in this space.

7. Quantum Infrastructure and Accessibility

Cloud-based quantum services are making quantum computing more accessible, reducing the need for costly hardware investments. Companies like IBM and Terra Quantum are pioneering this sector.

Current State of the Ecosystem

The quantum industry includes both mature companies ready for commercialization and early-stage startups focused on research and prototyping. While established firms dominate optimization, cryptography, and infrastructure, emerging startups drive advancements in experimental fields like photonics and quantum chemistry, shaping the future of the sector.

Key Ideas

Emerging Areas: Quantum computing, quantum AI, and simulation dominate the landscape.

Application Focus: Ranging from finance and cybersecurity to chemistry and materials science.

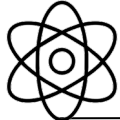
Different Maturity Levels: Established companies ready for the market vs. research-focused startups.

Democratization: Quantum cloud and dedicated infrastructure are making these technologies more accessible.

Potential Impact: Significant transformation in key sectors, with high projected economic value.

This summary highlights the current state and future opportunities in the quantum industry, emphasizing its transformative impact and key areas of innovation.





Quantum technology companies analysis (Geographic distribution pattern analysis)

Leads in **quantum software, optimization algorithms, and cryptography**. A strong ecosystem of major tech players and startups, driven by private and government investment, focuses on **finance, cybersecurity, and machine learning** applications.

North America
(U.S. and Canada)

- **Netherlands:** A key hub for quantum hardware, particularly in **superconducting** and **cryogenic** processors.
- **Germany:** Recognized for its leadership in quantum infrastructure, with applications in **automotive, chemical, and manufacturing** industries.
- **Switzerland:** A leader in quantum security, with companies specializing in quantum **cryptography** and random number generation for banking and telecommunications.
- **United Kingdom:** Excels in quantum software development and quantum **finance**, with applications in **logistics optimization** and **algorithmic trading**.

Europe

Primarily focused on quantum security and **secure telecommunications**, with China leading in **quantum communication** networks, driven by government initiatives. There is also interest in **materials simulation** and quantum **cryptography**.

Asia
(China, Japan, India)

Explores commercial applications in **quantum sensing** and **environmental monitoring**, with technologies aimed at resource management and sustainability.

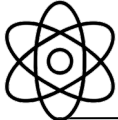
The quantum industry is still in its early stages, with a strong focus on **education** and workforce development. Several pilot projects are being developed in collaboration with universities and research institutions.

Latin America
(Brazil, Mexico)

- **France:** Specializes in quantum software for **pharmaceuticals** and sustainability, with advancements in **drug discovery** and molecular simulations.
- **Spain:** Focuses on quantum technologies for **healthcare**, including **biomedical imaging** and **high-precision sensors**.

Oceania
(Australia)





Quantum technology companies analysis (Patterns of the national ecosystem)

Galicia: The startup ecosystem in Galicia is driving **quantum cloud services** to **democratize access**. The region is positioning itself as a **quantum technology hub** through **CESGA-led initiatives**, including the **Quantum Technologies Hub**, a **Fujitsu partnership** for advanced computing, and **QMIO, Spain's first quantum computer**, supporting research in **medicine, AI, and biotechnology**. Additionally, efforts in **distributed quantum computing** reinforce Galicia's commitment to **accessibility and innovation** in the field.

Cantabria: The analysis of **companies in Cantabria** highlights a focus on **quantum computing for resource optimization and sustainability**. While still developing its quantum ecosystem, the region is exploring applications in **efficient resource management** and **industrial process optimization**. These efforts aim to **enhance energy efficiency** and support sustainable practices, leveraging quantum technology to address environmental challenges.

Basque Country: emerging as a key player in QT, focusing on **quantum algorithm optimization**. Initiatives like **Basque Quantum** and the **Biqain center** (Bizkaia Quantum Advanced Industries) are driving research and development, backed by major tech firms. Euskadi will host the **IBM System One** quantum computer in San Sebastián, enhancing its quantum infrastructure. In Bizkaia, a partnership with **Telefónica and Fujitsu** will install a **Digital Annealer** for complex problem-solving. Companies like **Multiverse Computing** are advancing quantum applications in industry, reinforcing the region's role as a **quantum innovation hub**.

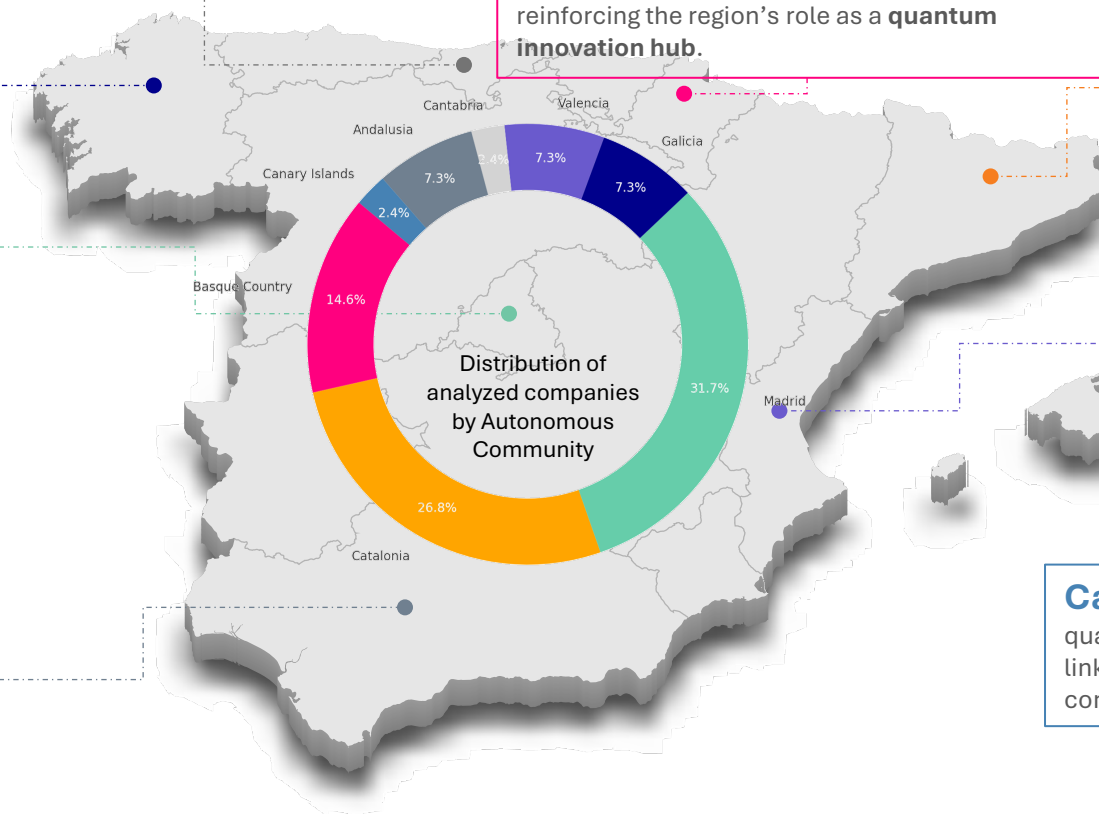
Catalonia: The analysis of companies in Catalonia highlights a strong focus on **quantum computing, optimization algorithms, and photonic technologies** for security and communications. The region is also advancing **quantum artificial intelligence and cloud computing**, aligned with its dynamic tech ecosystem. Catalonia is establishing itself as a **quantum hub**, fostering collaboration to accelerate quantum applications. It is also pioneering **quantum internet security**, integrating **Quantum Key Distribution (QKD) into telecom networks** and developing **analog quantum computers** for industrial solutions. These efforts reinforce Catalonia's leadership in **quantum innovation**.

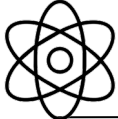
Madrid: The analysis of companies in Madrid highlights a strong focus on **quantum research** and **secure communications**, positioning it as a key hub for **quantum cryptography**. The region is driving initiatives like **MadQCI, a quantum key distribution (QKD) network** enhancing cybersecurity in sectors such as **energy, air traffic control, and fintech**, while integrating into the European quantum infrastructure (EuroQCI). Additionally, the **MADQuantum-CM** project is developing a **quantum-secure network** to strengthen communication resilience, and the recently announced **Quantum Computing Cluster** will foster research and industry adoption. These efforts reinforce Madrid's leadership in **quantum security technologies**.

Andalusia: Andalusia's **business ecosystem** emphasizes **consulting and digital transformation** in **quantum technology**, fostering **R&D and talent attraction**. Initiatives like **Hércules** provide **quantum simulators** to startups and companies, promoting quantum adoption in business.

Valencia: Emerging as a key player in **quantum optimization and cybersecurity**, focusing on **quantum cryptography** and **post-quantum encryption** to counter future cyber threats. The region also explores **quantum computing applications in machine learning and optimization**, reinforcing its role in advancing quantum technologies and cybersecurity solutions.

Canary Islands: An emerging center for quantum cryptography and cybersecurity, linked to data protection in tourism and e-commerce.

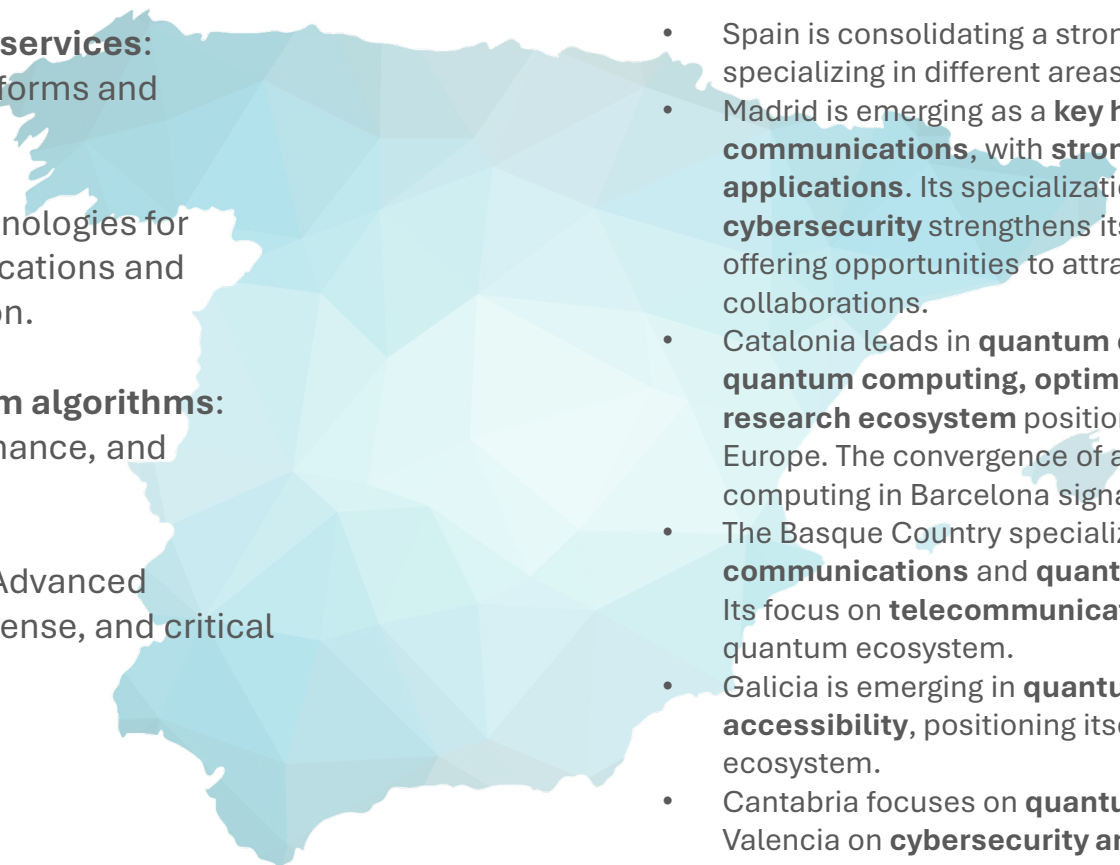




Quantum technology companies analysis (Patterns of the national ecosystem)

Key Trends

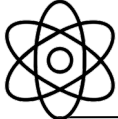
- **Quantum computing and services:** Development of cloud platforms and specialized consulting.
- **Quantum photonics:** Technologies for secure quantum communications and protected data transmission.
- **Optimization and quantum algorithms:** Applications in logistics, finance, and industrial processes.
- **Quantum cybersecurity:** Advanced encryption for banking, defense, and critical sectors.






Key Insights

- Spain is consolidating a strong quantum ecosystem with regions specializing in different areas.
- Madrid is emerging as a **key hub for quantum security and communications**, with **strong support in research and business applications**. Its specialization in **quantum cryptography and cybersecurity** strengthens its role in the European quantum industry, offering opportunities to attract investment and foster strategic collaborations.
- Catalonia leads in **quantum companies in Spain**, focusing on **quantum computing, optimization, and photonics**. Its **startup and research ecosystem** positions it as a key hub for quantum innovation in Europe. The convergence of artificial intelligence and quantum computing in Barcelona signals an emerging trend.
- The Basque Country specializes in **quantum photonics for secure communications** and **quantum algorithm optimization for industry**. Its focus on **telecommunications** strengthens its role in Spain's quantum ecosystem.
- Galicia is emerging in **quantum computing services and cloud accessibility**, positioning itself as a growing player in Spain's quantum ecosystem.
- Cantabria focuses on **quantum optimization and sustainability**, Valencia on **cybersecurity and optimization**, Andalucía on **consulting and digital transformation**, and the Canary Islands on **quantum cryptography and cybersecurity**, shaping a diverse quantum ecosystem in Spain.





Comparison of CSIC research priorities and Startup activity in Q.T.

	 CSIC	 Spain	 Global
Quantum semiconductor & superconducting	28,17	1,06	3,77
Photonics & optics	16,2	9,52	6,38
Quantum sensing & metrology	10,33	6,35	6,52
Quantum computing	9,39	6,88	8,84
Quantum Material & Silicon carbon & helium	7,28	0	3,19
Quantum simulation	7,04	1,06	0,87
Quantum AI & Data Science	5,16	16,93	7,68
Quantum communication & secure communication	3,52	7,94	6,52
Qubit control & error correction	2,82	2,65	4,2
Quantum imaging	1,88	1,06	1,3
Neutral & Trapped Atom Qubits	1,41	0,53	2,61
Post-quantum security	1,17	18,52	8,99
Quantum circuits	1,17	3,17	3,91
Quantum infrastructure	1,17	1,59	4,06
Cryogenic systems	0,94	0,53	2,03
Hybrid solutions & hybrid computing	0,7	0	1,59
Optimization & AI & quantum accelerators	0,7	4,23	4,93
Quantum chips	0,47	0,53	0,58
Diamond-based technologies	0,23	0	1,74
Scalable solutions	0,23	0,53	4,64
Quantum cloud	0	1,59	3,77
Quantum software	0	4,76	5,36
Consulting & services	0	10,58	6,52

Methodology

To compare the research focus of CSIC in quantum technologies with the activity developed by detected startups, a categorization approach was employed. The terms extracted from the analysis of CSIC research lines of groups were mapped to the technological categories identified in the startup landscape. This matching process aimed to identify overlaps and gaps between the interests of academic research at CSIC and the business-driven focus of startups, both at the Spanish and global levels.

