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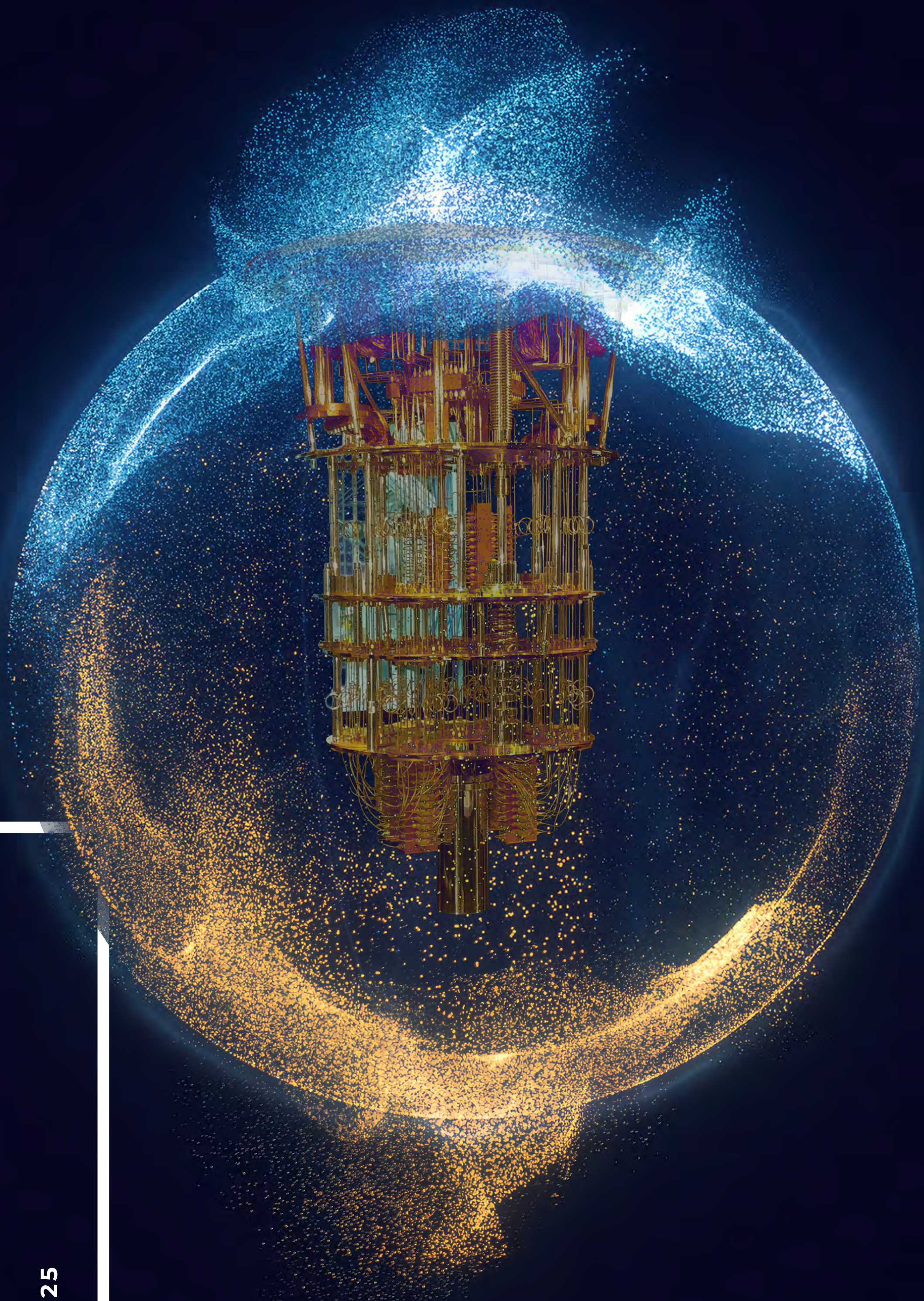

QUANTUM POLICY LAB

DECEMBER 2025

IS EUROPE READY FOR THE QUANTUM AGE?

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FIGURE LIST

ACKNOWLEDGMENTS

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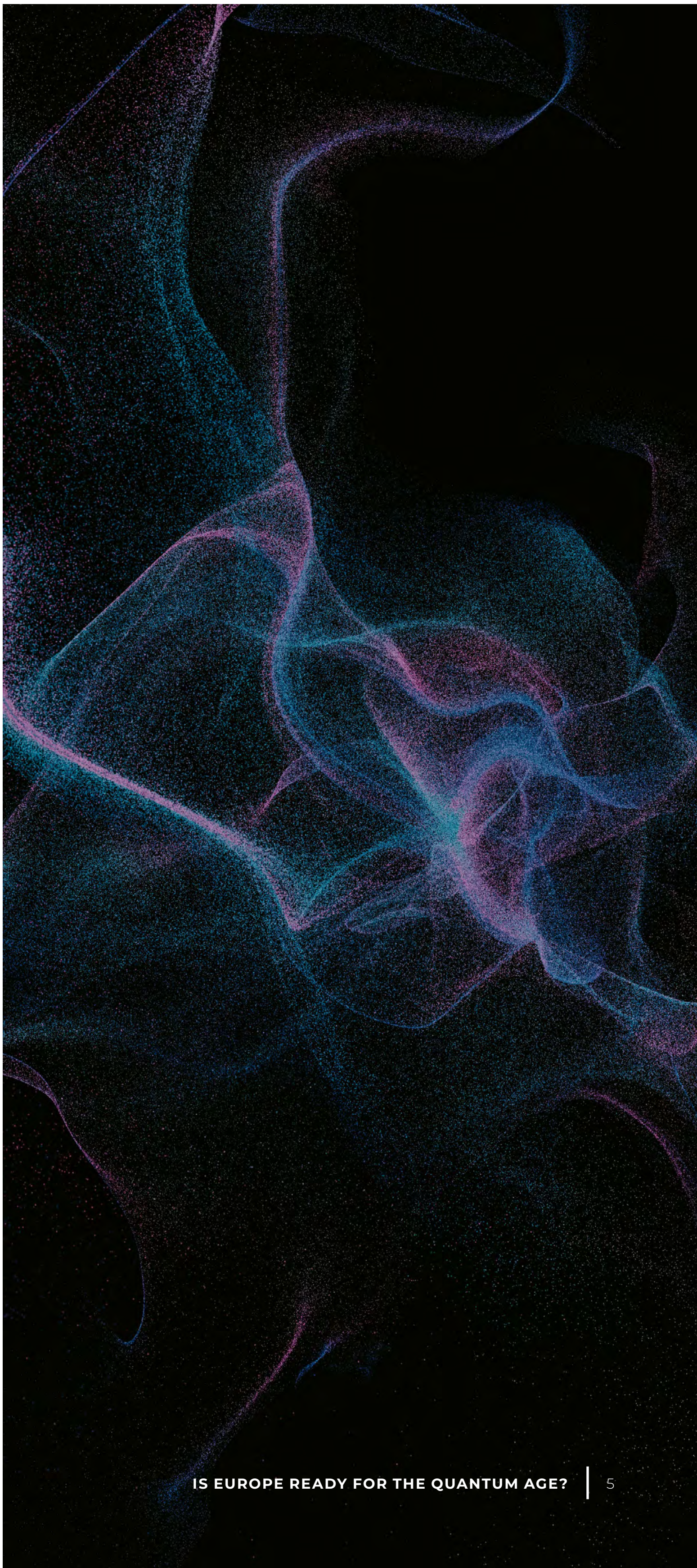