Findings and Insights

The comparative analysis reveals significant differences in priorities between CSIC and startups. CSIC's research is strongly oriented toward fundamental quantum science, with particular emphasis on **Quantum computing (9,39%)**, **Quantum materials & superconducting technologies (28,17%)**, and **Quantum sensing & metrology (10,33%)**. These areas are fundamental to the advancement of quantum technologies but often face challenges in direct commercialization.

Conversely, startups show greater interest in **post-Quantum security (18,52%)**, **Quantum AI & data science (16,93%)**, and **consulting & services (10,58%)**. These areas are more application-driven, focusing on immediate business and technological needs. The presence of startups in **photonics & optics (9,52%)** and **Quantum communication & secure communication (7,94%)** indicates a strong commercial pull toward cybersecurity and practical quantum applications.

The most significant discrepancy is observed in **superconducting technologies**, where CSIC has a dominant focus (28,17%) compared to only **1,06%** of startups. This suggests that while superconducting advancements are a major area of academic research, their industrial adoption remains limited, possibly due to technical and economic barriers in scaling these technologies.

On the other hand, **post-Quantum security and AI applications**, where startups show a high level of engagement, receive relatively less attention from CSIC researchers. This may indicate that while these topics are crucial for immediate industry needs, their deeper scientific exploration is still emerging in academia.

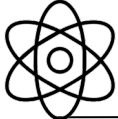
Hypothesis and Strategic Considerations

The differences observed stem from distinct priorities: **CSIC emphasizes long-term research**, while **startups focus on short-to-medium term commercialization**. The misalignment in areas like **Quantum cryptography**, AI-driven Quantum solutions, and consulting suggests an opportunity for stronger **academia-industry collaboration**. To bridge this gap, efforts should focus on:

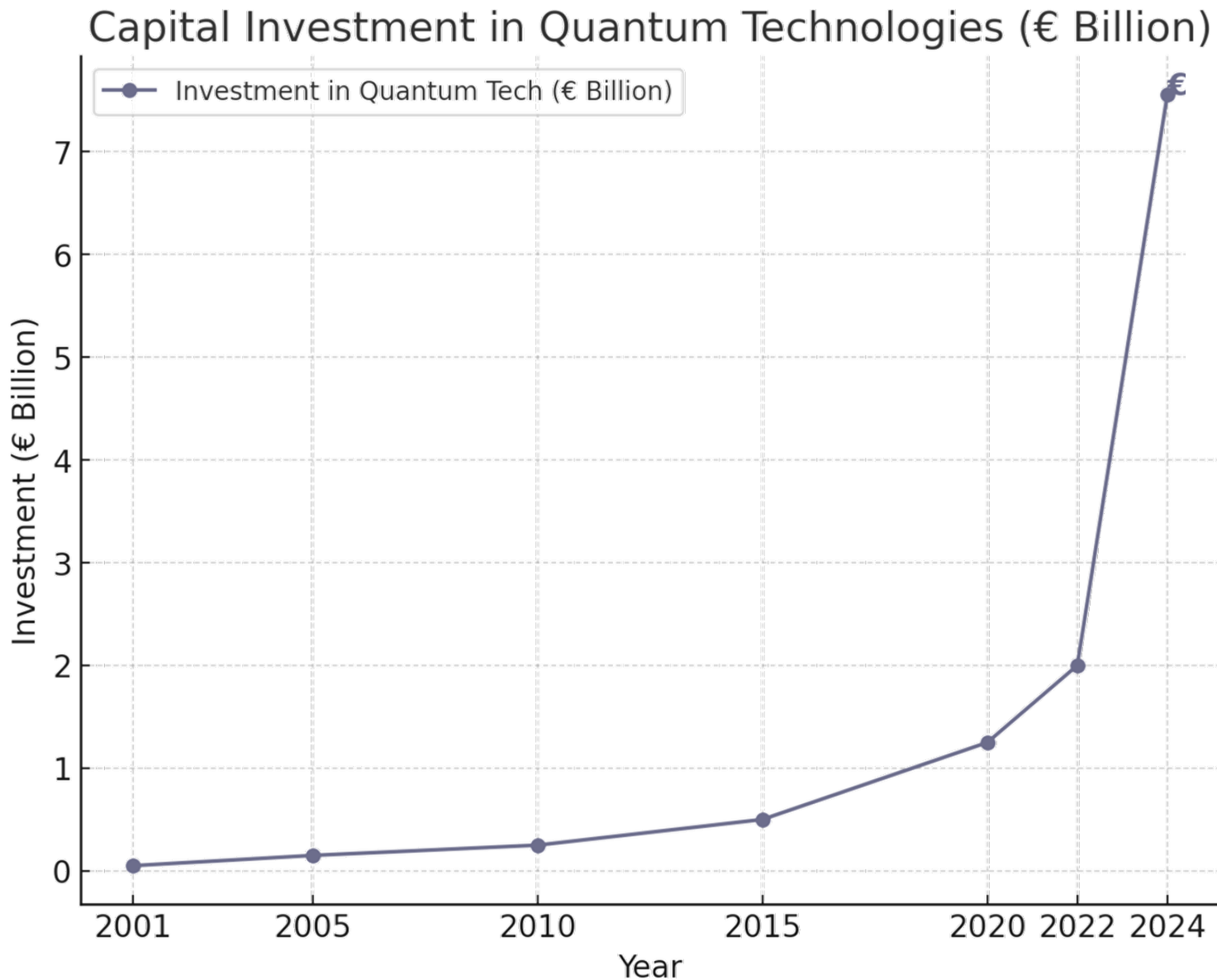
- Strengthening **Quantum AI** and **optimization research** for practical industry adoption.
- Enhancing post-Quantum security to meet **cybersecurity demands**.
- Accelerating scalability of **Quantum materials** and **superconducting technologies**.
- Aligning **Quantum sensing** and hardware with market needs for better technology transfer.

An integrated strategy between research and business innovation will maximize Quantum technology impact, drive industry uptake, and boost the competitiveness of Spanish and global ecosystems.

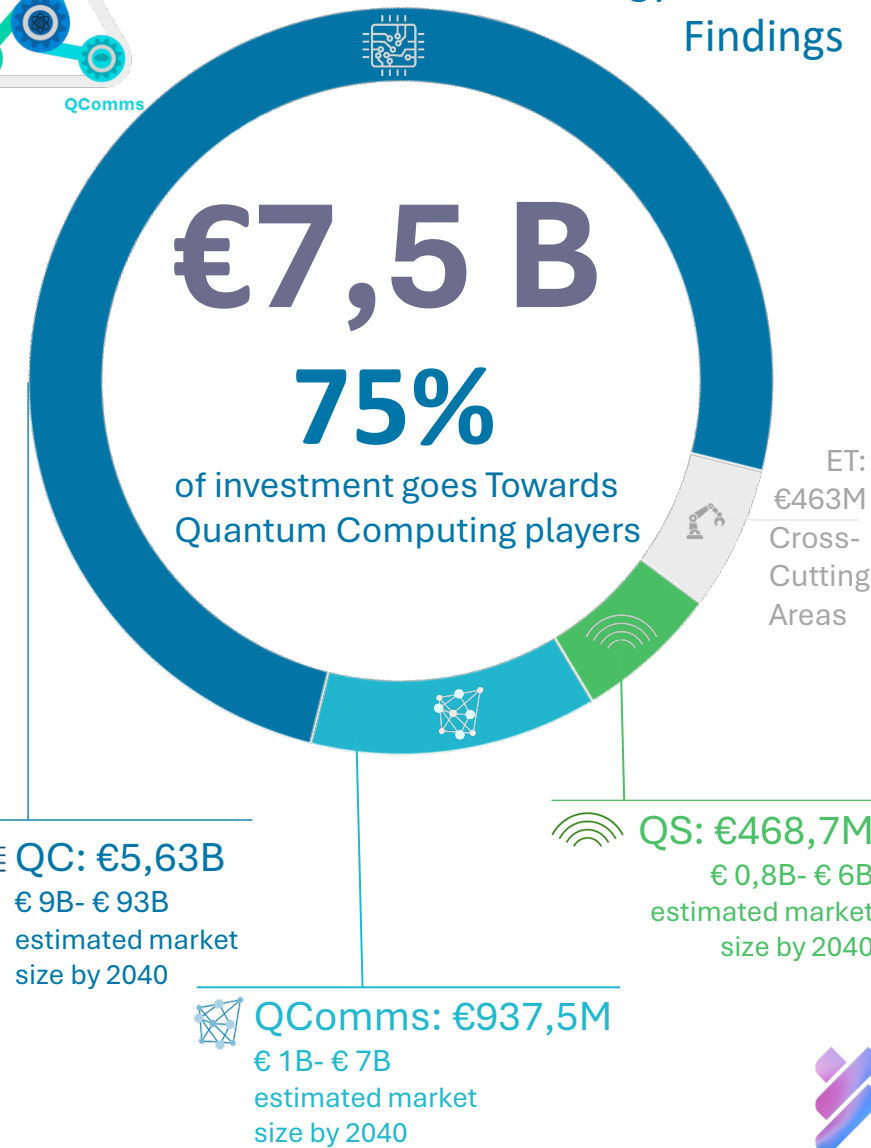


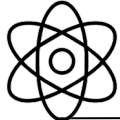


Quantum technology investment landscape



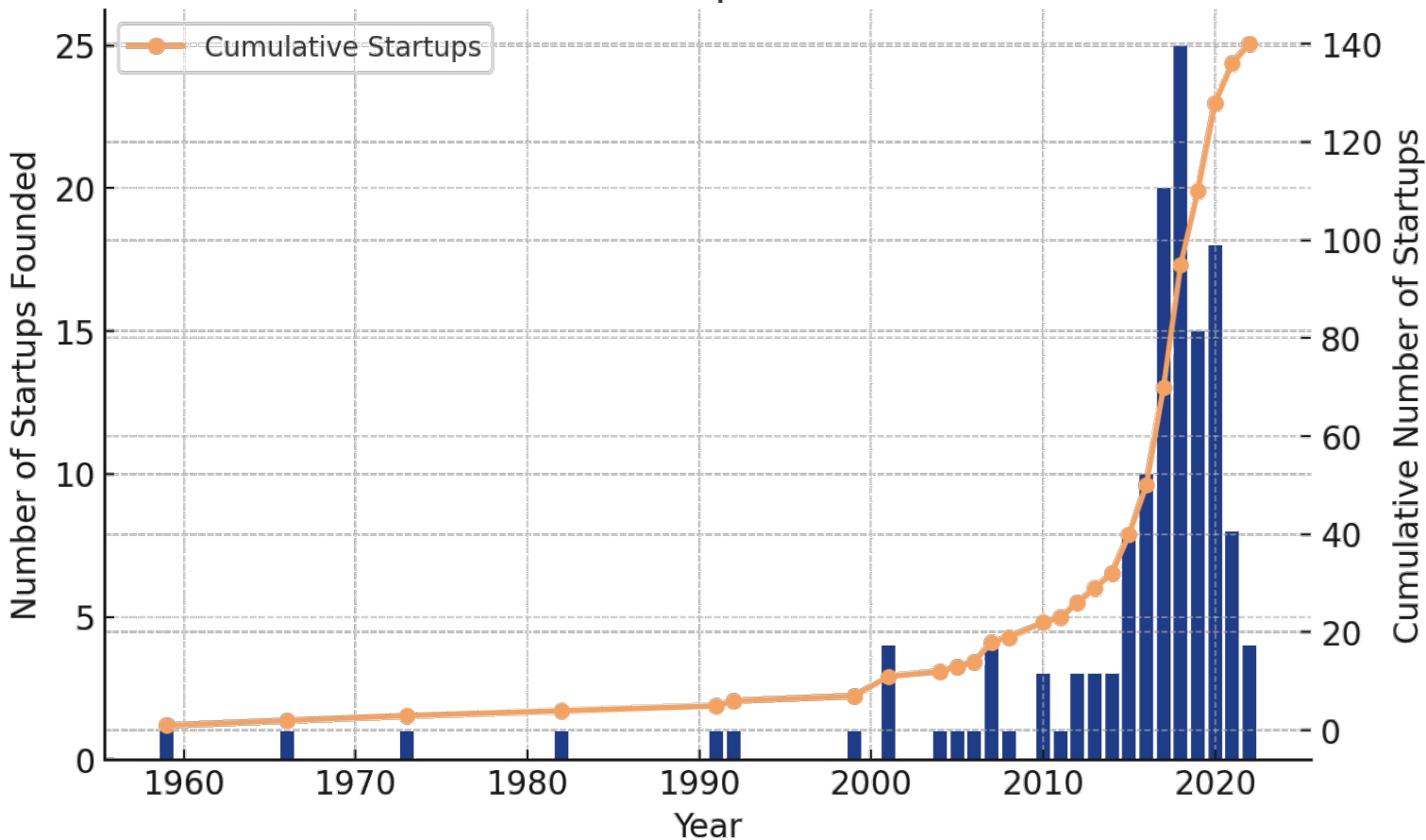
Estimated Summary of Quantum Technology Monitor Findings





Quantum technology investment landscape

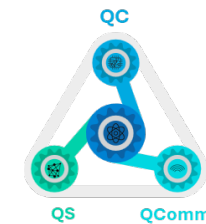
Number of QT Startups Founded Per Year



Number of QT start-ups founded per year

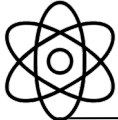
80%

of start-ups founded in past 5 years are in QC space



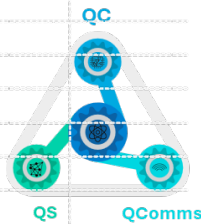
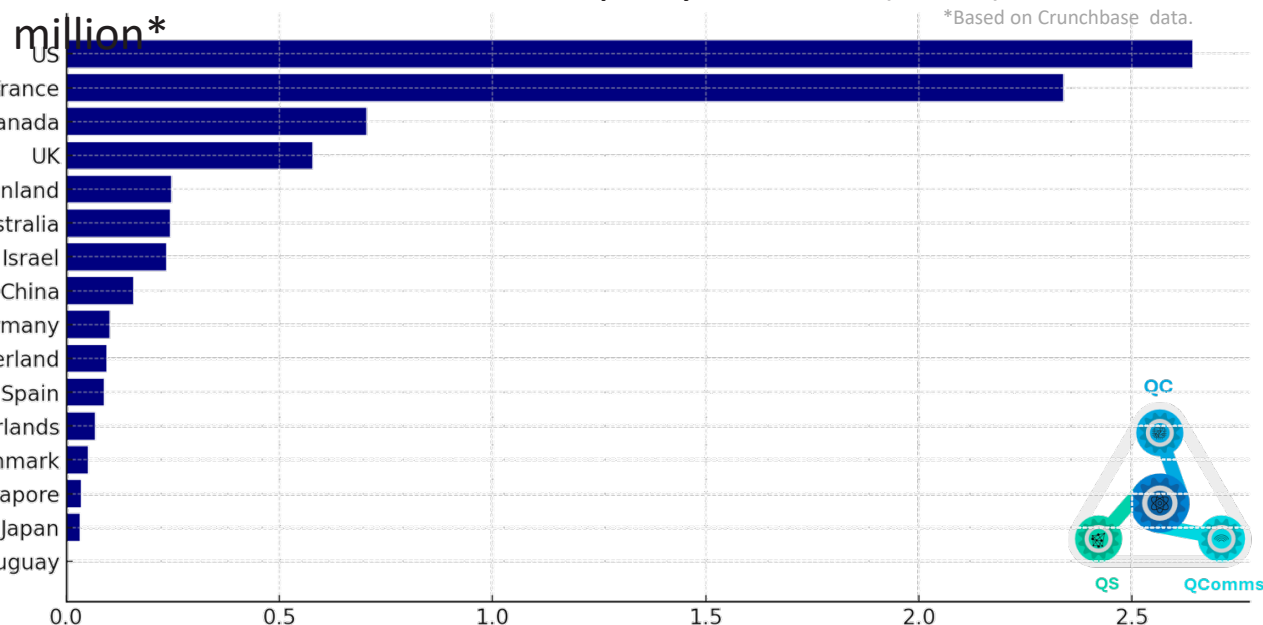
From the analyzed Quantum technology startups in this study, several insights can be drawn regarding the trends and challenges faced by the sector. One key observation is the shortage of specialized talent, as most experienced professionals—primarily those with an academic background in Quantum technologies—are already employed by existing startups, limiting the talent pool for new ventures. Additionally, the limited availability of practical use cases poses a significant challenge to the creation of new startups. Many applications, particularly in areas such as **Quantum sensing**, are still in the **early stages of development** and are not yet fully prepared for commercial deployment. Furthermore, investment trends indicate that investors tend to **prioritize** funding for **scale-ups and later-stage startups** over early-stage ventures, making it difficult for emerging companies to secure the necessary capital to develop and commercialize their technologies. These factors combined contribute to the observed slowdown in the formation of new startups within the Quantum technology ecosystem.



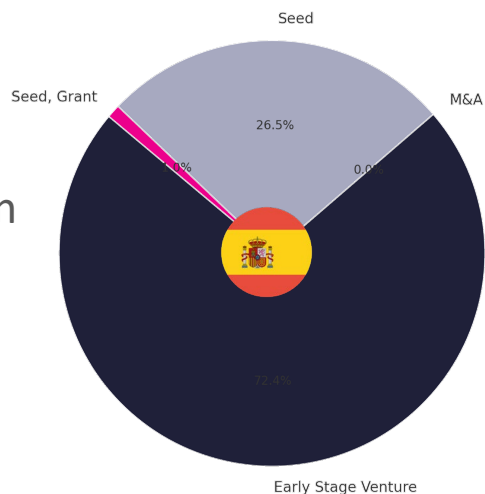


Quantum technology investment landscape

Total investment in QT start-ups by location (2024), €



Investment Breakdown by Funding Stage in Spain



Key Insights (Spain):

- 72,4% in early stage Venture, startups in growth phase.
- 26,5% in Seed funding, many still in early development.
- Minimal public funding & no M&A activity, limiting scaling.
- Need for later-stage investment to compete globally.

Global Investment in QT Startups: Key Insights

Investment in QT startups is growing rapidly, with venture capital, private equity, and corporate funds driving the sector. The leading investment destinations are the **United States (US), France, Canada, and the United Kingdom (UK)**, with the US dominating due to strong private funding and government-backed initiatives.

France and Canada attract significant investments thanks to their strong research ecosystems and government support for deep tech startups. The **UK** has focused on commercializing quantum technologies, boosting its funding. Other countries like **Germany, China, Israel, and Australia** are also growing but with lower investment levels.

Spain and other European countries have limited presence in the rankings, highlighting the need for stronger financing mechanisms and integration with EU initiatives to remain competitive in the Quantum race.

Funding structure & Startup stages

Venture capital accounts for almost **half of total funding**, while private investors and corporate funds make up around **80%** of investments. Public funding is still limited, mainly supporting early-stage R&D.

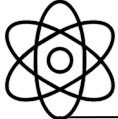
Most funding is concentrated in **early-stage startups** (Seed & Series A), reflecting the industry's emerging nature. As quantum technologies mature, later-stage funding (Series B & C) is expected to rise, supporting commercialization and scale-up.

QT investment is booming, with a strong concentration in leading nations. Spain and similar countries must **strengthen collaboration between startups, research centers, and investors** to attract more funding and compete globally.

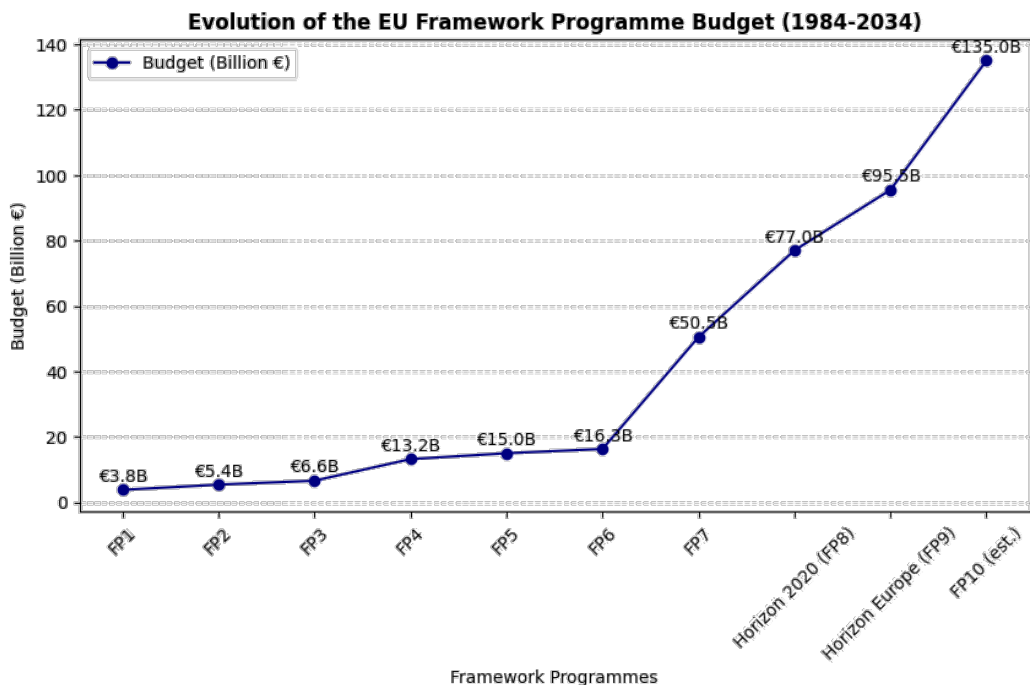


The 10th EU
Framework
Programme (FP10):
Scouting of
Planning Status
and Priorities





The next 10th EU Framework Programme (FP10) and the role of QT



Expected FP10 Planning Timeline (2024-2028)

The roadmap for the 10th EU Framework Programme (FP10) follows a structured timeline. In **2024**, strategic groundwork is being laid, including the mid-term evaluation of Horizon Europe and expert recommendations from reports such as those by Draghi, Letta, and Heitor. By **2025**, the European Commission is expected to present the official legislative proposal for FP10, following the appointment of the new Commission and discussions on the Multiannual Financial Framework (MFF). **2026** will be dedicated to negotiations between the EU Council and Parliament to finalize the programme's budget, priorities, and implementation framework. In **2027**, FP10 is expected to be formally adopted to ensure a seamless transition from Horizon Europe. Finally, in **2028**, the programme will be officially launched, and the first funding calls for proposals will be opened.

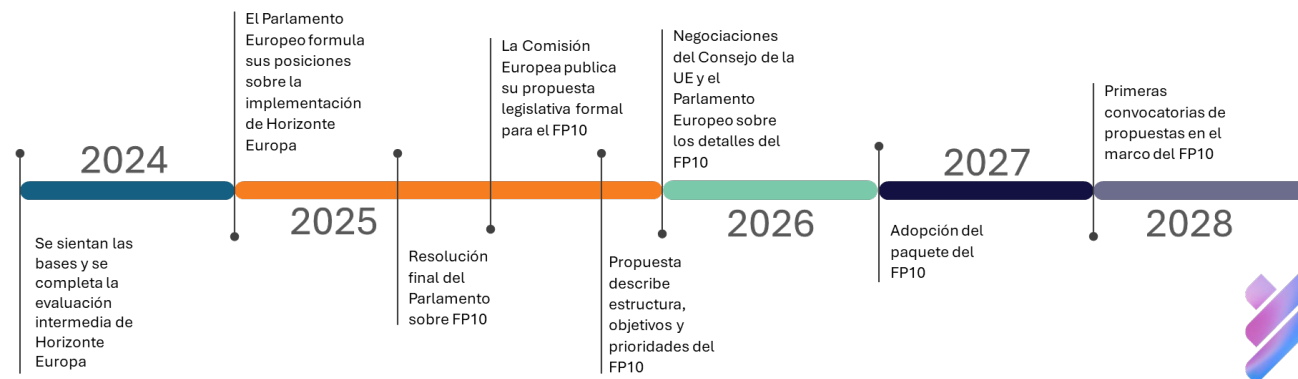
Context

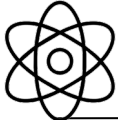
The FP10 is set to succeed Horizon Europe, covering the period 2028-2034. Its planning is already underway, with key stakeholders shaping its structure, priorities, and budget. The primary goal of FP10 is to enhance European competitiveness through research and innovation while addressing global challenges. The programme will retain a multi-pillar structure similar to Horizon Europe, with a focus on scientific excellence, industrial competitiveness, and social impact.

One of FP10's key areas of emphasis will be **emerging technologies**, particularly **quantum technologies**, which have been identified as a strategic priority for Europe's technological sovereignty.

Budget Evolution

The next FP10 is expected to follow the trend of increasing budgets over the decades, reflecting the growing importance of scientific and technological advancement in Europe's strategy. The budget has grown **exponentially**, from **€3.75 billion in FP1** to nearly **€95.5 billion in Horizon Europe (FP9, 2021-2027)**. Projections for FP10 indicate a further increase, with estimates suggesting a budget between **€120 billion and €150 billion**, though some stakeholders advocate for a **€200 billion investment** to ensure Europe remains globally competitive. This increased funding will be directed towards **strategic areas**, including quantum technologies, artificial intelligence, and sustainability-driven innovation.





The next 10th EU Framework Programme (FP10) and the role of QT

The Significance of QT in FP10

QT are expected to play a central role in FP10, building upon the investments made in previous EU research programmes. Since the launch of the **Quantum Flagship** in 2018, a €10 billion initiative under Horizon 2020 and Horizon Europe, Europe has positioned itself at the forefront of Quantum research. FP10 is anticipated to **expand and accelerate** these efforts, ensuring that Europe remains competitive in the global race for quantum advancements.

Strategic Competitiveness

QT, alongside AI and semiconductors, are seen as **critical enablers** of Europe's digital and industrial future. The European Commission has highlighted **quantum computing, quantum communication, and quantum sensing** as priority areas for FP10, essential for achieving technological independence.

Key Applications and Funding Focus

- **Quantum Computing:** Development of next-generation quantum processors and scalable quantum architectures.
- **Quantum Communication:** Secure quantum encryption networks, including projects like EuroQCI.
- **Quantum Sensing & Metrology:** High-precision measurement tools for applications in defense, healthcare, and environmental monitoring.

R&D and Industrial Growth

FP10 will likely emphasize **collaborative funding mechanisms** to connect academia, industry, and startups, fostering a strong European Quantum ecosystem. This aligns with the vision of creating **European centers of excellence** in QT, ensuring talent development and research leadership.

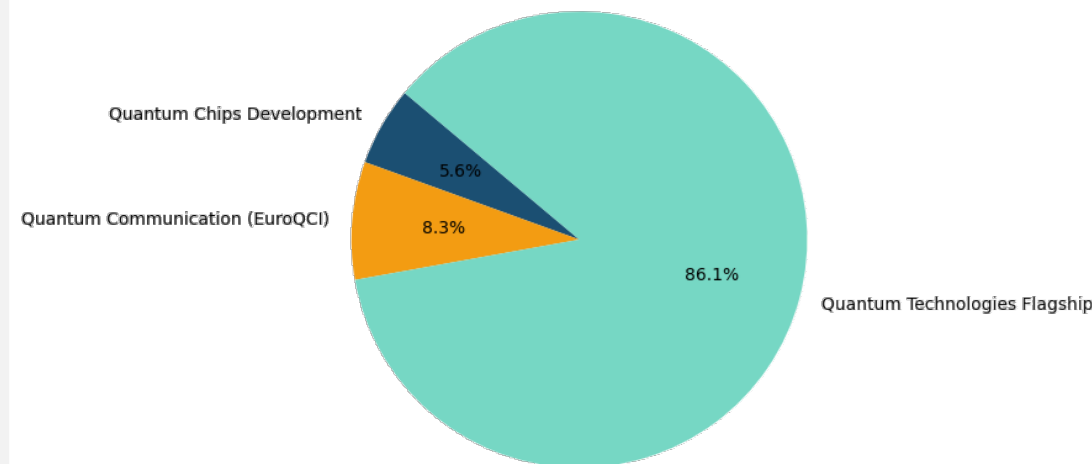
Security and Sovereignty

Quantum encryption is particularly relevant for Europe's cybersecurity strategy, as quantum-resistant cryptography will be vital for protecting critical infrastructures and communications.

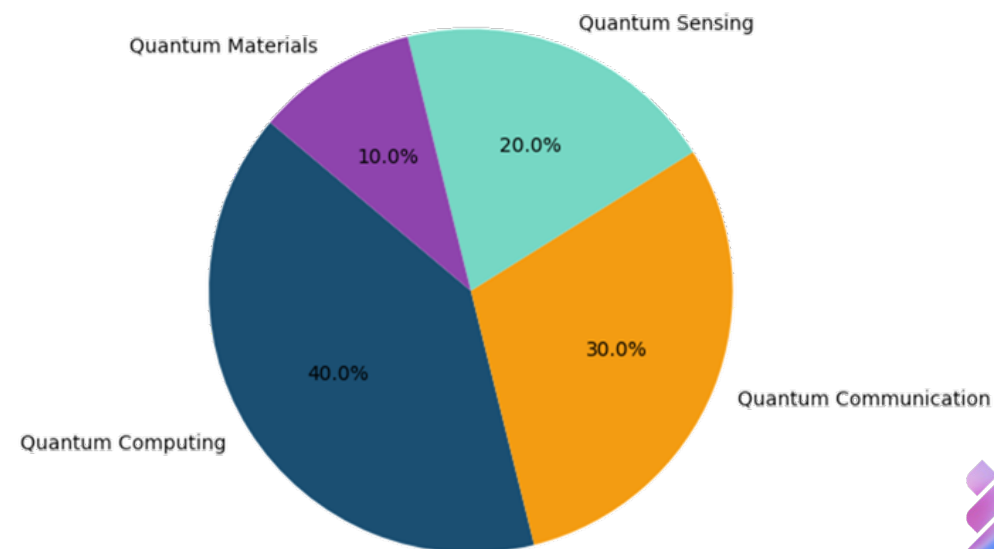
Funding Allocation and Future Roadmap

The European Commission's strategic outlook places **QT among the most heavily funded areas within FP10's digital and industrial innovation budget**. Quantum R&D will not be isolated but will intersect with fields like AI, supercomputing, and green technologies, reinforcing Europe's position in emerging scientific frontiers.