EXECUTIVE SUMMARY

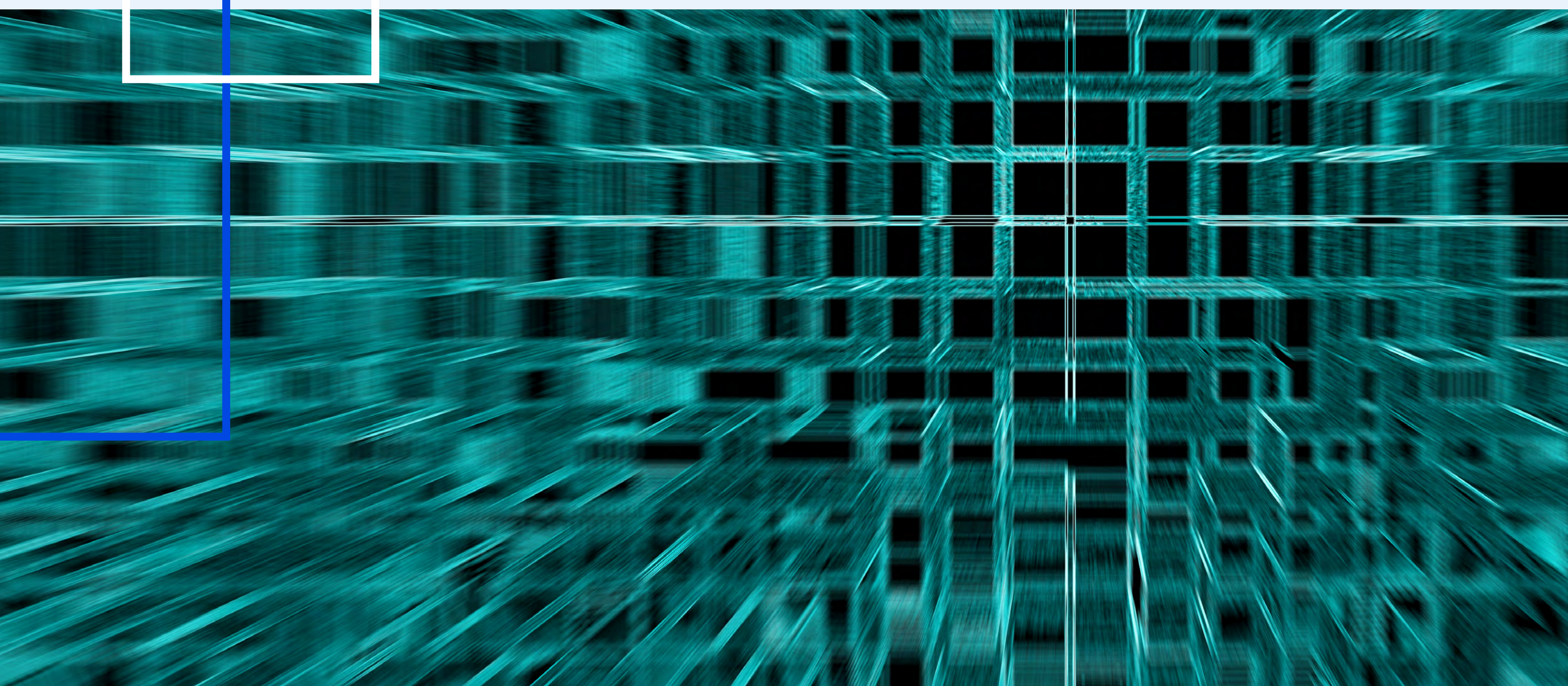
The ***Is Europe Ready for the Quantum Age?*** report examines Europe's readiness to lead in the rapidly evolving field of quantum technologies—a sector that promises to redefine computing, communications, sensing, and cybersecurity. With 2025 marking the *International Year of Quantum Science and Technology* and the launch of the EU's Quantum Europe Strategy, the report assesses whether Europe can transform its scientific excellence into strategic autonomy and industrial leadership by 2030.

CONTEXT AND OBJECTIVES

The EU's new Quantum Europe Strategy seeks to establish Europe as a global quantum leader by 2030 through five pillars: research excellence, infrastructure, ecosystem strengthening, defense and security applications, and talent development.

The **Quantum Policy Lab (QPL)**—a collaboration between the **Center for the Governance of Change (CGC)** at **IE University** and the **Centre for Future Generations (CFG)**—conducted this study to identify barriers and enablers for effective quantum governance and development across Europe.

The report draws on 15 expert interviews with policymakers, industry leaders, and researchers from key EU countries (Spain, France, Germany, Denmark) and a foresight workshop with 12 subject matter experts (Sovereign Quantum Europe by 2040) held in July 2025 at the IE Tower in Madrid. The analysis focuses on four core technology areas—quantum communications, sensing, computing, and post-quantum cryptography—with special attention to defense and cybersecurity as primary use cases.



STRATEGIC PRIORITIES FOR ACTION

To secure Europe's position as a global quantum leader, coordinated action is needed to overcome fragmentation and translate scientific excellence into industrial and strategic strength. This report identifies five strategic priorities to make this vision a reality:

01/ Governance and Sovereignty

- Align national quantum roadmaps under a coherent EU Quantum Strategy.
- Establish a high-level quantum board and permanent secretariat to coordinate and monitor progress.
- Create independent advisory bodies for long-term foresight and strategic guidance.

02/ Industrial Policy and Investment

- Develop 2–3 European hyperscale quantum champions.
- Launch Plan 10×10—a long-term investment fund for deep-tech startups.
- Create defense sandboxes and testbeds for dual-use quantum applications.

03/ Infrastructure and Supply Chains

- Onshore production of semiconductors and critical materials.
- Build an interconnected, multi-platform European quantum hub.
- Secure trusted international supply chain partnerships.

04/ Talent and Culture

- Introduce mobility visas, retention programs, and cross-sector rotations.
- Expand education and upskilling initiatives.
- Encourage risk-taking and experimentation through flexible funding.

05/ Technology Convergence and Diplomacy

- Integrate quantum, AI, and cyber R&D in mission-driven programs.
- Use scientific collaboration as a diplomatic tool.
- Position Europe as a neutral but strategic techno-diplomatic power.

> Europe stands scientifically ready but strategically incomplete. Its challenge is to convert world-class research into sovereign capability.

THREE-HORIZON ROADMAP

Building on the Foresight Workshop, participants developed a three-horizon roadmap to operationalize the five strategic priorities. Each phase includes concrete milestones and builds on the previous one, aligning governance, investment, and diplomacy to progressively strengthen autonomy and industrial capacity.

Short-term (2025–2030):
Implement the EU Quantum Strategy; launch defense sandboxes and the quantum hub; align Member State policies; introduce talent mobility programs.

Medium-term (2030–2035):
Establish European quantum champions and secure supply chains; integrate quantum into defense; strengthen global techno-diplomacy and interoperability.

Long-term (2035–2040):
Operate the world's largest interoperable quantum network; export trusted quantum solutions; embed quantum technologies across Europe's economy and defense.

CONCLUSIONS AND OUTLOOK

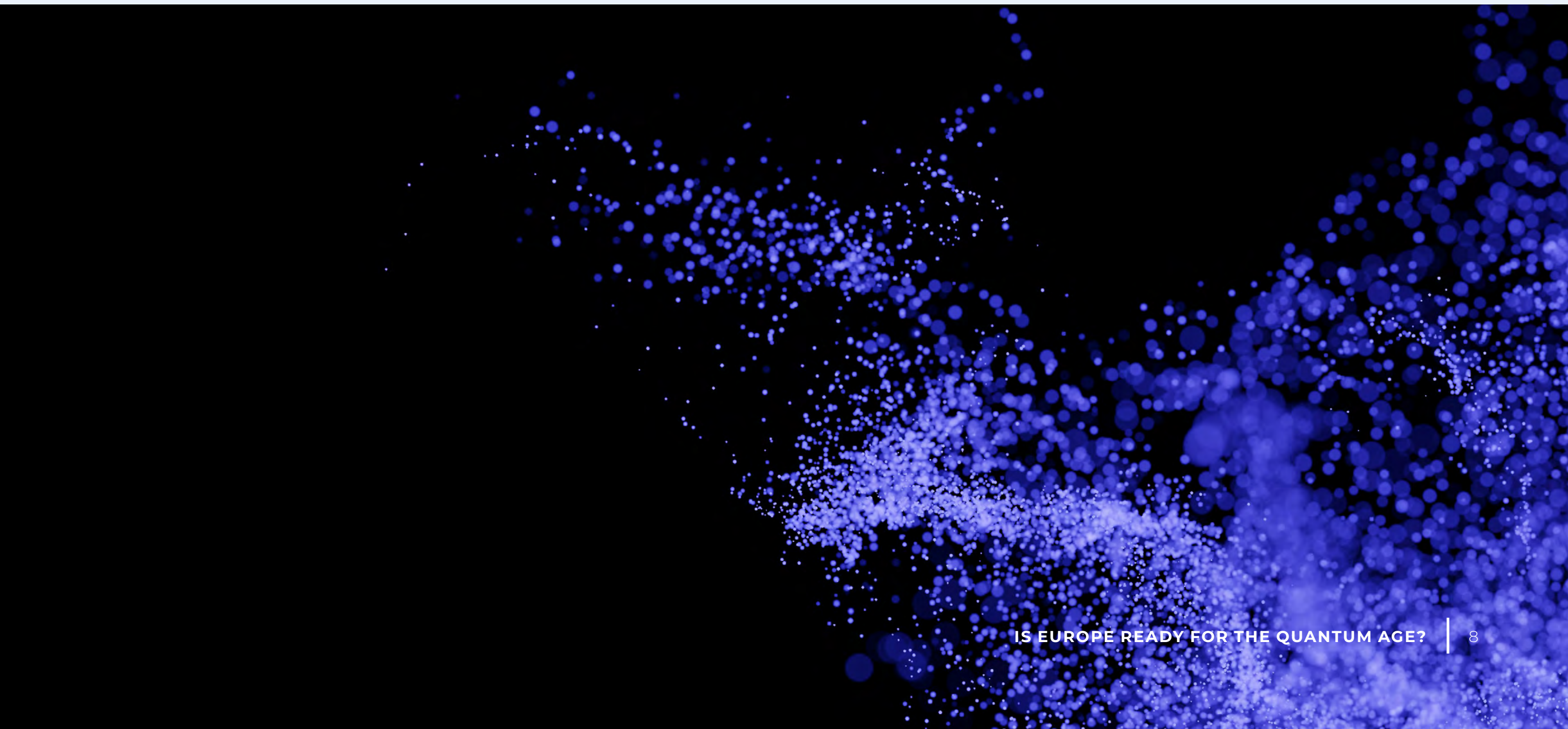
Quantum technologies are becoming a foundation of global power. Europe possesses strong scientific and institutional assets but lacks strategic coherence, industrial scale, and investment agility.