EU Funding Distribution in Quantum Technologies (in million €)

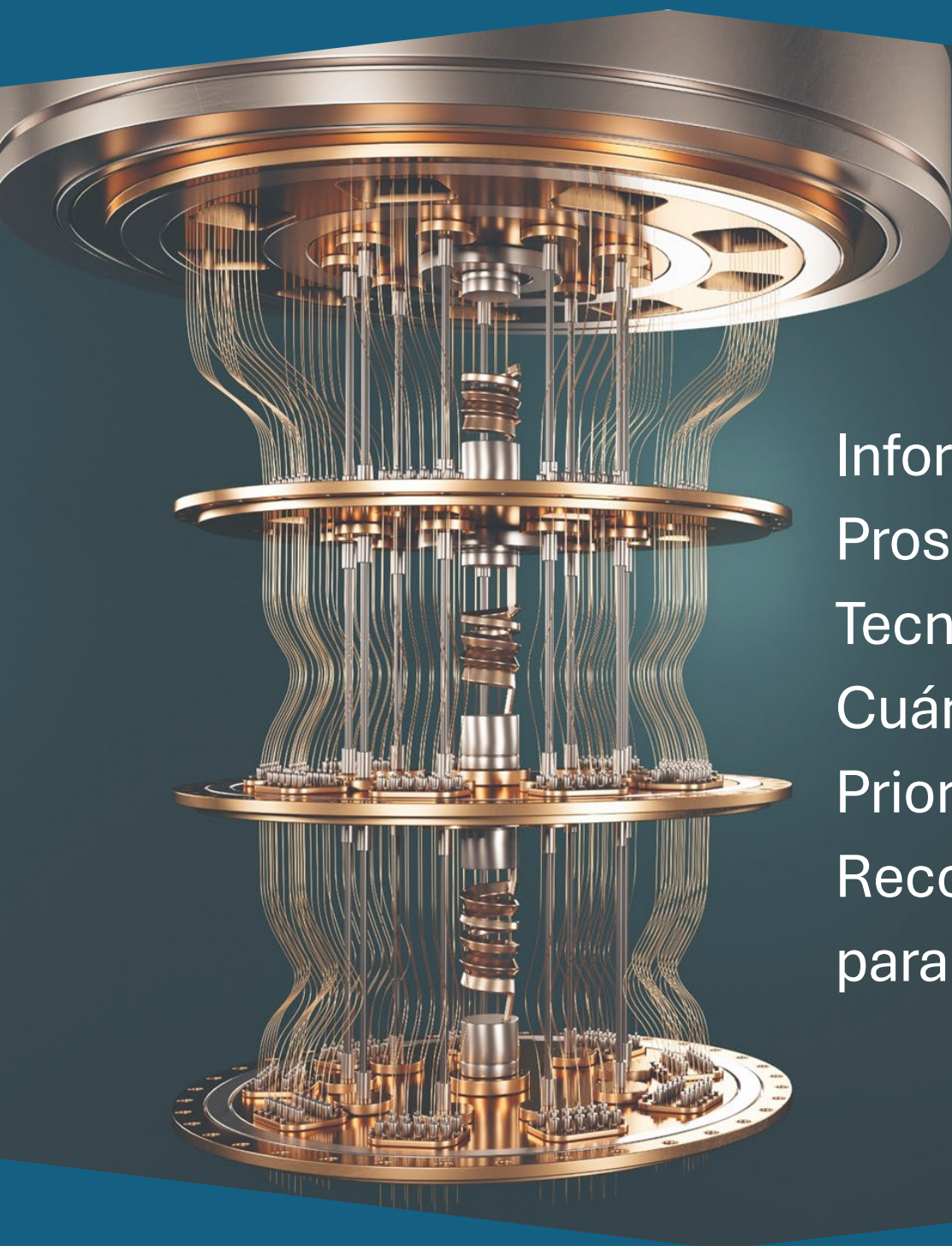


Estimated FP10 Budget Allocation for Quantum Technologies



Annex I:
Foresight Report.
Priorities and
Recommendations
(in Spanish)





Informe de Prospectiva: Tecnologías Cuánticas - Prioridades y Recomendaciones para el CSIC

 **Fundación
General CSIC**

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Introducción

El presente informe técnico resume las opiniones de una encuesta de prospectiva tecnológica realizada a expertos en **tecnologías cuánticas**, con el objetivo de orientar al Consejo Superior de Investigaciones Científicas (CSIC) en su estrategia para los próximos 5-10 años. La encuesta reunió a investigadores y directivos de empresas punteras, cubriendo ámbitos desde la computación cuántica hasta la comunicación, la simulación y los sensores cuánticos. A partir de sus respuestas, se identifican **líneas de investigación prioritarias**, propuestas de **modelos organizativos** para maximizar la excelencia científica, formas de **colaboración** entre actores (académicos e industriales) y vías para **impulsar la transferencia tecnológica** hacia la industria y el sector productivo. Todo ello se complementa con ejemplos internacionales y casos de éxito que refuerzan las recomendaciones.

Este microinforme, alimentado por la opinión de expertos relevantes, ofrece prioridades y recomendaciones para que el CSIC capitalice las oportunidades y fortalezca su liderazgo científico-tecnológico en la era cuántica. Entre las conclusiones más destacadas, varios expertos subrayan la importancia de evitar la dispersión de esfuerzos y centrar la estrategia en áreas específicas con alto potencial de impacto. En particular, se identifica el desarrollo de sensores cuánticos y de chips orientados a sectores estratégicos como la defensa o la biotecnología, como una oportunidad clara para que España, y el CSIC en particular, consoliden una posición de liderazgo a nivel europeo, siempre que exista una apuesta decidida y coordinada.

Participantes

Se ha diseñado un cuestionario para una estrategia de prospectiva con el objetivo de recopilar la opinión y visión de un amplio conjunto de expertos destacados en tecnologías cuánticas, procedentes tanto del mundo de la investigación como del sector empresarial. Sus áreas de especialización abarcan principalmente la **computación cuántica** (hardware y software) y la **fotónica**, con representación también en campos como las **comunicaciones cuánticas** o la **criptografía poscuántica**, el software híbrido y de inspiración cuántica, como alguna de las áreas más destacadas. Todos los expertos dieron su consentimiento para compartir sus opiniones para este análisis, lo que permitió recopilar tanto valoraciones cuantitativas como comentarios abiertos. Algunos de los expertos amablemente han aceptado también aparecer como mencionados como muestra de la heterogeneidad alcanzada y de su alto conocimiento en el campo analizado.

 <p>David Gómez Plaza Perfil profesional</p> <p>Director de Tecnologías Avanzadas de Fabricación en Tekniker. David Gómez Plaza participa activamente en la aplicación de tecnologías emergentes, incluyendo la computación cuántica, en procesos industriales avanzados. Su trabajo se centra en impulsar la transferencia tecnológica y la innovación aplicada a sectores estratégicos.</p>	 <p>Samuel Fernández Lorenzo Perfil profesional</p> <p>CEO de Inspiration-Q. Samuel Fernández Lorenzo lidera una empresa pionera en el desarrollo de soluciones basadas en tecnologías cuánticas. Con una visión orientada a la aplicación práctica, promueve la adopción de estas tecnologías en sectores industriales mediante el diseño de herramientas accesibles y escalables.</p>	 <p>Iñigo Artundo Perfil profesional</p> <p>CEO de VLC Photonics. Iñigo Artundo trabaja en el ámbito de la fotónica integrada, una tecnología clave para el desarrollo de sistemas cuánticos avanzados. Su experiencia combina la gestión empresarial con el impulso a la I+D en aplicaciones cuánticas para comunicaciones y sensórica.</p>
 <p>Víctor Canivell Perfil profesional</p> <p>Cofundador y presidente de Qilimanjaro Quantum Tech. Víctor Canivell lidera iniciativas centradas en computación cuántica aplicada. Su trayectoria combina experiencia tecnológica y visión estratégica para posicionar a su empresa como referente en soluciones cuánticas accesibles y de alto impacto.</p>	 <p>Juan José García Ripoll Perfil profesional</p> <p>Investigador del CSIC y coordinador de la Plataforma de Tecnologías Cuánticas, Juan José García Ripoll es una figura clave en el impulso a la investigación cuántica en España. Su trabajo se centra en la teoría cuántica y en el desarrollo de algoritmos y arquitecturas para computación y simulación cuántica.</p>	 <p>Elena Yndurain Perfil profesional</p> <p>Profesora en IE University y autora del libro <i>Quantum Computing for Beginners</i>, Elena Yndurain combina la divulgación con la formación de nuevas generaciones de profesionales en tecnologías cuánticas. Su labor académica contribuye a acercar este campo emergente a estudiantes, empresas e instituciones.</p>
 <p>Carlos Kuchkovsky Perfil profesional</p> <p>CEO de QCentroid. Carlos Kuchkovsky impulsa el desarrollo de plataformas que integran inteligencia artificial, blockchain y computación cuántica. Con una sólida experiencia en innovación tecnológica, lidera soluciones orientadas a resolver problemas complejos en entornos empresariales.</p>	 <p>Enrique Lizaso Perfil profesional</p> <p>CEO de Multiverse Computing. Enrique Lizaso lidera una de las empresas europeas más reconocidas en computación cuántica aplicada a las finanzas y la industria. Su enfoque combina el rigor científico con la estrategia empresarial para llevar la computación cuántica al entorno real.</p>	 <p>Benito Alén Perfil profesional</p> <p>Investigador en el CSIC y fundador de g2-Zero, Benito Alén trabaja en la interfaz entre la investigación fundamental en tecnologías cuánticas y su aplicación práctica. Su trayectoria combina el desarrollo científico con el impulso a iniciativas emprendedoras en el ámbito cuántico.</p>

Áreas de investigación cuántica prioritarias (próximos 5-10 años)

Análisis cualitativo

Un primer bloque de la consulta indagó **qué líneas de I+D en tecnologías cuánticas** debería priorizar un organismo como el CSIC en sus planes estratégicos de los próximos 5-10 años. De las respuestas cualitativas de los expertos se desprenden una serie de áreas clave recurrentes:

- **Computación Cuántica (Hardware y Software):** Prácticamente todos los expertos coincidieron en la importancia de impulsar la computación cuántica. Esto abarca el desarrollo de **hardware cuántico escalable** (nuevos cúbits, chips integrados, electrónica criogénica, fotónica integrada, etc.) y los avances en **software y algoritmos cuánticos**. Varios encuestados mencionan la necesidad de trabajar en algoritmos con potencial de aplicación relativamente cercana, por

ejemplo, en **simulación cuántica de procesos químicos** o métodos variacionales, que podrían generar ventajas en pocos años. Al mismo tiempo, señalan que no se debe descuidar la investigación en **corrección de errores cuánticos y tolerancia a fallos**, dada su relevancia para escalar la computación cuántica de forma fiable. En este sentido, se destaca priorizar la búsqueda de “*qubits más estables y menos estudiados*” (p.ej. cúbits topológicos) y tecnologías de cómputo especializadas donde el CSIC pueda aportar algo diferencial, complementando los esfuerzos de grandes consorcios internacionales.

- **Sensores cuánticos y metrología:** La **sensorización cuántica** emerge como área prioritaria en múltiples respuestas. El **desarrollo de sensores cuánticos ultraprecisos** (basados en fenómenos de entrelazamiento y coherencia cuántica) para medir campos magnéticos, gravitatorios, electromagnéticos, etc., es identificado como un nicho de **alta potencialidad**. Estos sensores prometen mejoras de varios órdenes de magnitud en sensibilidad respecto a sensores clásicos, con aplicaciones en salud (imagen médica, neurociencia, etc.), geofísica, defensa, navegación y otros campos. Los expertos sugieren orientar esfuerzos a lograr sensores **más robustos y portables**, junto con la **integración de estos dispositivos en entornos industriales** para facilitar su transferencia. Un ejemplo mencionado es la mejora de **relojes atómicos cuánticos** (estándares de tiempo ultraprecisos por debajo de 10^{-18} de error) y su posible impacto en sectores como telecomunicaciones, GPS y banca. Cabe señalar que esta es un área donde la madurez tecnológica es relativamente cercana, y algunos opinan que podría ser la primera en lograr integración comercial efectiva antes que la propia computación cuántica general. Esta línea es coherente con el diagnóstico europeo recogido en iniciativas como la Quantum Flagship, y se alinea con la ventana de oportunidad identificada por los expertos. Dado su mayor grado de madurez tecnológica y menor riesgo de concentración tecnológica, la sensoría y metrología cuántica representa un área estratégica en la que el CSIC puede ejercer un liderazgo diferencial, especialmente en aplicaciones relacionadas con defensa, biomedicina, navegación o telecomunicaciones avanzadas.
- **Comunicaciones cuánticas y criptografía:** La **comunicación cuántica segura** (particularmente la **distribución cuántica de claves**, QKD) y el desarrollo de una futura **Internet cuántica** aparecen también entre las prioridades. Diversos expertos animan a priorizar tecnologías habilitadoras como los **repetidores cuánticos** (para extender la distancia de redes QKD más allá de los límites actuales) y las **memorias cuánticas** de larga duración, que son fundamentales para redes de largo alcance. Asimismo, se menciona la mejora en la generación y detección de **fotones entrelazados** y la implementación de **protocolos de comunicación cuántica robustos** frente a pérdidas y decoherencia. Estas líneas, aunque todavía en fase de investigación, conectan con la necesidad estratégica de garantizar **seguridad poscuántica** en las comunicaciones: en palabras de un experto, “*no está claro si gobiernos y empresas están preparados para adaptarse a la criptografía poscuántica*”, subrayando el rol que puede jugar el CSIC en educar y liderar esta transición. De hecho, a nivel internacional, países como **China** han logrado hitos como la primera red QKD satelital a escala global, demostrando la viabilidad de comunicaciones ultra-seguras. Europa también avanza con proyectos como **EuroQCI** para desplegar una red cuántica

paneuropea, lo que indica que este campo será crucial en la próxima década, aunque plagado de actores/competidores con gran dominio de este ámbito.

- **Aplicaciones cuánticas en ciencia e industria:** Varios expertos recomiendan al CSIC enfocar parte de sus esfuerzos en **aplicaciones concretas de la computación cuántica** que tengan potencial de transferencia tecnológica en un periodo de 3-5 años. Ámbitos mencionados incluyen la **química cuántica y modelado de nuevos materiales** (por ejemplo, simular catalizadores o fármacos a nivel molecular), la **optimización logística y financiera**, y la aplicación de métodos cuánticos en **inteligencia artificial y machine learning** (QML). No obstante, matizan que en ciertos campos empresariales (finanzas, IA, optimización...) es probable que las soluciones puramente cuánticas tarden aún en madurar, por ello proponen una aproximación dual: impulsar **algoritmos híbridos o de “inspiración cuántica”** que funcionen en hardware clásico, aprovechando técnicas cuánticas, para obtener beneficios a corto plazo mientras las computadoras cuánticas no alcanzan la escala necesaria. Esta estrategia de **“quick wins”** evitaría un posible **“invierno cuántico”** (decepción por falta de resultados prácticos), similar al invierno de la IA en las décadas pasadas. La idea es mantener expectativas realistas, demostrar resultados parciales útiles (por ejemplo, en optimización de carteras financieras o en aprendizaje automático con algoritmos cuántico-inspirados) e ir preparando el terreno para una adopción industrial más amplia cuando el hardware cuántico lo permita.
- **Otras áreas emergentes:** Adicionalmente, se señalaron áreas como la **materia cuántica**¹ y nuevos materiales para tecnologías cuánticas (por ejemplo, **superconductores avanzados y cúbits topológicos**), que podrían ser críticas para futuros avances. También la convergencia de lo cuántico con otras disciplinas: se sugiere explorar sinergias con líneas ya presentes en CSIC, por ejemplo, aplicando computación cuántica a **biología y ciencias de la vida**, a **ciencias de la Tierra** (meteorología cuántica) o a **telecomunicaciones clásicas** (interfaces cuántico-clásicas). Esta aproximación interdisciplinaria aprovecharía fortalezas existentes del CSIC para acelerar aplicaciones disruptivas (por ejemplo, sensores cuánticos aplicados a biomedicina, o algoritmos cuánticos para estudiar el cambio climático). En cuanto a **tecnologías habilitadoras**, algunos mencionan la importancia de desarrollos en electrónica criogénica, sistemas de control, **fotónica integrada** (esencial para interconectar cúbits y para comunicaciones cuánticas) e incluso el uso de **técnicas de IA** para optimizar diseños de hardware cuántico. Todas estas sublíneas alimentan el ecosistema de investigación cuántica, y es importante que el CSIC mantenga un **portafolio equilibrado** entre investigación fundamental de largo plazo (por ejemplo, nuevos principios físicos) y desarrollo tecnológico orientado a resultados tangibles.

¹ El término "**materia cuántica**" se refiere a un área emergente de la física y las tecnologías cuánticas que estudia y explota **estados de la materia cuyo comportamiento está gobernado por fenómenos cuánticos colectivos**, como la **superposición, entrelazamiento, o efectos topológicos**. No se trata de "otra forma de materia", sino de **fases o sistemas materiales** donde las propiedades cuánticas no son solo una curiosidad microscópica, sino que **se manifiestan a gran escala y pueden ser utilizadas tecnológicamente**. En este concepto se puede incluir, entre otros, condensados de Bose-Einstein, superconductores, superfluidos, materiales topológicos, cristales de espín, trampas de iones, etc.

En resumen, las **prioridades temáticas** identificadas abarcan la **computación cuántica** (en toda su stack: hardware, software, algoritmos, corrección de errores), las **comunicaciones cuánticas seguras**, la **senórica y metrología cuántica**, y las **aplicaciones interdisciplinarias** que puedan traducirse en innovación. Estas áreas coinciden en gran medida con las tendencias internacionales: por ejemplo, Alemania estructura su estrategia en cuatro pilares (computación, comunicación, simulación y metrología cuánticas)^{Error! Marcador no definido.}, y el **Quantum Flagship** de la UE financia proyectos punteros en computación (por ejemplo, procesadores superconductores *OpenSuperQ*), simulación de materiales, comunicaciones (red EU Quantum Internet) y sensores gravitacionales, entre otros. Se trata, por tanto, de campos donde **existe masa crítica global** y en los que el CSIC debería posicionarse liderando nichos específicos, como sugieren alguno de los expertos posicionando al CSIC como referente en nichos específicos de computación cuántica y colaborando activamente a nivel internacional.

Análisis cuantitativo

Para tener también una fotografía más cuantitativa a nivel nacional, se les pidió a los expertos que evaluaran distintos aspectos. El análisis de las respuestas revela un **consenso claro en torno a las prioridades de investigación, sectores estratégicos de aplicación y barreras críticas a superar**. Los datos recopilados mediante escalas de valoración, en escala de 1 (mínima) a 5 (máxima), y preguntas de opción múltiple (Figura 1) permiten extraer las siguientes conclusiones:

Áreas de I+D más relevantes:

Las siguientes gráficas muestran la valoración de diferentes áreas cuánticas en una escala del 1 al 5, representadas mediante barras divergentes. Las respuestas con puntuaciones bajas (1 y 2) se sitúan a la izquierda en colores cálidos, las respuestas neutras (3) en el centro en gris, y las puntuaciones altas (4 y 5) a la derecha en tonos azules. Esta representación permite identificar visualmente el grado de consenso y prioridad que los expertos otorgan a cada área, facilitando la comparación entre ellas.

Computación cuántica (Hardware)

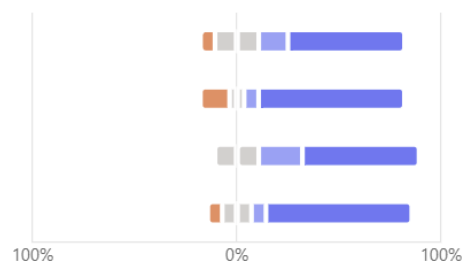
● 1 ● 2 ● 3 ● 4 ● 5

Arquitecturas de hardware cuántico (superconductores, atrapamiento de iones, fotónica cuántica, etc.)

Chips cuánticos y desarrollo de procesadores (fabricación, integración y escalabilidad de chips cuánticos)

Corrección de errores y tolerancia a fallos (códigos cuánticos, mitigación de ruido)

Interconexión de procesadores cuánticos (redes de cúbits y escalabilidad)



Computación cuántica (Software y Algoritmos)

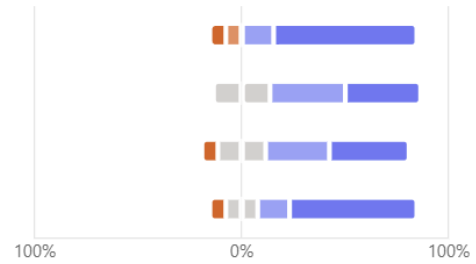
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Algoritmos cuánticos y complejidad computacional (Shor, Grover, variacionales, etc.)

Compiladores y software cuántico (desarrollo de entornos de programación eficientes)

Híbridos cuántico-clásicos (computación cuántica integrada con HPC - High Performance Computing)

Interconexión de procesadores cuánticos (redes de cúbits y escalabilidad)



Comunicación cuántica

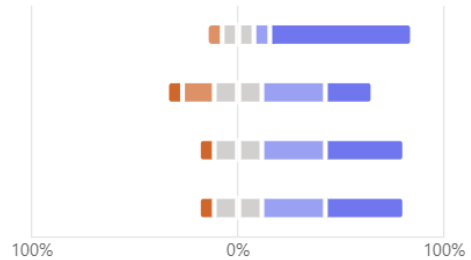
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Distribución cuántica de claves (QKD) y criptografía post-cuántica

Redes cuánticas y teleportación cuántica

Internet cuántico y protocolos de comunicación segura

Memorias cuánticas y repetidores cuánticos



Simulación cuántica

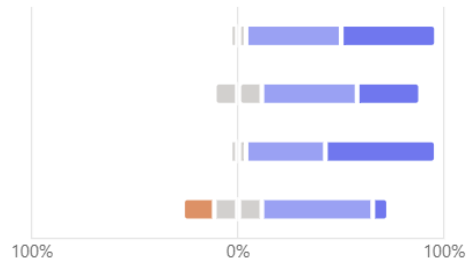
● 1 ● 2 ● 3 ● 4 ● 5

Modelado de materiales y nuevos compuestos (superconductores, baterías, fármacos)

Física de sistemas fuertemente correlacionados

Modelos cuánticos para química computacional

Simulación de dinámica cuántica en biología y salud



Sensores y metrología cuántica

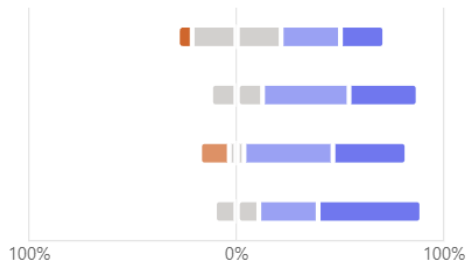
● 1 ● 2 ● 3 ● 4 ● 5

Relojes atómicos y estándares de tiempo ultraprecisos

Detección cuántica de campos gravitacionales y magnéticos

Interferometría cuántica y sensores ultraprecisos para navegación

Sensores cuánticos en medicina y neurociencia



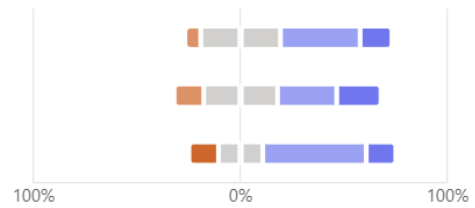
Materiales y tecnología cuántica aplicada

● 1 ● 2 ● 3 ● 4 ● 5

Materiales y cúbits topológicos

Desarrollo de superconductores avanzados

Interfaces cuántico-clásicas para integración industrial



Aplicaciones industriales y socioeconómicas

● 1 ● 2 ● 3 ● 4 ● 5

Impacto de la computación cuántica en optimización y logística

Aplicaciones en finanzas y modelado de riesgos

Uso en inteligencia artificial y Machine Learning cuántico

Nuevos paradigmas de seguridad en redes y blockchain cuántico

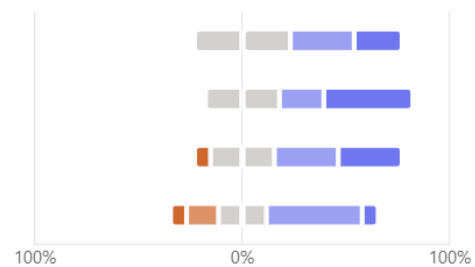


Figura 1. Análisis cuantitativo de la encuesta de prospectiva científico-tecnológica sobre las prioridades de la I+D

El análisis de los resultados presente en esta representación gráfica permite identificar de forma clara las áreas consideradas de mayor relevancia por los expertos. En general, se observa un consenso elevado en torno a temáticas como la simulación cuántica, el desarrollo de software y algoritmos cuánticos, y la computación cuántica en hardware, que concentran la mayoría de las respuestas en los valores 4 y 5. También destacan como prioritarios los sensores cuánticos y las aplicaciones industriales vinculadas a la optimización, la inteligencia artificial y la ciberseguridad. En cambio, otras áreas como la comunicación cuántica o los nuevos materiales muestran una mayor dispersión en las valoraciones, lo que indica menor consenso o prioridad percibida. De forma más esquemática, se pueden extraer 3 ideas clave:

- La **computación cuántica**, tanto en hardware como en algoritmos y software, fue identificada como el eje más dinámico y con mayor impacto a corto-medio plazo.
- La **simulación cuántica**, aplicada a materiales, química y biología, también se destacó por su potencial transformador.
- Ámbitos como la **sensores y la metrología cuántica** recibieron valoraciones algo menores, pero se reconocen como campos emergentes con alta aplicabilidad en salud, defensa o geofísica.

Sectores con mayor impacto potencial

La Figura 2 ilustra un panorama general de sectores económicos que, según los expertos, resultarán más beneficiados por las tecnologías cuánticas en la próxima década.

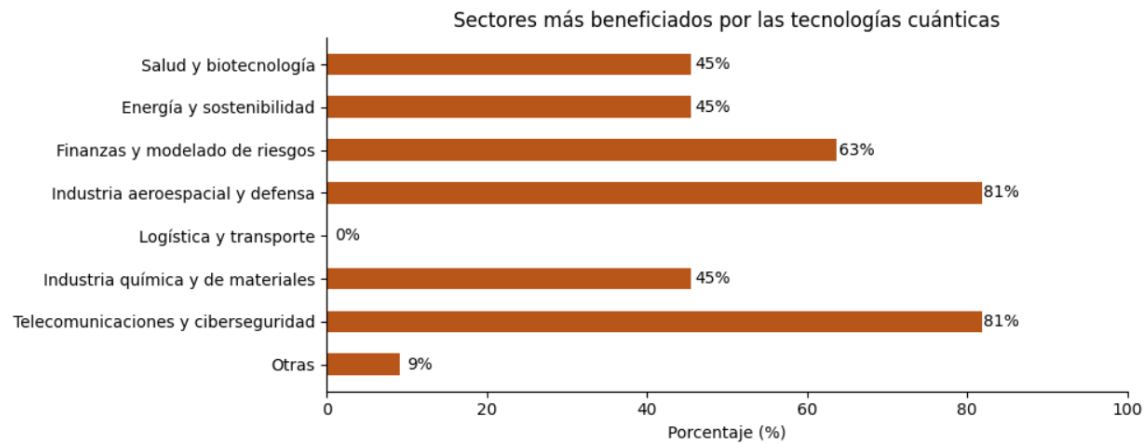


Figura 2. Sectores que los expertos consideran más beneficiados por los avances en tecnologías cuánticas en los próximos 10-15 años. Destacan Telecomunicaciones/Ciberseguridad, Defensa/Aeroespacial y Finanzas, entre otros.

En este análisis los expertos consideran que los sectores con mayor potencial de beneficio por las tecnologías cuánticas son la **industria aeroespacial y defensa** y las **telecomunicaciones y ciberseguridad** (81%), seguidos de **finanzas** (63%) y de **salud, biotecnología, energía e industria química** (45%). Se identifican aplicaciones clave en navegación segura, criptografía avanzada, descubrimiento de fármacos y optimización energética. En contraste, el sector de **logística y transporte** no fue seleccionado como un potencial beneficiario, lo que nos ha sorprendido desde el punto de vista del análisis, ya que este es un sector típicamente considerado como un beneficiario clave de estas tecnologías. La baja priorización podría deberse a la percepción de que otros sectores, como la defensa o las telecomunicaciones, tienen una necesidad más urgente y visible de estas tecnologías en el presente, o bien a que los sectores industriales más convencionales están alejados del área de especialización de los expertos. Sin embargo en las respuestas abiertas de los profesionales encuestados sí que se mencionan ejemplos prácticos donde las tecnologías cuánticas podrían tener aplicaciones significativas, como en la optimización de rutas o la gestión eficiente de cadenas de suministro. Esto puede indicar que, si bien no se considera un área crítica para la adopción inmediata de tecnologías cuánticas, los expertos reconocen su potencial a largo plazo.