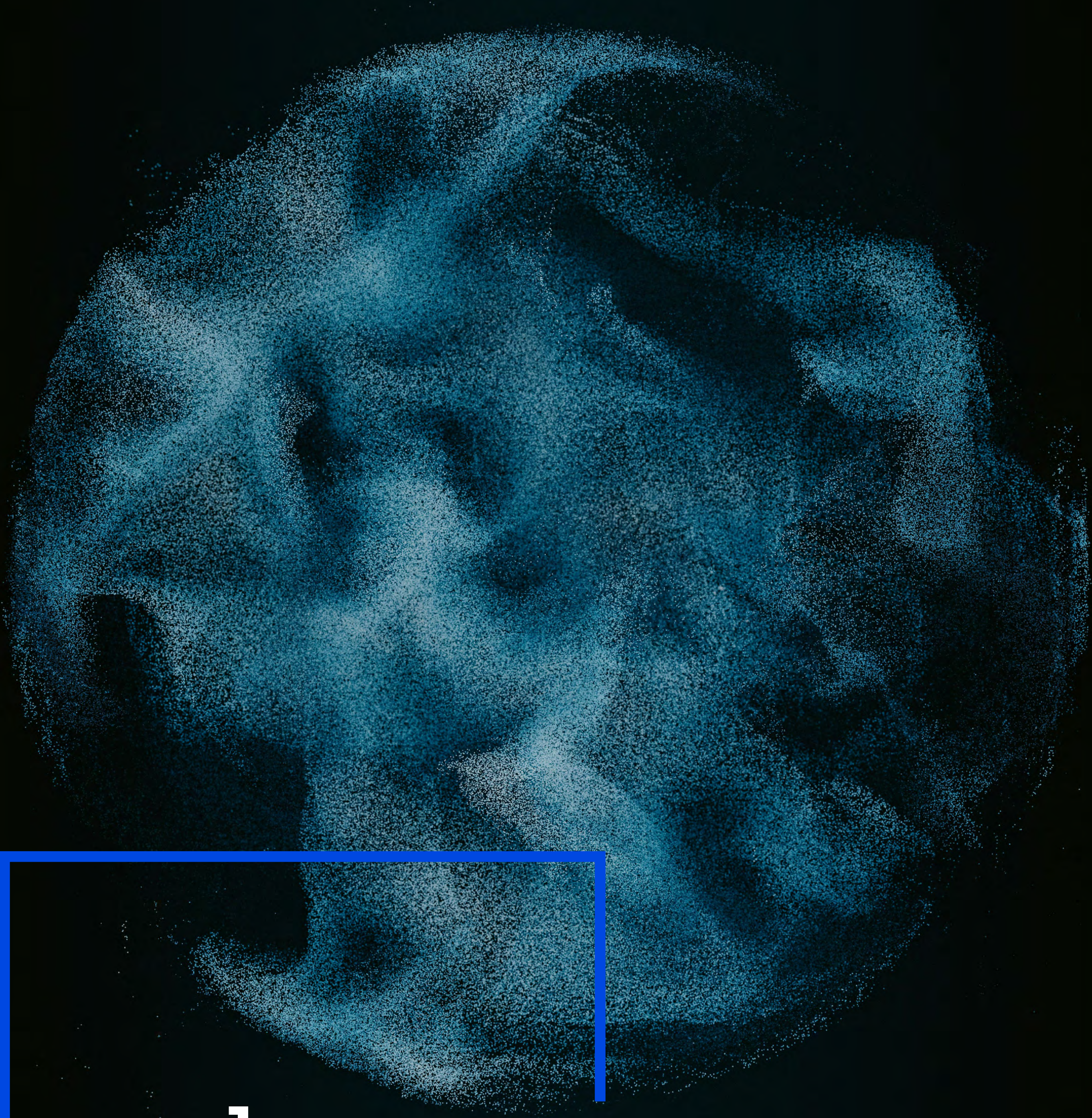
To turn scientific excellence into sovereignty, Europe must:

- Align governance and sustain institutional continuity.
- Build a robust industrial base with global champions and resilient supply chains.
- Balance key tensions: sovereignty vs. cooperation, innovation vs. protectionism, and integration vs. fragmentation.

A mission-oriented, DARPA-like approach, deeper public–private partnerships, and active techno-diplomacy will be essential.

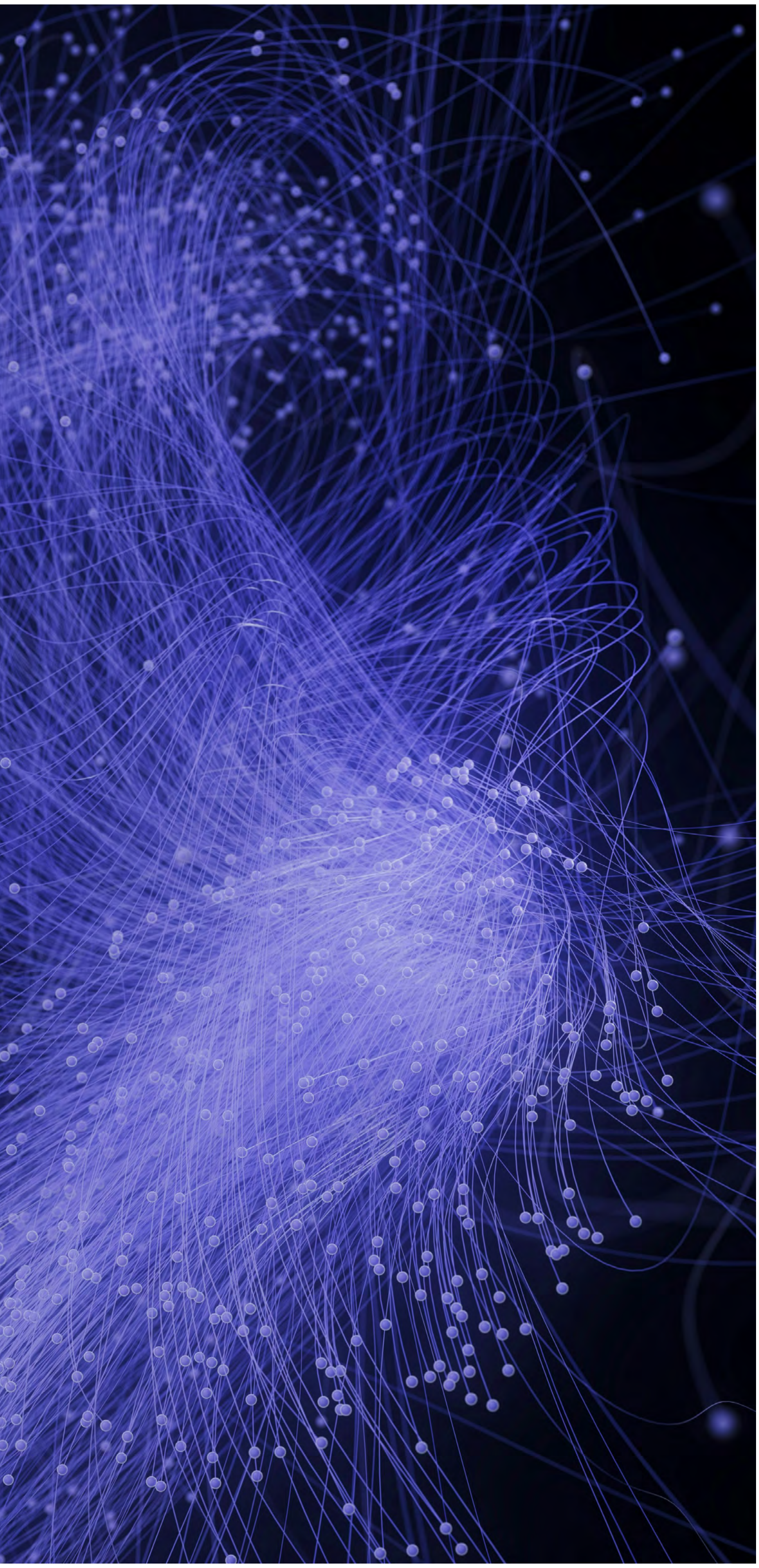
Europe stands scientifically ready but strategically incomplete. Its challenge is to convert world-class research into sovereign capability. Achieving quantum leadership will require unified governance, long-term investment, and cross-border cooperation. The next decade will determine whether Europe becomes a quantum leader shaping global standards or a dependent follower in the new technological era.





1.
INTRODUCTION

1. INTRODUCTION



The United Nations proclaimed 2025 as *the International Year of Quantum Science and Technology* (IYQ), marking the 100th anniversary of the development of quantum mechanics, the science that has sparked the emergence of quantum technologies (Figure 1). These technologies have recently gained traction worldwide, with public and private investors pouring nearly USD $2.0 billion into Quantum Technology start-ups in 2024, a 50% increase compared to USD $1.3 billion in 2023.[1] In fact, 2025 marks a turning point for Quantum Technologies with real-life commercial applications, as they are being tested through pilots, relevant proofs of concepts (POC), and operational deployments. This underscores the need to raise public awareness of the potential and far-reaching impact of quantum science and its applications in all aspects of life.

Recognizing this potential, on July 2, 2025, the European Union (EU) launched the Quantum Europe Strategy to "position Europe as a global leader in quantum by 2030" (*Figure 2*).[2] The Strategy seeks to leverage Europe's strengths to build a resilient and sovereign quantum ecosystem, transforming cutting-edge research into market-ready applications, driving startup growth, and reinforcing Europe's position as both a scientific leader and a future quantum powerhouse. It responds to recent appeals from senior European leaders to strengthen the EU's global competitiveness, foster innovation, and secure its technological edge.

1 Soller, Henning, Shabani, Sara, and Svejstrup, Waldemar. The Year of Quantum: From concept to reality in 2025. McKinsey & Company. 2025. Available from: https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025

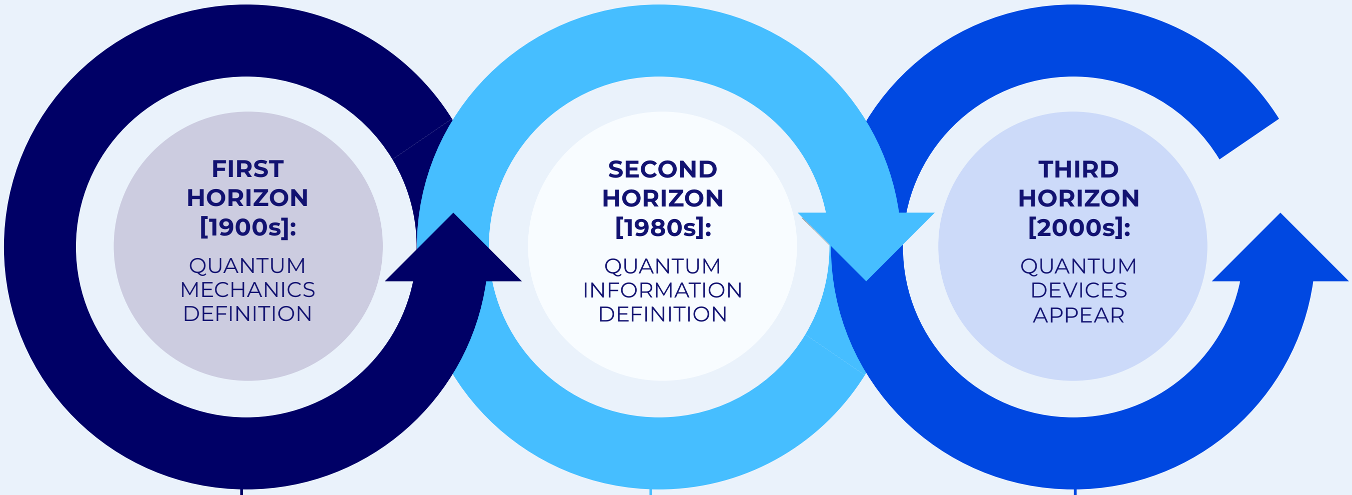
2 European Commission. Quantum Europe Strategy. Policy and Legislation. 2025. Available from: https://digital-strategy.ec.europa.eu/en/library/quantum-europe-strategy

Figure 1. **The Quantum Revolution Evolution.**

THE QUANTUM REVOLUTION EVOLUTION

Quantum information appeared in the 1990s as an evolution from quantum mechanics defined in the 1980's.

THIS EVOLUTION CAN BE DIVIDED INTO THREE HORIZONS:

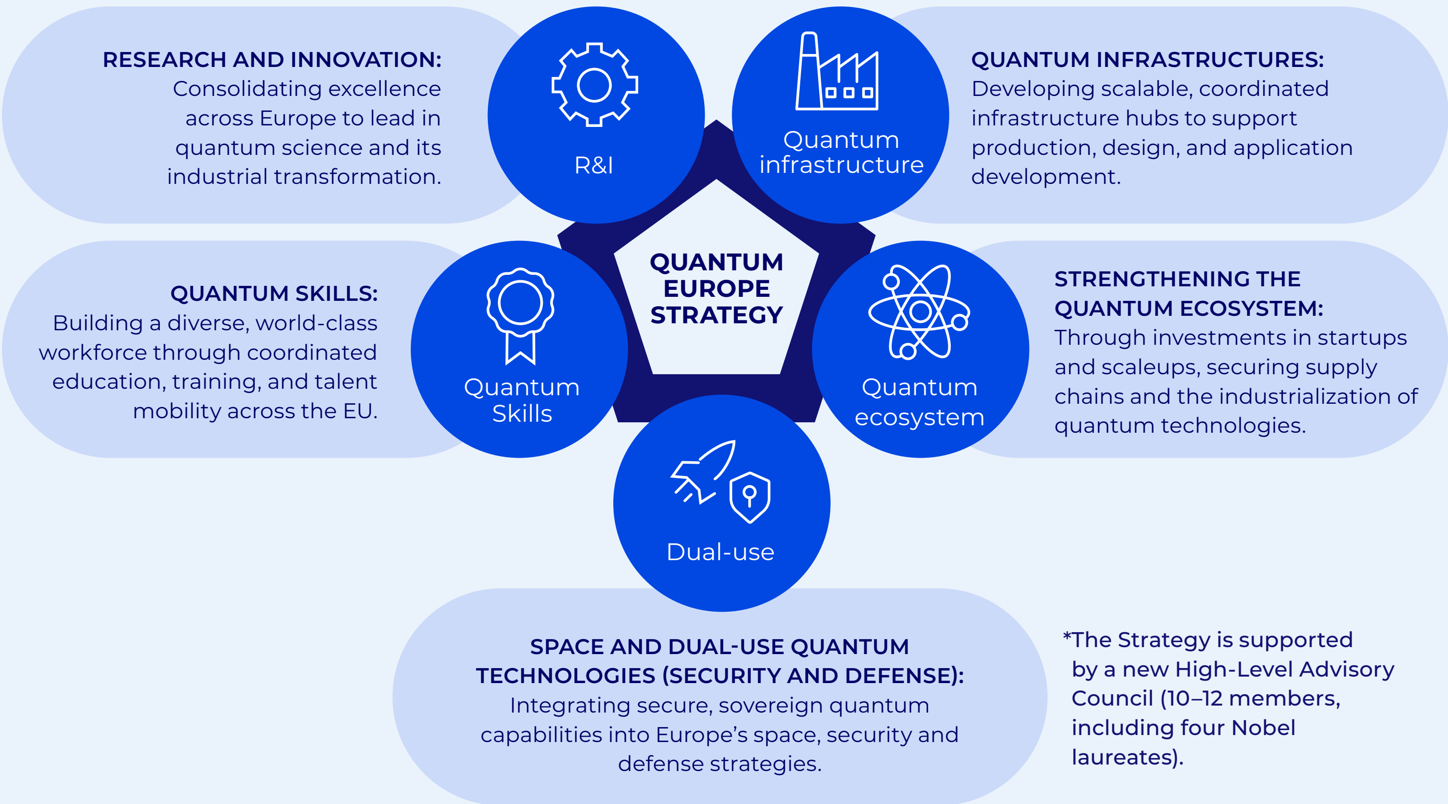


German physicist, Max Planck, proposed to quantify energy to describe its behavior at the atomic level. Schrödinger developed wave mechanics that analyses particle dynamics. Heisenberg defined the uncertainty principle, describing subatomic particles. Hilbert provided the mathematical basis for formulating quantum theory, and Dirac defined the bra-ket notation to represent quantum states in Hilbert space.

Aspuru-Guzik and his team demonstrate the practicality of the quantum computer by simulating H2; D-Wave and IBM launch the first commercial quantum computers; China demonstrates secure quantum communication over satellite and long distance on the ground. A battle begins with large financial investments to quantum companies to help advance technology. Large industrial companies begin proof-of-concept testing for risk analysis, molecular chemistry simulations, fraud identification, routing, portfolio management, logistics optimization, etc.

Benioff, Feynman, and Deutsch introduced the definition of the Quantum Computer by introducing the properties of superposition and quantum entanglement; Bennett and Brassard lay the foundations of quantum information distribution; Shor and Grover show quantum advantage with factorization and search algorithms; Chuang, Gershenfeld and Kubinec created the first two-cubit quantum computer.

Figure 2. **The Quantum Europe Strategy* (2025), builds on the Quantum Flagship Initiative (2018), covers four technologies (quantum sensing, communications, computing, and post-quantum cryptography) and rests on five pillars:**



*The Strategy is supported by a new High-Level Advisory Council (10–12 members, including four Nobel laureates).

In his report on the future of European competitiveness, published in September 2024, Mario Draghi, Former Prime Minister of Italy (2021-2022) and former President of the European Central Bank (2011-2019) warned that Europe was falling behind its global competitors in digital innovation, noting that "five of the top ten tech companies globally in terms of quantum investment are based in the US and four in China, while none are in the EU."[3] He stressed that quantum computing is poised to become the next major technological wave. However, unless Europe closes its investment gap, overcomes fragmentation, and strengthens pan-European coordination, it risks becoming dependent rather than sovereign in this critical domain.

Enrico Letta, former Prime Minister of Italy (2013-2014) and Dean of the IE School of Politics, Economics and Global Affairs, has reinforced this sense of urgency by calling for the creation of a "fifth freedom" within the Single Market: the freedom of research and creation, unbound by artificial or disciplinary borders.[4] Such a step, he argues, would transform Europe's fragmented efforts into unified opportunities for growth and innovation, unlocking the potential of large-scale, cross-border projects in fields such as Artificial Intelligence and Quantum Technologies. To Letta, investing in quantum is not only about advancing science; it is fundamental to strengthening Europe's industrial base, security, and strategic autonomy.

3 Draghi, Mario. The future of European Competitiveness. European Commission. 2024. Available from: https://commission.europa.eu/topics/eu-competitiveness/draghi-report_en

4 Letta, Enrico- Much more than a market. European Commission.2024. Available from: https://www.consilium.europa.eu/media/ny3j24sm/much-more-than-a-market-report-by-enrico-letta.pdf

European Commission President, Ursula von der Leyen, has firmly anchored Quantum Technologies among the EU's strategic priorities. At the 'Choose Europe for Science' event in May 2025, von der Leyen declared:

> "We want Europe to be a leader in priority technologies from AI to quantum … We want scientists, researchers, academics and highly skilled workers to choose Europe."[5]

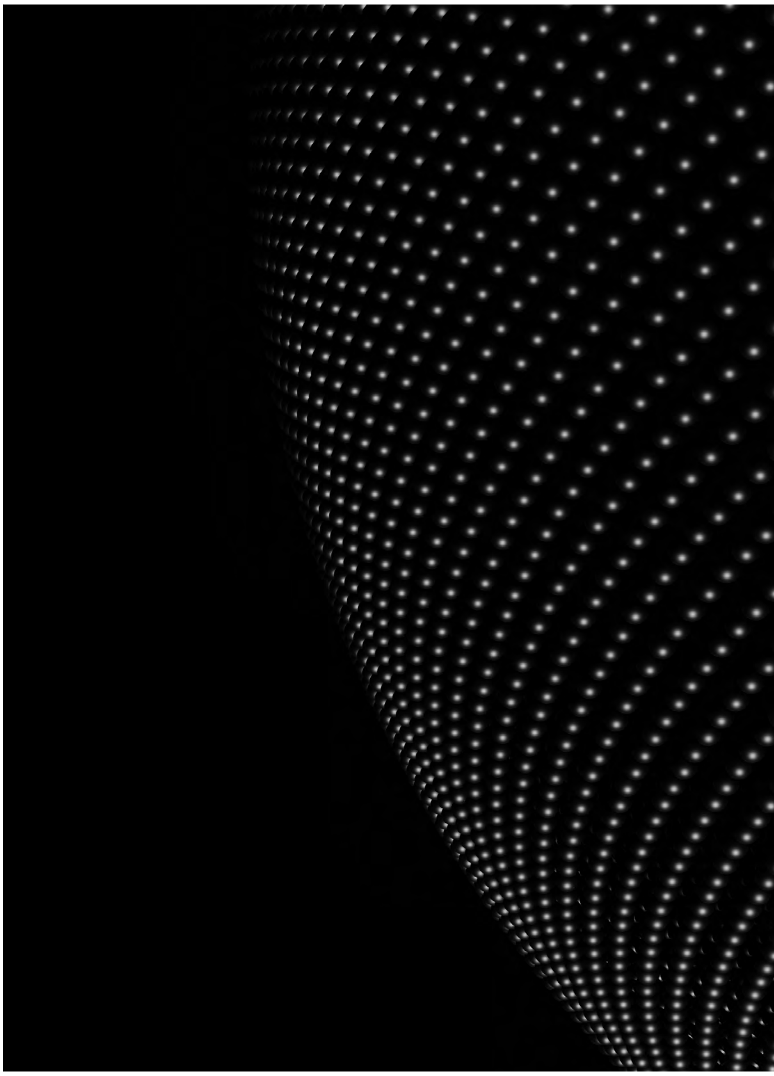
Von der Leyen also pledged to enshrine freedom of scientific research in EU law, underscoring Europe's role as a global hub for innovation and academic freedom.

Taken together, these perspectives demonstrate that advancing quantum technologies is not optional—it is essential to Europe's competitiveness, resilience, and sovereignty. By scaling investment, coordinating fragmented initiatives, and embedding quantum at the heart of its strategic agenda, Europe can close the innovation gap, strengthen its industrial capabilities, attract world-class talent, and ensure that quantum technologies deliver their full societal potential.

In this context, the **Quantum Policy Lab (QPL)** aims to support the advancement of quantum technologies as a means of enhancing Europe's competitiveness The project seeks to equip public and private decision-makers with analysis, skills and foresight to shape a quantum policy agenda that enables these technologies to reach their full societal potential. The first phase focused on assessing prevailing attitudes, knowledge gaps, and practical challenges influencing the European quantum development ecosystem.