Obstáculos más relevantes en España

Se preguntó a los expertos cuáles son los **obstáculos más importantes** para el desarrollo y adopción de las tecnologías cuánticas en España. Las respuestas, de tipo selección múltiple, se ilustran a continuación:

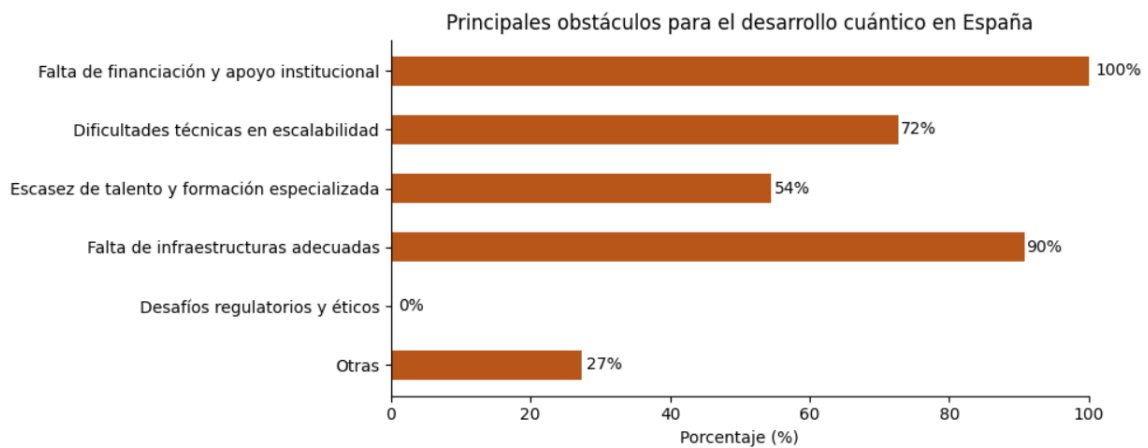


Figura 3. Obstáculos considerados más urgentes de abordar para impulsar el desarrollo de las tecnologías cuánticas en España (porcentaje de expertos que mencionan cada obstáculo).

La **falta de financiación** es señalada unánimemente por los expertos como el principal obstáculo para el desarrollo cuántico en España, seguida por la **escasez de infraestructuras especializadas**, como laboratorios y centros de computación. También destacan las **dificultades técnicas de escalabilidad**, propias del campo, y la **falta de talento cualificado**, que afecta a la capacidad de crecimiento del sector. En contraste, los **aspectos regulatorios y éticos** no se consideran barreras urgentes. En conjunto, las barreras detectadas son principalmente **estructurales**, aunque los expertos confían en que los retos científicos pueden superarse si se dispone de los recursos y condiciones adecuados.

Medidas estratégicas prioritarias

Ante estos obstáculos, se consultó a los expertos sobre qué **medidas deberían priorizarse en España** para fortalecer la I+D en tecnologías cuánticas. Podían seleccionar múltiples opciones. Los resultados se presentan en la siguiente gráfica:

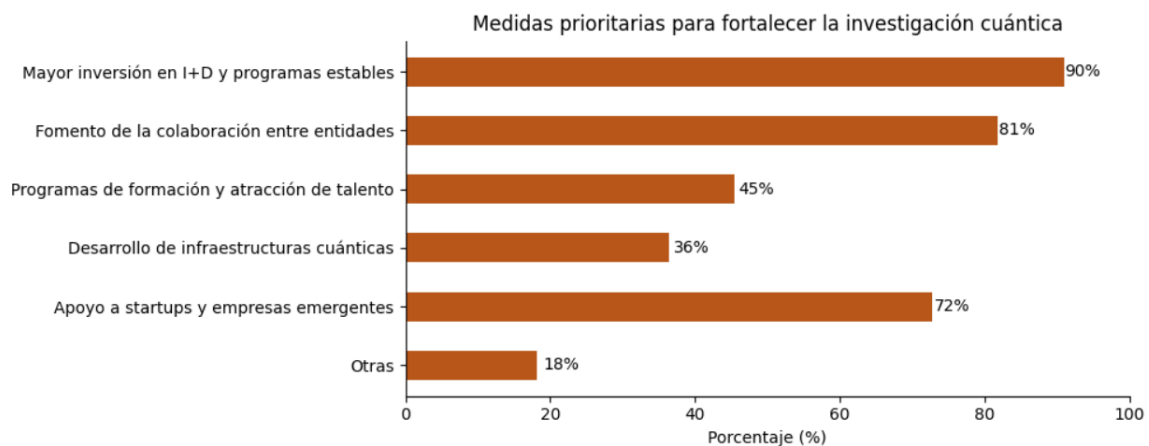


Figura 4. Principales **medidas prioritarias** propuestas por los expertos para fortalecer la investigación cuántica en España. Además de la inversión en I+D, destaca el apoyo a startups cuánticas y la colaboración con la industria.

La medida más respaldada por los expertos (90%) fue **aumentar la financiación en I+D cuántica mediante programas estables**, seguida del **fomento de la colaboración entre entidades** (81%), especialmente entre academia, industria y organismos públicos. También destacan el **apoyo a startups cuánticas** (72%), consideradas clave para llevar la innovación al mercado, y la **formación y atracción de talento** (45%), esencial para

sostener el crecimiento del sector. El **desarrollo de infraestructuras** (36%) y propuestas como un **Quantum HUB** completan el conjunto de medidas. En general, se percibe una fuerte alineación entre los principales obstáculos detectados (financiación, talento, infraestructura) y las soluciones propuestas por los expertos.

Modelo organizativo en el CSIC para fomentar la excelencia

Otra cuestión clave de la encuesta fue **cómo debería organizarse internamente el CSIC** para maximizar su impacto en tecnologías cuánticas y fomentar investigación de excelencia. Los expertos valoraron distintos **modelos organizativos**, desde estructuras internas hasta formas de colaboración, y sus respuestas apuntan a **combinar varias estrategias** complementarias:

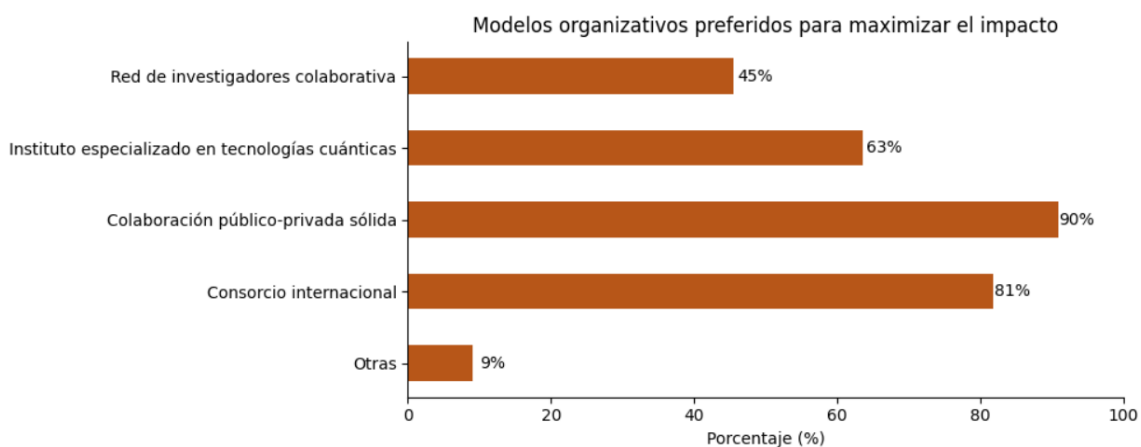


Figura 5. Modelos organizativos considerados más adecuados para maximizar el impacto en tecnologías cuánticas (según la encuesta a expertos). La mayoría aboga por alianzas público-privadas e institutos especializados, seguido por la participación en consorcios internacionales.

- **Instituto o centro de excelencia cuántica dedicado:** Existe un consenso en la necesidad de **concentrar capacidades e infraestructuras** en torno a un centro especializado. Aproximadamente **2 de cada 3 expertos** sugieren crear un **Instituto especializado en Tecnologías Cuánticas** dentro del CSIC, es decir, una unidad centralizada (o red coordinada) que cuente con instalaciones propias de vanguardia para experimentación cuántica. Actualmente, uno de los obstáculos señalados es la **falta de infraestructuras adecuadas** en España (ver Figura 3), por lo que dotar a este instituto de laboratorios punteros (criogenia, salas limpias para nanofabricación, láseres avanzados, etc.) sería prioritario. Un instituto dedicado permitiría también **atraer talento internacional**, concentrar proyectos estratégicos y servir de referencia nacional. Este modelo se alinea con esfuerzos en otros países: por ejemplo, Alemania cuenta con nuevos centros como el **Centro de Tecnologías Cuánticas Integradas (IQST)** en Ulm/Stuttgart y el **Laboratorio de Óptica Cuántica** en Hamburgo, enfocados en investigación de frontera². En USA, la iniciativa nacional cuántica financió centros en laboratorios nacionales (Argonne, Oak Ridge, etc.), y a nivel nacional por ejemplo, el País Vasco recientemente anunció la creación del **IBM-Euskadi Quantum Center**, fruto de la alianza entre el Gobierno Vasco e IBM, que invertirá 120 M€ hasta 2028 en un

centro con un computador cuántico IBM y acuerdos con empresas tractoras. Estos ejemplos refuerzan la idea de que contar con **hubs cuánticos** bien equipados es una buena estrategia para competir globalmente.

- **Colaboración público-privada intensa:** Casi la totalidad de los expertos (más del 80%) coincide en que el modelo de mayor impacto pasa por **alianzas estrechas entre organismos públicos de investigación y empresas**. Este enfoque de “*co-innovación*” público-privada implica desde la co-creación de agendas de I+D hasta la compartición de riesgos y recursos. Para el CSIC, esto se traduciría en establecer **convenios de colaboración, laboratorios mixtos o consorcios con empresas** interesadas en las tecnologías cuánticas. Por ejemplo, podría replicarse el modelo de algunos **centros Fraunhofer** en Alemania, que trabajan directamente con la industria para llevar tecnologías del laboratorio al mercado². Un caso ilustrativo es el **Fraunhofer Centre for Applied Photonics (CAP)** en Reino Unido, que ha actuado como puente tecnológico en numerosos proyectos cuánticos colaborativos, desde el desarrollo de fuentes láser para comunicaciones cuánticas hasta sistemas completos de sensores de átomos fríos, en estrecha asociación con empresas de los sectores aeroespacial y de defensa. Este tipo de interacciones permiten orientar la investigación hacia soluciones concretas, acelerando la **transferencia de conocimientos** y aumentando la financiación disponible (al combinar fondos públicos con inversión privada). En España, además del proyecto CUCO³, convendría impulsar **plataformas público-privadas** en torno a retos cuánticos específicos (por ejemplo, un consorcio para desarrollar un prototipo de sensor cuántico para uso biomédico, con participación de hospitales y empresas de tecnología sanitaria). La colaboración con grandes empresas puede proporcionar casos de uso reales, datos y escenarios donde probar las tecnologías, a la vez que prepara a dichas empresas para adoptar los avances (reduciendo la *brecha de conocimiento* entre academia e industria, identificada como barrera en la integración de estas tecnologías).
- **Redes de investigadores y consorcios (nacionales e internacionales):** Otra pieza importante del puzzle de la innovación es la organización en **redes colaborativas**. Aunque el CSIC no cuenta actualmente con un instituto dedicado específicamente a tecnologías cuánticas, sí dispone de una **red interna de grupos de investigación**, articulada a través de la Plataforma de Tecnologías Cuánticas (QTEP). A partir de esta base, resulta fundamental **impulsar una red distribuida más amplia**, que integre no solo a grupos del CSIC, si no también a universidades y otros actores relevantes, que fomente una colaboración efectiva entre equipos, evitando el trabajo en silos. Un experto recomendó “*coordinar una red de centros de excelencia cuántica, nacional, interconectada con las europeas*”. Esto sugiere establecer mecanismos formales de coordinación entre las distintas unidades que investigan temas cuánticos en España, compartiendo

² cap.fraunhofer.co.uk

³ El proyecto CUCO (Computación Cuántica en la Industria) es una iniciativa española de colaboración público-privada que busca explorar el potencial de la computación cuántica para resolver problemas complejos en sectores estratégicos como la energía, la automoción, la ingeniería o las finanzas. Está coordinado por GMV y cuenta con la participación de grandes empresas, universidades y centros de investigación.

infraestructuras y conocimiento (por ejemplo, bancos de pruebas, clústers de computación, etc.). A nivel internacional, la participación en **consorcios globales** es igualmente esencial, e incluso en colaboraciones transatlánticas con USA, Canadá, Japón, etc. Esto facilita el acceso a proyectos punteros, talento internacional, y a estar al día de avances que ningún grupo aislado podría lograr. Ser parte de consorcios internacionales también **visibiliza la capacidad científica del CSIC** y puede atraer financiación competitiva de la UE. En concreto, los expertos ven con buenos ojos que el CSIC lidere o colidere iniciativas europeas en áreas donde tenga fortaleza (por ejemplo, simulación cuántica en química, o desarrollo de cierto tipo de hardware). También sugieren aprovechar la infraestructura de **supercomputación nacional** (Red Española de Supercomputación) integrándola con capacidades cuánticas experimentales, por ejemplo, el **CESGA** en Galicia que instalará un computador cuántico conectado a su supercomputador tradicional creando de facto un **ecosistema distribuido híbrido cuántico-clásico**.

- **Agilidad organizativa y apoyo estratégico:** Más allá de la estructura formal, varios participantes hicieron hincapié en **reformas internas** para potenciar la excelencia. Señalan la importancia de reducir la burocracia en la gestión de proyectos e inversiones científicas (ya que los trámites administrativos lentos pueden dejar fuera a los centros españoles de la carrera cuántica internacional). Asimismo, recomiendan políticas agresivas de **captación de talento**, facilitando la incorporación de jóvenes investigadores altamente cualificados, incluso desde el extranjero, con contratos atractivos y estabilidad. *“Apostar por talento joven internacional de forma seria y ambiciosa”*, resume un experto. Esto requeriría no solo financiación, sino también ofrecer perspectivas de carrera, laboratorios equipados y quizás crear **programas de cátedras o tenure-track cuánticas**⁴ en el CSIC. Otro aspecto señalado es cuidar la **imagen y visibilidad** del organismo, mediante la promoción de visitas, demostraciones de tecnología, comunicación divulgativa y marketing científico, para posicionar al CSIC como actor central en este ámbito (como anécdota alguno de los expertos referencia cómo en una visita con una startup japonesa percibió instalaciones descuidadas, algo a corregir para impresionar a potenciales colaboradores internacionales).

Como breve extracto de todas estas ideas que han suministrados los expertos, se puede resumir que el modelo óptimo combina un **núcleo fuerte (instituto)** con capacidades propias de I+D, enlazado con una **“constelación” de colaboraciones:** alianzas empresa-centro, redes nacionales temáticas y participación en esquemas internacionales. Esta combinación permitiría al CSIC tanto **generar ciencia de excelencia** (a través de laboratorios y equipos dedicados) como **orientarla hacia el impacto** (mediante las colaboraciones estratégicas). Cabe reforzar que, para sostener este modelo, hará falta un incremento sustancial en la **financiación** y un apoyo institucional claro, aspectos abordados en la siguiente sección.

⁴ Se trata de un modelo de contratación muy usado en países como USA. o Alemania, que **permite a jóvenes investigadores prometerles una plaza permanente** si cumplen ciertos objetivos en unos años (normalmente 4-6). En España es menos común, pero ya se empieza a aplicar en algunas universidades y centros (por ejemplo, el ICREA en Cataluña o programas Ramón y Cajal).

Colaboración entre investigadores e industria

Una investigación de excelencia en tecnologías cuánticas requiere una **colaboración fluida** tanto intra como interinstitucional, abarcando la academia, centros tecnológicos y la industria. Los expertos consultados ofrecieron ideas sobre **cómo deberían relacionarse los investigadores entre sí y con la industria** para maximizar la innovación:

- **Colaboración multidisciplinar interna:** Dado el carácter interdisciplinar de las tecnologías cuánticas (física, ingeniería, ciencia de materiales, computación, matemáticas...), se enfatiza la necesidad de **equipos y proyectos multidisciplinares**. En lugar de grupos aislados trabajando cada uno en “su” área, se propone fomentar proyectos integrados donde, por ejemplo, físicos experimentales trabajen junto a expertos en software/cuántico y especialistas en alguna aplicación (química, biología, etc.). El CSIC, con su amplia variedad de institutos (microelectrónica, física fundamental, química, inteligencia artificial, etc.), está bien posicionado para orquestar estas colaboraciones internas. Se podrían crear **programas transversales cuánticos** que unan departamentos distintos (por ejemplo, un programa de *Quantum Computing for Biology* involucrando al Instituto de Física Fundamental y a un instituto de biología molecular del CSIC). Este enfoque derriba barreras disciplinarias e **incrementa la creatividad** en la resolución de problemas, facilitando también la formación cruzada de jóvenes científicos en varias áreas. La creación de una **Red de investigadores cuánticos nacional**, aunque tuvo menor apoyo relativo en la encuesta (véase Figura 5), también fue mencionada. Ya existen intentos como la **Red Española de Tecnologías Cuánticas**, pero los expertos ven margen para reforzarla, con mayor coordinación desde el propio CSIC y posiblemente otras agencias.
- **Vínculos con la industria (grandes empresas y PYMEs):** Como ya se destacó en el modelo organizativo, **estrechar lazos con el sector productivo** es crítico. Los expertos sugieren varias formas prácticas de lograrlo: **proyectos de I+D cooperativos** (cofinanciados por fondos públicos y empresas, con objetivos de desarrollos tecnológicos concretos), **estancias de investigadores en empresas y viceversa**, foros periódicos de encuentro (workshops, hackatones cuánticos con participación de ambos mundos) y, muy importante, **casos piloto de uso**. Respecto a esto último, se propone identificar junto con empresas problemas específicos donde una solución cuántica (o cuántico-inspirada) pueda aplicarse, y desarrollar **pruebas de concepto** que demuestren el valor añadido. Lograr *early adopters* industriales servirá para **pulir la tecnología** con feedback real y para crear “*evangelizadores*” corporativos que difundan los beneficios. Algunos expertos también ven necesario **educar a la alta dirección de empresas e instituciones** sobre la realidad cuántica para alinear expectativas. En palabras de un experto, “*hace falta educar a empresas del IBEX y PYMEs innovadoras*” sobre lo que estas tecnologías pueden (y no pueden aún) hacer. Este esfuerzo formativo podría adoptar la forma de **cursos ejecutivos, seminarios y material divulgativo** ofrecido por el CSIC en colaboración con universidades y clústers empresariales.
- **Ecosistema de innovación abierta:** Más allá de colaboraciones bilaterales CSIC-empresa, se apunta a crear un **ecosistema más amplio** que incluya startups,

centros tecnológicos, agencias públicas y usuarios finales. Una idea concreta es establecer un **“Quantum Hub”** como la manera óptima de que confluyan todos estos actores. Por ejemplo, el **Basque Quantum** lanzado en 2023 reúne al Gobierno Vasco, IBM, universidades y empresas para impulsar conjuntamente varias iniciativas cuánticas. Del mismo modo, el CSIC podría liderar un **hub nacional cuántico** que organice desafíos tecnológicos (*grand challenges*), aporte infraestructura compartida (como acceso en la nube a prototipos de computadores cuánticos para desarrolladores, similar al modelo IBM Quantum Experience) y sirva de incubadora de proyectos. Este hub podría tener sedes físicas (laboratorios abiertos) y virtuales (plataformas online de experimentación cuántica). Varias respuestas enfatizaron también la colaboración con **consorcios europeos**, en ese sentido, el CSIC debería seguir participando activamente en proyectos Horizon Europe sobre cuántica, y trabajar de la mano con redes como la **Quantum Industry Consortium (QuIC)** europea que aglutina empresas e instituciones del sector.

- **Colaboración con otros sectores científicos:** Un punto interesante es extender la colaboración **más allá del ámbito cuántico per se**. Es decir, vincular a los investigadores cuánticos con aquellos sectores que podrían beneficiarse de la tecnología. Por ejemplo, colaborar con bioinformáticos para explorar algoritmos cuánticos en genómica, o con climatólogos para aplicaciones en modelos climáticos. Esta **inmersión en problemas reales de otros dominios** ayudará a descubrir aplicaciones de alto valor social y económico, evitando que la investigación cuántica quede confinada al laboratorio sin conectar con necesidades reales. Algunos expertos advierten que es necesario *“identificar áreas de aplicación con ROI (Retorno de la Inversión) real y dejar de lado proyectos de innovación que solo buscan la nota de prensa”*. Por tanto, una comunicación frecuente con otros sectores (mediante comités interdisciplinarios, proyectos transversales o incluso estancias) permitirá enfocar esfuerzos en donde haya un **retorno tangible** potencial.

Intentando aglutinar las ideas en este apartado, se puede resumir que los expertos ven importante que la colaboración en el ámbito cuántico deba ser **extensa y diversa**. La era de la ciencia individual o aislada ha quedado atrás en un campo tan complejo; el éxito dependerá de **equipos integrados, alianzas estratégicas con la industria** y una **comunidad cohesionada** que intercambie conocimiento ágilmente. Los expertos insisten en que la estructura institucional debe facilitar, y no entorpecer, estas relaciones. Cuando se les preguntó qué falta para la integración efectiva de las tecnologías cuánticas en la industria, mencionaron la **falta de visibilidad de las aplicaciones reales** y la **escasez de comunicación entre empresas e investigadores** como barreras urgentes a abordar. Por ello, recomiendan intensificar eventos de transferencia, **demostradores tecnológicos** y espacios de encuentro que conecten la oferta científica con la demanda empresarial.

Impulso de la transferencia tecnológica hacia las empresas

La **transferencia de tecnología** desde los laboratorios hacia el tejido productivo es un objetivo central para convertir la inversión en I+D en crecimiento económico y liderazgo industrial. En el ámbito de las tecnologías cuánticas, los expertos reconocen que esta transferencia enfrenta desafíos especialmente particulares debido al **bajo nivel de madurez (TRL)** de muchas de estas tecnologías. A continuación, se sintetizan las recomendaciones proporcionadas para **fomentar y acelerar la transferencia tecnológica** hacia las empresas:

- **Apoyo a Startups y Spin-offs cuánticas:** Una de las medidas más repetidas es reforzar el **emprendimiento de base cuántica**. En la encuesta, **64% de los expertos** priorizaron explícitamente el “*apoyo a startups y empresas emergentes en el sector cuántico*” (véase la Figura 4), lo que incluye facilitar la creación de spin-offs desde los centros de investigación. Se proponen **programas de incubación y aceleración especializados** en tecnologías cuánticas, con financiación semilla (capital semilla), mentorización experta y acceso a instalaciones del CSIC para desarrollos iniciales. También se ve con buenos ojos incrementar instrumentos como subvenciones **NEOTEC** (CDTI) u otros fondos públicos dedicados a proyectos empresariales cuánticos en etapas tempranas. El objetivo es crear un *pipeline* donde los resultados científicos prometedores puedan transformarse en prototipos comerciales en startups con el acompañamiento institucional adecuado. España ya cuenta con casos de éxito emergentes: *Multiverse Computing* (software cuántico para finanzas) o *Qilimanjaro* (computación cuántica analógica) que surgieron de entornos académicos o las propias surgidas del CSIC como son G2-Zero, Inspiration-Q, Nanological, Q-Dynamics. Consolidar más empresas así ayudaría a retener talento (ofreciendo salidas profesionales a doctores e ingenieros especializados) y atraer inversión privada al sector.
- **Mecanismos de financiación adaptados:** La financiación pública tradicional de la ciencia (proyectos competitivos académicos) puede no ser suficiente para llevar este tipo de tecnologías disruptivas a mercado. Los expertos sugieren modelos específicos como **fondos de prueba de concepto** (*PoC grants*) orientados a madurar resultados hacia un producto mínimo viable. También abogan por **financiación estable y a largo plazo** para líneas cuánticas estratégicas: por ejemplo, programas de 5-10 años que permitan desarrollar prototipos complejos sin la incertidumbre de convocatorias anuales. Esto es crucial sobre todo en hardware experimental, donde montar un laboratorio cuesta millones y requiere continuidad. Un experto enfatiza que “*no es posible reclutar buenos experimentalistas a coste cero y pedirles que lo arranquen todo sin apoyo*”, resaltando la necesidad de inversión de riesgo inicial para montar laboratorios especializados. Otra idea es involucrar en la financiación a actores privados mediante **consorcios público-privados**: por ejemplo, crear un programa cofinanciado al 50% por administraciones y grandes empresas para resolver retos concretos (similar a los **CIEN** del CDTI, pero enfocados en cuántica). De hecho, uno de los encuestados plantea directamente “*la creación de consorcios público-privados para la resolución de retos concretos mediante proyectos colaborativos*”. Este esquema permite que la empresa co-defina el objetivo (asegurando

relevancia de mercado) y que luego adopte los resultados, mientras los centros reciben recursos adicionales. Por último, se destaca la importancia de aprovechar fondos europeos (Digital Europe, Horizon Europe, etc.) y nacionales (Planes de Recuperación) orientados a transferencia: **Quantum Spain** y el **Fondo NextTech** son ejemplos de movilización de capital público-privado para tecnologías disruptivas. El CSIC debe posicionarse para canalizar parte de esos fondos hacia sus iniciativas (por ejemplo, liderando propuestas consorciadas) y demostrar capacidad de ejecución. En este sentido, sería estratégico que el CSIC colabore con otros actores públicos y privados en el diseño de **instrumentos financieros** orientados a incrementar la inversión privada en tecnologías cuánticas. La baja movilización de capital privado en España se muestra como una debilidad estructural frente a otras potencias, como USA. Por ello, a nivel de las administraciones públicas sería fundamental explorar la introducción de incentivos fiscales a empresas inversoras, esquemas de cofinanciación como la plataforma STEP⁵, o modelos inspirados en la Quantum Act⁶ europea para apoyar *start-ups deep-tech* en fases tempranas.

- **Infraestructura compartida y acceso abierto:** Para bajar las barreras de entrada a la experimentación cuántica de empresas (especialmente PYMEs), se sugiere que el CSIC ofrezca **infraestructuras como servicio**. Esto podría incluir permitir a empresas el uso (en modo *sandbox*) de instalaciones singulares (sala blanca de nanofabricación, banco de pruebas de fotónica cuántica, computadores cuánticos experimentales vía cloud, etc.) bajo convenios. Tal enfoque reduce la necesidad de inversión inicial de la empresa y agiliza que puedan “*probar antes de comprar*” la tecnología. Un experto menciona específicamente facilitar “*acceso a sistemas de computación cuántica en modo nube*” e **integración con entornos clásicos/ML** existentes, para que desarrolladores industriales puedan empezar a experimentar con algoritmos cuánticos sin tener hardware propio. Iniciativas similares existen a nivel internacional: IBM, IonQ y otros ya ofrecen acceso remoto a sus procesadores cuánticos; en España, la alianza con IBM en Euskadi dará acceso al IBM Quantum System One a empresas locales. El CSIC podría negociar acuerdos para ofrecer esos accesos a la comunidad científica-industrial más amplia, y a futuro, si cuenta con un procesador cuántico propio (vía Quantum Spain), abrirlo en un modelo de *Quantum HPC* nacional.
- **Facilitar la gestión de la propiedad intelectual (PI):** Un aspecto práctico de la transferencia es cómo se manejan patentes, licencias y propiedad intelectual generada en el CSIC. Para acelerar la transferencia, es importante tener **políticas de PI flexibles y proactivas**. Esto podría incluir la identificación temprana de los resultados patentables y apoyarlos (con abogados de patentes especializados en cuántica), licenciar tecnologías a startups de manera ágil y con condiciones favorables (por ejemplo, royalties bajos los primeros años), e incluso explorar modelos de **open innovation** en los que ciertos desarrollos se liberen

⁵ La Plataforma de Tecnologías Estratégicas para Europa (STEP, por sus siglas en inglés) es una iniciativa de la UE lanzada en 2023 para coordinar y reforzar la inversión en tecnologías críticas como la microelectrónica, la inteligencia artificial, la computación cuántica o las tecnologías limpias, con el objetivo de fortalecer la soberanía tecnológica e industrial de Europa.

⁶ Quantum Act es una propuesta legislativa europea destinada a consolidar el liderazgo de la UE en tecnologías cuánticas, mediante el refuerzo de programas de financiación, la creación de infraestructuras compartidas y el impulso a la colaboración público-privada en áreas como la computación, comunicación y sensorica cuántica.

abiertamente para fomentar su adopción estándar (pensemos en protocolos o software cuántico). Los expertos hicieron notar la necesidad de “*mecanismos de transferencia más ágiles y facilitar el acceso de las empresas a recursos y conocimientos del CSIC*”. Esto podría traducirse en oficinas de transferencia especializadas en tecnologías deep-tech, con equipos comerciales que hablen el lenguaje de la industria y promuevan activamente la cartera de tecnologías cuánticas del CSIC en ferias, congresos y visitas corporativas.

- **Casos de éxito y divulgación:** Finalmente, un factor que **cataliza la transferencia** es la existencia de **historias de éxito** que otros quieran emular. Alguno de los expertos menciona que, hasta la fecha, “*no hay aún resultados concretos a nivel de aplicación práctica que demuestren una ventaja de negocio*” en la mayoría de las industrias, si bien existen pruebas de concepto prometedoras. Por tanto, es vital que en los próximos años el CSIC contribuya a lograr **demos aplicadas**: por ejemplo, un algoritmo cuántico corriendo en hardware real que supere a un método clásico en un problema de química o de finanzas, etc. Una vez haya uno o dos éxitos tangibles (aunque sean modestos), se debe **comunicar ampliamente** a la industria y sociedad, para romper la percepción de que la cuántica es solo teórica o a muy largo plazo. Organizar eventos demostrativos, challenges públicos (como Kaggle pero de algoritmos cuánticos), o publicar *white papers* con resultados en colaboración con empresas, ayudará a **crear tracción**. Del lado contrario, también conviene **gestionar las expectativas**: los expertos advierten contra la **sobre-promesa**. Una comunicación equilibrada, celebrando los hitos, pero aclarando las limitaciones actuales, mantendría el apoyo sin generar desilusión.