Building on this, the present report identifies the main barriers and enablers for an effective quantum governance and development within the EU as of 2025.

The report is structured to move from context-setting to forward-looking recommendations. Following the introduction, and after reviewing foundational concepts of how quantum technologies and their industry operate, the report outlines the research methodology used for this study. The subsequent sections draw on insights from the expert interviews to analyze the current state of quantum technologies in Europe, including the region's strategic positioning, governance structures, and investment landscape, as well as the barriers and enablers shaping quantum development. Building on these findings, the report presents a forward-looking roadmap inspired by the expert workshop, which articulates a shared vision for Europe's quantum future, identifies key challenges and enabling factors, and outlines strategic pillars to translate ambition into coordinated action. The report concludes with policy recommendations and next steps to advance effective quantum governance and development across the EU.



5 Pelé, Anne-Françoise. Choose Europe for Science: EU Pledges €500M to Attract Researchers. 2025. EE Times Europe. Available from: https://www.eetimes.eu/choose-europe-for-science-eu-pledges-e500m-to-attract-researchers

2.
TECHNOLOGY OVERVIEW

2. TECHNOLOGY OVERVIEW

This section provides a foundational understanding of quantum technologies, including their operational mechanisms and level of maturity. This understanding is essential for evaluating Europe's competitiveness and policy readiness in quantum, as well as for the effective design of any strategy or governance framework.

Quantum mechanics is the branch of physics that explains how nature behaves at extremely small scales, such as atoms and subatomic particles. Its principles underpin many everyday technologies already in use, from X-rays to semiconductors.

The world stands at the threshold of the second quantum revolution, a new era in which scientists, physicists, and engineers will apply the principles of quantum mechanics to manipulate individual atoms and electrons, examining and shaping the world through a quantum lens. It is a transformative era in which technological prowess will make it possible to manipulate, control, and exploit individual quantum systems for practical applications, based on direct control and use of quantum phenomena.

At the heart of this revolution are quantum computers, which store and process information encoded in **qubits**, which are quantum bits. Unlike classical bits, which can only store the values 0 or 1, qubits can exist in a state of **superposition**, which allows them to store both values simultaneously. This provides exponential computing power, as they can represent up to 2^n values; each qubit added doubles the capacity. The following table shows the impressive growth of qubits:

Figure 3. **Bits and Qubits (own elaboration).**

N	bits (2 x N)	qubits (2^N)
2	2 x 2 = 4	$2^2 = 4$
3	2 x 3 = 6	$2^3 = 8$
....		
200	2 x 100 = 200	$2^{100} = 1267650600228229401496703205376$

Additionally, qubits can act as a single “block” when they are **entangled**, meaning any action performed on one qubit affects the entire entangled block, and reading information from one provides insight into the others. Once one qubit is measured, the state of the second qubit is instantly determined. Particles become interconnected in such a way that the state of one particle, no matter how far apart they are, instantly affects the state of another.

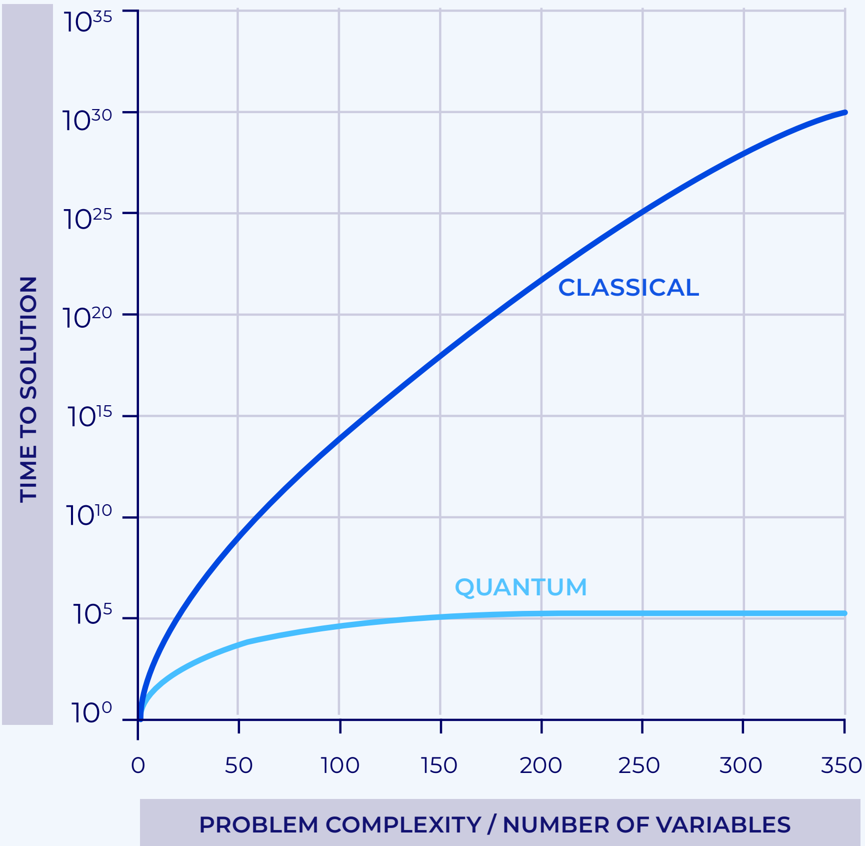
This means there is a block of 2^n values at our disposal to perform massive parallel computations. For example, if there is a system of eight qubits, it can carry out 2^8 (256) simultaneous processes. A classical equivalent would require 256 processors, each updating one value in parallel. This phenomenon is known as **quantum parallelism** and provides exponential acceleration, allowing operations to be performed quickly, regardless of the calculation’s complexity. This is shown in *Figure 4* Quantum advantage.

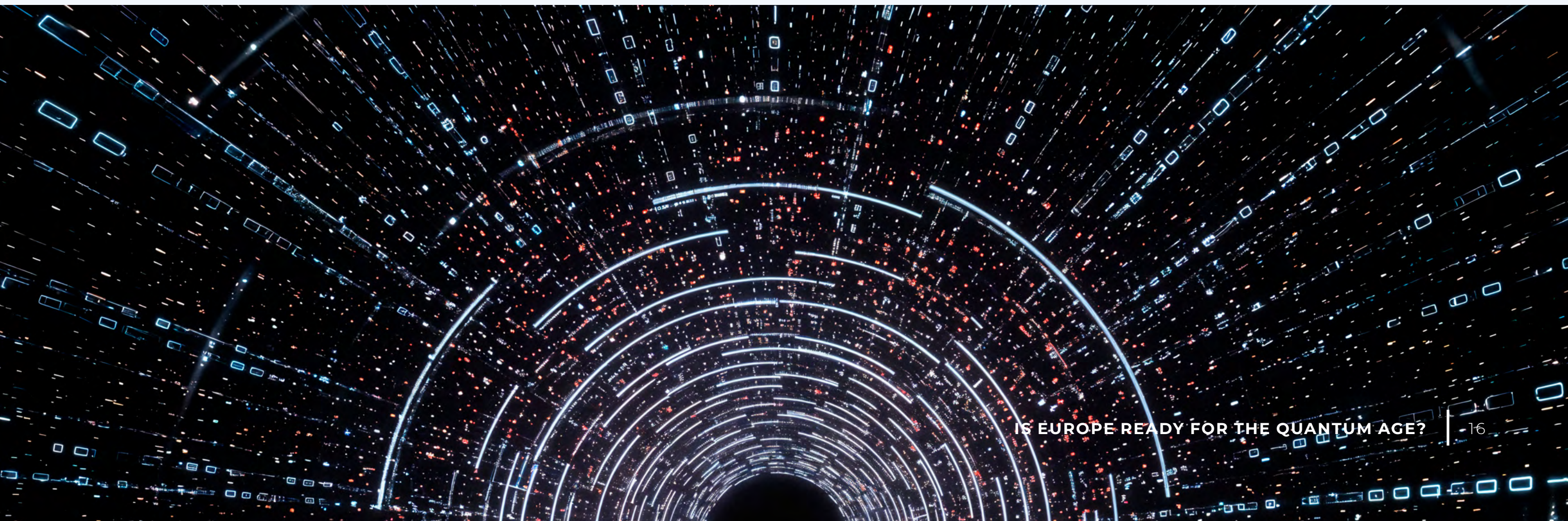
Figure 4. **Quantum advantage.**

Typically, as the size of a problem increases, so does the number of steps required to solve it, which means it takes more time and may become impossible to tackle it.