Por tanto, en este apartado e intentando sintetizar las ideas de los expertos, para **llevar la innovación cuántica del laboratorio al mercado**, el CSIC debe actuar en múltiples frentes: fomentar un “**vibrante**” **tejido de startups** y spin-offs (apoyando a los emprendedores científicos), co-desarrollar con la industria soluciones a problemas reales, dotar de **financiación y espacios adecuados** para la experimentación aplicada, y derribar obstáculos burocráticos o de PI que ralentizan la transferencia. Los expertos coinciden en que España tiene una base científica notable en cuántica, pero transformar ese conocimiento en impacto económico requiere **políticas activas de transferencia**. Varios de nuestros países vecinos han lanzado programas en esa dirección (por ejemplo, el Reino Unido integró la participación industrial desde el inicio de su Programa Nacional Cuántico, y Alemania está incentivando la creación de *startups* cuánticas con fondos gubernamentales). Por tanto, es imperativo que el CSIC y las agencias nacionales acompañen la excelencia científica con igual empeño en la **excelencia innovadora**, cerrando así el ciclo de I+D+i.

Recomendaciones finales

A la luz de todo lo analizado anteriormente, se presentan a continuación **5 recomendaciones clave** para los responsables del CSIC, recopilando los puntos prioritarios identificados por los expertos y reforzado con casos de éxitos internacionales:

- 1. Priorización de líneas de I+D cuánticas con alto potencial:** En su plan estratégico, el CSIC debe focalizar recursos en las áreas cuánticas más prometedoras:
 - ✓ **Sensores y metrología cuántica**, donde es factible lograr aplicaciones comerciales en el corto-medio plazo (magnetometría, relojes atómicos, etc.).
 - ✓ **Computación cuántica escalable**, incluyendo hardware (chips superconductores, trampas de iones, fotónica integrada) y software/algoritmos (especialmente simulación cuántica de materiales y química).
 - ✓ **Comunicaciones cuánticas seguras**, apoyando desarrollos en QKD, repetidores y redes cuánticas.
 - ✓ **Algoritmos/cuántica aplicada a problemas industriales** (optimización, machine learning, criptografía poscuántica).

Parece recomendable un equilibrio entre investigación fundamental (por ejemplo, corrección de errores, nuevos estados cuánticos) y la orientada a aplicaciones concretas. Destaca prioritariamente el campo de los sensores y los chips cuánticos aplicados a defensa y biotecnología como ámbitos en los que existe menor competencia global y mayores opciones de liderazgo. Para el CSIC, focalizar sus capacidades en estas líneas puede representar una ventaja comparativa frente a otros actores más avanzados en computación cuántica general, un campo donde la competencia global es mucho más intensa. Para lograr esto, una opción sería crear programas internos dedicados a estas áreas, con financiación pluriannual, y evaluar periódicamente su avance en métricas científicas y de transferencia.

- 2. Creación de un “Instituto Cuántico de Excelencia” dedicado con infraestructura de vanguardia:** Establecer (o reforzar) un **centro especializado en tecnologías cuánticas** dentro del CSIC, dotado de equipamiento puntero y personal dedicado. Este instituto actuaría como **nodo central** que concentre laboratorios (criogenia, micro/nanofabricación, computación de alto rendimiento, etc.), atraiga talento internacional con ofertas competitivas y coordine las iniciativas cuánticas dispersas en otros centros. El instituto debe concebirse con una visión abierta: sirviendo de *hub* para colaboraciones con universidades, participando en redes globales y facilitando acceso a sus instalaciones a proyectos externos estratégicos. Conseguir financiación extraordinaria (nacional y europea) para montar las **infraestructuras críticas** (por ejemplo, salas limpias para nanofotónica cuántica, o un centro de datos cuántico) podría ser crucial; se pueden alinear estas inversiones con fondos *Next Generation EU* u otros programas. Este instituto, respaldado al más alto nivel por el CSIC, será la **cara**

visible de la apuesta cuántica española, aumentando la capacidad de competir con los grandes centros internacionales.

Como estrategia complementaria, se propone valorar, en una primera fase, el refuerzo coordinado de las capacidades existentes antes de la creación de un instituto específico. En lugar de partir desde cero, puede resultar más eficaz identificar y potenciar aquellos grupos que ya muestran un desempeño destacado en líneas clave (como el desarrollo de materiales cuánticos, sensores avanzados o computación híbrida), asegurando una financiación dirigida a objetivos concretos y evaluables. La red de grupos que forman parte de la plataforma QTEP muestra que el CSIC cuenta con nodos de excelencia científica en distintos centros y especialidades, a menudo afectados por la dispersión y la baja masa crítica, que podrían formar el núcleo de una red articulada de colaboración y especialización progresiva. Esta aproximación gradual permitiría avanzar en la estructuración del ecosistema cuántico del CSIC desde una base ya consolidada, favoreciendo impactos a corto y medio plazo sin perder ambición estratégica a largo plazo.

3. **Impulso de Alianzas Público-Privadas y Consorcios de Innovación:** Desarrollar una estrategia decidida de **colaboración con la industria**. Esto puede implicar, entre otras:
 - ✓ La identificación de algunos **proyectos tractores** en tecnologías cuánticas de interés industrial (por ejemplo, un prototipo de sensor cuántico para salud, o un módulo de cifrado cuántico para comunicaciones críticas) e involucrar desde el inicio a empresas relevantes en su co-desarrollo.
 - ✓ Establecer **convenios marco** con corporaciones (nacionales o multinacionales con presencia en España) para cooperación en I+D cuántico, con intercambio de personal incluido cuando sea posible.
 - ✓ Participar activamente en **consorcios público-privados** como los financiados por CDTI (proyectos CIEN u otros), presentando propuestas alineadas con las tecnologías cuánticas prioritarias. El CSIC debería también explorar la creación de **laboratorios conjuntos** con empresas (similar a los “*Joint Research Labs*” internacionales), donde personal mixto trabaje bajo el mismo techo en resolver problemas específicos con soluciones cuánticas. Estas fórmulas permitirán compartir costes y riesgos, a la par que aseguran que la investigación del CSIC tenga un camino claro hacia la aplicación. A nivel internacional, sería recomendable que el CSIC siga e intensifique su liderazgo en programas colaborativos como el **Quantum Flagship** de la UE, buscando ser coordinador en más proyectos europeos e integrándose en redes globales. La **diplomacia científica** cuántica será importante: vincularse con hubs de otros países (Francia, Alemania, UK, USA., Canadá, etc.) para intercambiar mejores prácticas, resultados y eventualmente desarrollar estándares comunes.
4. **Aumento de la financiación y búsqueda de nuevos modelos de apoyo:** Como cimientamiento de todo lo anterior, sería imprescindible un **incremento notable en la inversión en I+D cuántica**. Los expertos recomiendan abogar ante las instancias

gubernamentales por un **plan de financiación sostenido a 10 años** para tecnologías cuánticas, con recursos para personal, infraestructuras y proyectos. Más allá del presupuesto base, aprovechar oportunidades de financiación competitiva: por ejemplo, liderar propuestas al programa *HEurope* de la Comisión Europea en temas cuánticos, o a iniciativas como **EuroHPC JU** que cofinancia ordenadores cuánticos piloto. Complementariamente, adaptar los modelos de financiación existentes, creando **convocatorias específicas** (o cupos dedicados) en planes nacionales para proyectos cuánticos de alto riesgo/alto impacto, con evaluadores expertos internacionales dada la especificidad del área. Explorar instrumentos de **compra pública innovadora** en cuántica, por ejemplo, que ciertos ministerios cofinancien desarrollos cuánticos que necesiten (defensa, sanidad, etc.) asegurando un “cliente lanzador”. Adicionalmente, dotar de **flexibilidad administrativa** a los centros que ejecuten estos proyectos: autorizaciones para contratar rápidamente talento internacional, facilidades en importación de equipos especiales, etc. Sin este soporte financiero y normativo, las mejores estrategias pueden verse mermadas. Los expertos unánimemente priorizaron la “*mayor inversión en I+D y creación de centros de excelencia*” como medida necesaria, lo cual refuerza que, sin recursos suficientes, el resto de recomendaciones no alcanzará el impacto deseado.

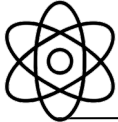
- 5. Desarrollo de talento y capital humano cuántico:** Fortalecer la **formación de especialistas cuánticos** y la atracción de talento es vital para sustentar el ecosistema. Se recomienda al CSIC colaborar con universidades en la creación de **programas de posgrado especializados** (másteres y doctorados en tecnologías cuánticas) para aumentar el flujo de investigadores jóvenes formados. Asimismo, instaurar **programas de becas y contratos postdoctorales** específicamente en este ámbito, incluyendo oportunidades de estancias en centros de referencia en el extranjero para adquirir experiencia. Paralelamente, implementar un plan para **retener y atraer líderes**, ofreciendo plazas estables a científicos destacados (nacionales o extranjeros) que trabajen en campos cuánticos, simplificando su incorporación. Un punto crítico señalado por los expertos es reducir la burocracia en la contratación y oferta de condiciones competitivas a nivel internacional. Esto puede requerir iniciativas excepcionales en coordinación con las administraciones (por ejemplo, un programa tipo “*ICREA Cuántica*” a nivel nacional). También es aconsejable fomentar la **formación continua** del personal del CSIC en estas nuevas áreas: cursos internos, estancias cortas en laboratorios punteros, etc., para reconvertir o actualizar a investigadores de campos afines interesados en sumarse a la “ola cuántica”. Por último, promover la **divulgación** y vocaciones STEM cuánticas desde etapas tempranas (charlas en grados, eventos en institutos, etc.) ayudará a garantizar una **cantera** a medio plazo de científicos e ingenieros preparados. En resumen, sin personas formadas y motivadas, será más complicado los avances. Invertir en talento es invertir en el futuro cuántico.

Las tecnologías cuánticas representan tanto una **oportunidad estratégica** como un desafío organizativo. El CSIC, como buque insignia de la ciencia española, tiene la posibilidad y responsabilidad de desempeñar un papel protagonista en la revolución cuántica focalizando sus esfuerzos en líneas prioritarias con potencial transformador, adaptando su modelo organizativo hacia la colaboración y la agilidad, e impulsando

decididamente la conversión del conocimiento en innovación. Esta aproximación a una hoja de ruta, dirigida por la voz de una comunidad de expertos relevantes, sitúa a la **excelencia científica** y la **relevancia socioeconómica** como dos caras de la misma moneda. Alcanzar el equilibrio óptimo entre ambas será clave para que España y el CSIC como líder, se posicionen a la vanguardia de la segunda revolución cuántica, contribuyendo al progreso tecnológico y generando un impacto positivo en la sociedad y la economía del país.

Annex II: Developed Activity Timeline

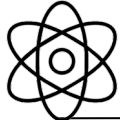




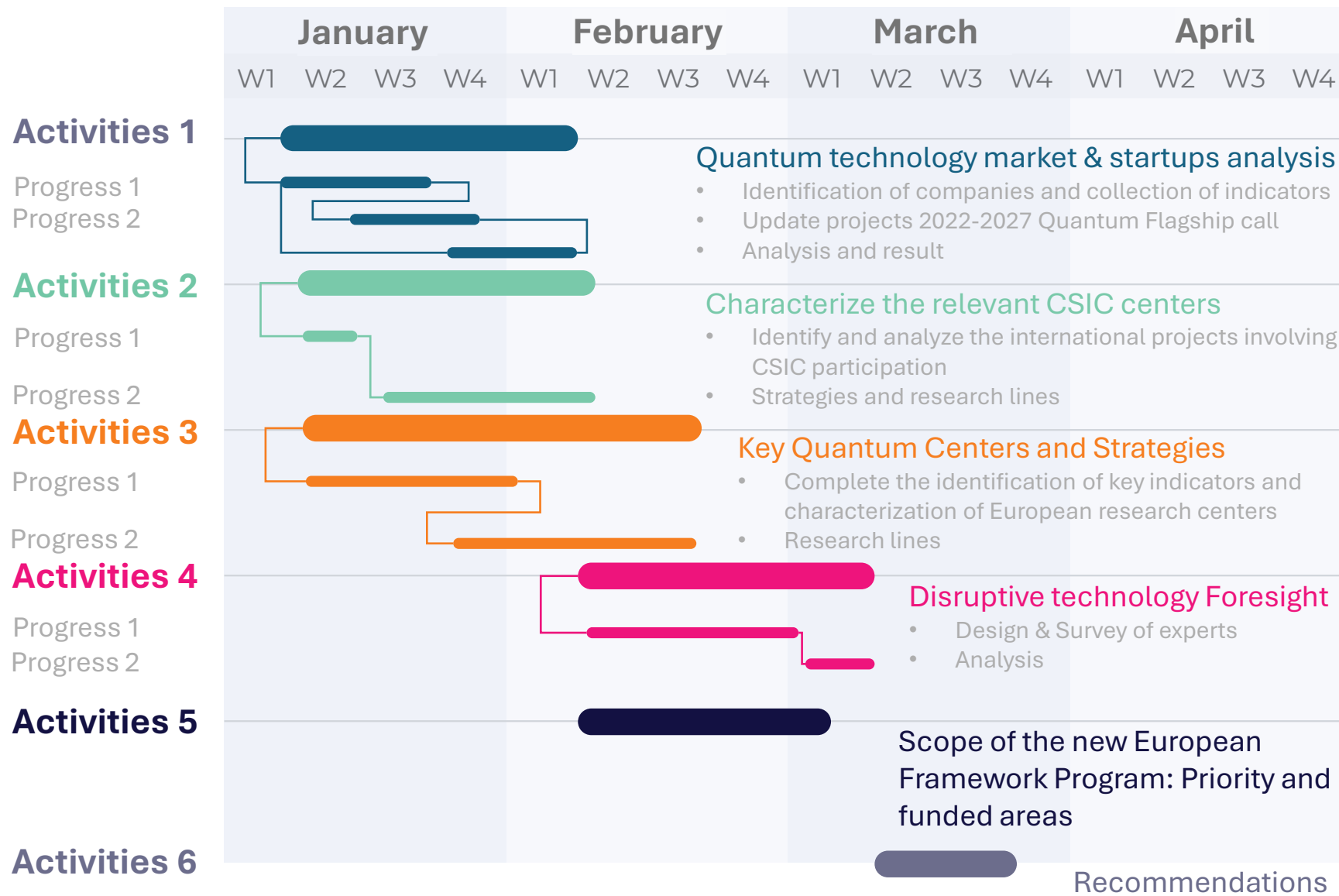
Implemented Activities

- ✓ **Activities 1.** Quantum technology market & startups analysis.
Update of data on European projects identified in the 2022-2027 call of the Quantum Flagship program.
- ✓ **Activities 2.** Characterize the relevant CSIC centers engaged in research activities in Quantum Technologies, along with their strategies and research lines. Identify and analyze the international projects involving CSIC participation.
- ✓ **Activities 3.** Key Quantum Centers and Strategies: Complete the identification of key indicators and characterization of European research centers in quantum technologies to finalize the Roadmap. Complement the information with their main research lines to conduct a comparative analysis.
- ✓ **Activities 4.** Foresight study on disruptive technologies in the emerging field of Quantum technologies.
Consultation with experts from different sectors.
- ✓ **Activities 5.** Scope of the new European Framework Program: Priority and funded areas.
- ✓ **Activities 6.** Recommendations on strategic lines





Implemented Activities Roadmap (2025)





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