In contrast, with a quantum algorithm, the number of steps does not grow at the same rate of the problem size, this makes the resolution more efficient and “faster”. It can be hundreds or thousands of times faster or more efficient, achieving what is known as quantum advantage.

The image on the right shows an exponential improvement—solving a problem in hours instead of years.





2.1. APPLICABILITY

Quantum mechanics promises to revolutionize three types of technologies:

01/ Quantum sensors:
Detect a wide range of extremely small signals.

02/ Quantum communications:
Encrypt data in an unbreakable and non-interceptable way.

03/ Quantum computers:
Solve complex mathematical computations exponentially better.

A fourth category is the security threat that quantum computers pose to current **encryption methods**, which will need to be taken care of with resistant cryptographic algorithms. These categories are explained in *Figure 5* Quantum technology categories.

Focusing on the security threat, it is important to recognize that quantum computers pose a significant risk to current cryptographic methods, as their advanced capabilities could render existing data encryption systems based on mathematical formulas obsolete. This endangers the security of data, whether stored or transmitted, including everyday encrypted information such as emails, phone calls, passwords, cloud storage, financial transactions, digital certificates, and medical records.

Even if quantum computing is not fully operational and does not currently pose a risk to cybersecurity systems, hackers may be capturing and storing today's data for decryption tomorrow. Michele Mosca, deputy director of the Institute for Quantum Computing at the University of Waterloo, estimates that by 2031, more than half of today's cryptographic schemes will be obsolete.[6]

Figure 5. **Quantum technology categories.**

QUANTUM SENSORS TO DETECT PHYSICAL QUANTITIES

- Description: Devices that detect and measure changes in physical parameters.
- Applicability: Medicine, geophysics, and more scientific/technological areas.
- Example: Measuring extremely small changes in gravity fields that influence GPS accuracy.

QUANTUM COMPUTERS TO SOLVE ALGORITHMS

- Description: Algorithms that solve problems that have multidimensional data or are stochastic by nature.
- Applicability: Problems that either require a lot of memory or a long processing time to run properly.
- Example: Number factorization for cryptography, unstructured data in databases search, data classification in Artificial Intelligence, network optimization in distribution, electron behavior for physical or chemical analysis, or stochastic distribution for simulation analysis or risk modeling.

QUANTUM COMMUNICATIONS FOR DATA TRANSFER

- Description: Data encryption for sharing data between two geographically distant parties.
- Applicability: Long and short distance communication, with waves, fibre, cloud and edge computing.
- Example: Securing telecommunications infrastructure for internet and industry-specific data transmissions.

QUANTUM-SAFE ENCRYPTION ALGORITHMS

- Description: Encrypt information to keep it safe, using a secret key to encode it to prevent unauthorized access.
- Applicability: Avoid forging digital signatures, stealing encryption keys and fraudulent authentication.
- Example: Protect data at rest like passwords, personal information, and in-transit when it is transmitted online.

6 Mosca, Michele. Quantum Computing: A New Threat to Cybersecurity. Global Risk Institute. 2016. Available from: https://globalriskinstitute.org/publication/quantum-computing-cybersecurity

To address this risk, three main security approaches are being developed (*Figure 6*).

Figure 6. **Quantum security approaches.**

SECURE QUANTUM CRYPTOGRAPHY (SQC)	▪ Uses the fundamental properties of quantum mechanics, which make eavesdropping impossible, as the system can detect if the key has been tampered with and discards it. ▪ It exploits the no-cloning theorem and the fact that a system cannot be observed without altering or disturbing it. ▪ One example is Quantum Key Distribution (QKD), which secures communication using a new cryptographic protocol.
QUANTUM RANDOM NUMBER GENERATORS (QRNG)	▪ Utilize quantum mechanics to generate truly random numbers, thereby avoiding the issue of pattern repetition commonly encountered in conventional pseudo-random number generators. ▪ This technology is already available in commercial hardware chips and has applications across multiple sectors, such as automotive, mobile devices, and IoT devices.
POST-QUANTUM CRYPTOGRAPHY (PQC)	▪ It is based on highly complex conventional mathematical cryptographic systems that are secure against both quantum and classical computers. ▪ It interoperates with existing communication protocols and networks. It is also referred to as quantum-safe or post-quantum algorithms. ▪ In 2016, the US National Institute of Standards and Technology (NIST) launched a competition to identify cryptographic methods resistant to quantum attacks, with the goal of establishing a new standard. The following algorithms have been selected and approved so far: **LATTICE-BASED:** ▪ CRYSTALS-Kyber: Key encapsulation mechanism ▪ CRYSTALS-Dilithium: For digital signatures ▪ FALCON: A lightweight digital signature **HASH-BASED:** ▪ SPHINCS+: For document signatures

2.2. STATE OF THE ART

Quantum technologies are progressing at different levels of maturity, as summarized in *Figure 7*.

Quantum security is underway as companies worldwide update their cybersecurity systems to make them able to resist attacks from future quantum computers, with government mandates in several countries requiring a transition by 2030, requiring all cryptographic systems to be updated to "quantum safe" (or post-quantum) standards by then. **Quantum communications** are being piloted by telecommunications providers across metropolitan networks, data centers, and critical infrastructure such as electricity grids. The applicability of **Quantum sensors** is already being demonstrated in the aviation sector, particularly in Assured Positioning, Navigation, and Timing (APNT) systems. These implementations enhance navigation accuracy and reliability, providing secure and continuous positioning even in environments where GPS signals are disrupted or unavailable. By contrast, **quantum computers** remain the least mature among quantum technologies. While small-scale proof of concepts and experiments have demonstrated their basic principles, practical applications are still limited because the technology requires much larger numbers of stable, error-corrected qubits to perform meaningful computations.

A key challenge in bringing quantum technologies to commercial scale lies in developing fault-tolerant systems—those capable of maintaining quantum properties long enough to perform operations reliably, without losing information or introducing errors.

Currently, quantum systems exhibit markedly higher error rates—roughly one qubit in a thousand fails—compared to classical systems, where bit failure occurs on the order of one in a billion. This vast reliability gap illustrates the scale of the engineering problem.

> As a result, current research and industrial efforts are focused on advancing error-correction techniques and improving qubit stability, making them less vulnerable to environmental noise and fluctuations.

Achieving this stability is particularly demanding for quantum computers, which must operate in extreme conditions— often inside dilution refrigerators at temperatures close to absolute zero, with precise shielding, microwave controls, vacuum systems, and lasers.

Looking ahead, progress over the next five to ten years will depend on how effectively companies and governments can scale up quantum hardware manufacturing. The ability to produce stable, large-scale, fault-tolerant systems will likely be the decisive factor in determining global leadership in quantum technology.

Figure 7. **Quantum maturity stages.**

QUANTUM COMPUTERS	QUANTUM SENSORS	QUANTUM COMMUNICATIONS	QUANTUM SECURITY
Proof of concept tests	Demonstrations of applicability	Prototypes running in real environments	Substitutions of current methods

→ → → TECHNOLOGY MATURITY LEVEL → → →

Overcoming the limitations of error rates and system instability depends largely on how qubits are built and controlled. As of today, the main approaches include:

- **Superconducting qubits** mimic atoms using special materials such as aluminum or niobium that conduct electricity without resistance.
- **Trapped-ion qubits are real atoms**, chemical elements, in the periodic table. They are trapped in an electromagnetic field using static voltages.
- **Photonic qubits are individual particles of light**, photons, that encode quantum information in a ring along with the scattering unit.
- **Diamond qubits** are created by introducing a single nitrogen atom and a neighboring vacancy defect into a diamond lattice structure.
- **Neutral atom qubits** are one-atom states (single ultracold neutral atoms), such as rubidium, arranged in configurable arrays.
- **Quantum dots** are created by confining electrons in a semiconductor in which they move through the material, conducting electricity.
- **Topological qubits** are created using Majorana fermions anyons, a type of quasiparticles.

There is a race to build a high-quality qubit that will enable quantum technology to scale to commercialization. On this race, the supply of materials essential for quantum hardware—particularly isotopically enriched or ultra-pure forms—plays a critical role. These materials are highly concentrated, low-volume, geopolitically sensitive, and are required for hardware components such as dilution refrigerators, qubits, interconnects, or lasers systems. The materials, country of origin, and their use can be seen in *Figure 8*.

Figure 8. **Materials analysis (own elaboration based on data from sources in the reference list).**

MATERIAL	MAIN PRODUCING COUNTRIES	TECHNICAL LIMITATION	QUANTUM TECHNOLOGY USE
Helium-3 (^{3}He)	United States, Russia, Canada, France, China	Limited supply; dependence on nuclear programs	Dilution refrigerators for cooling to millikelvin.
Indium (In)	China, South Korea, Japan, Canada, France, Belgium	Limited supply; volatile pricing and purity challenges	Interconnects, wiring, and bonding for chips and optical components
Ytterbium (Yb isotopes)	China, Russia, United States, Myanmar, India, Australia	Energy-intensive and slow; supply chain dominated by China	Trapped-ion qubits; atomic clocks; laser cooling and optical lattice experiments.
Strontium (Sr isotopes)	China, Mexico, Spain, Iran	Technically demanding; few producers	Optical lattice clocks, trapped-ion qubits, precision measurement devices
Tantalum (Ta)	Democratic Republic of Congo, Rwanda, Nigeria, Brazil, China	Conflict mineral: ethical sourcing and refining are difficult	Superconducting qubits and resonators
Niobium (Nb)	Brazil, Canada	Requires ultra-high purity; supply geographically concentrated	Superconducting qubits and resonators.
High-purity Aluminum (Al)	Australia, China, Russia, Canada, Norway, Japan, United States, India	Achieving purity and oxide control is difficult	Josephson junctions for superconducting qubits
Silicon-28 (Si-28)	United States, France, Germany, Japan, Russia	Limited supply; technically complex; small volumes	Spin qubits; silicon quantum processors
Germanium	China, Canada, Russia, Belgium	Limited supply; high cost, temperature sensitive	Quantum dots; spin qubits; photonic detectors

2.3. INDUSTRY ANALYSIS

The quantum industry is characterized by rapid growth, intense competition, and significant technological fragmentation. Developing stable qubits has become a global contest among different quantum providers, including large technology corporations and a growing number of startups. This is most evident in quantum computing. As illustrated in *Figure 9*, technology providers vary not only in their chosen qubit architecture, but also in their time of entry into the field and regional origin. The US leads in the number of startups, while Europe, Canada, and Australia host strong emerging players, including IQM, Pasqal, Xanadu, and Dirac.

Figure 9. **Technology providers by qubit approaches—non-exhaustive.**

	TRAPPED IONS	TOPOLOGICAL	SUPER-CONDUCTING	PHOTONICS	DIAMOND	COLD / NEUTRAL ATOMS	SEMICONDUCTOR / DOTS / SPINS	ANNEALER / ADIABATIC
1999								**D-WAVE**
2005		MICROSOFT						
2006			GOOGLE					
2007						**INFLEQTION**		
2013			RIGETTI					
2014			**ANYON TECHNOLOGIES**					
2015	**IONQ**							
2016								
2016			IBM	**PSI QUANTUM**				
2016			QUANTUM CIRCUITS	**XANADU**				
2017	**UNIVERSAL QUANTUM**		**ORIGIN QUANTUM**				**QUANTUM MOTION**	FUJITSU
2017			**OQC**				INTEL	
2018				**QUANTUM COMPUTING INC.**		**QUERA**		
2018	**AQT**		**IQM**	**QUANDELA**		**ATOM COMPUTING**		
2019	**OXFORD IONICS**		**AWS**	**AEGIQ**	**QUANTUM BRILLIANCE**	**PASQAL**		
2019				**ORCA**				
2019				**QUIX QUANTUM**				
2019				**JIUZHANG**				
2020	**ELEQTRON**		**ALICE 6 BOB**				**C12 QUANTUM ELECTRONICS**	**QILIMANJARO**
2021	**QUANTINUUM**			**TURINGQ**		**ATOMQL**		
2022			**ATLANTIC QUANTUM**				**DIRAC**	
2022			**QOLAB**				**ARQUE SYSTEM**	

Europe US Canada Australia Japan China **Bold**= quantum native companies

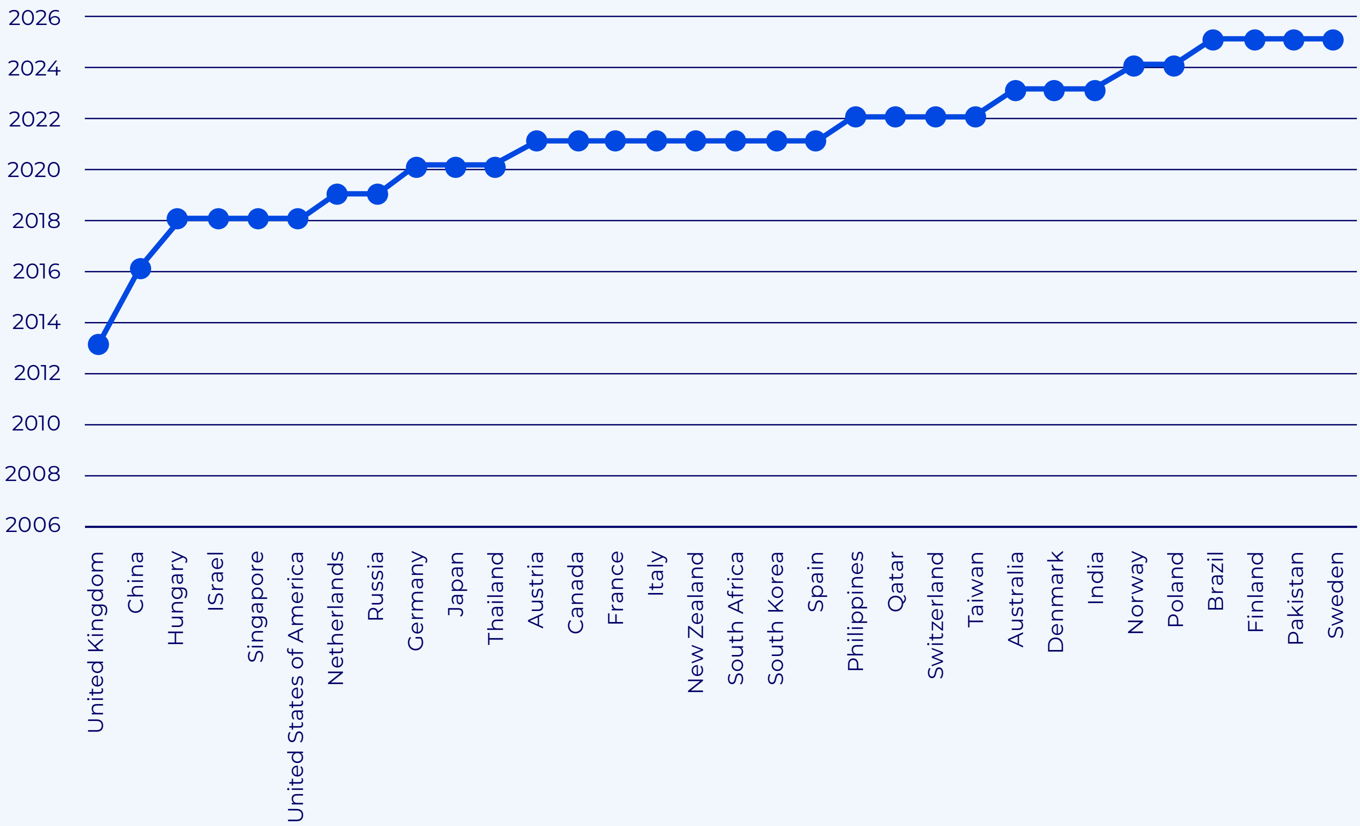
Source: Own elaboration based on information from company websites.

National investments in Quantum Technologies (*Figure 11*) have increased rapidly over the past decade. The first significant growth occurred in 2018, when China demonstrated its quantum communications experiment, the US launched its national program, and the EU introduced the Quantum Flagship initiative. A second wave took place in 2021, driven by post-pandemic digital and innovation recovery plans. Since then, nearly every major economy has announced quantum initiatives.

By early 2025, global national investments announced had reached approximately USD $44 billion, with nearly USD $10 billion announced in that year alone, led by major initiatives in Japan, Spain, andt the US.

Overall, there are marked differences across countries and regions (*Figure 10 and Figure 11*).

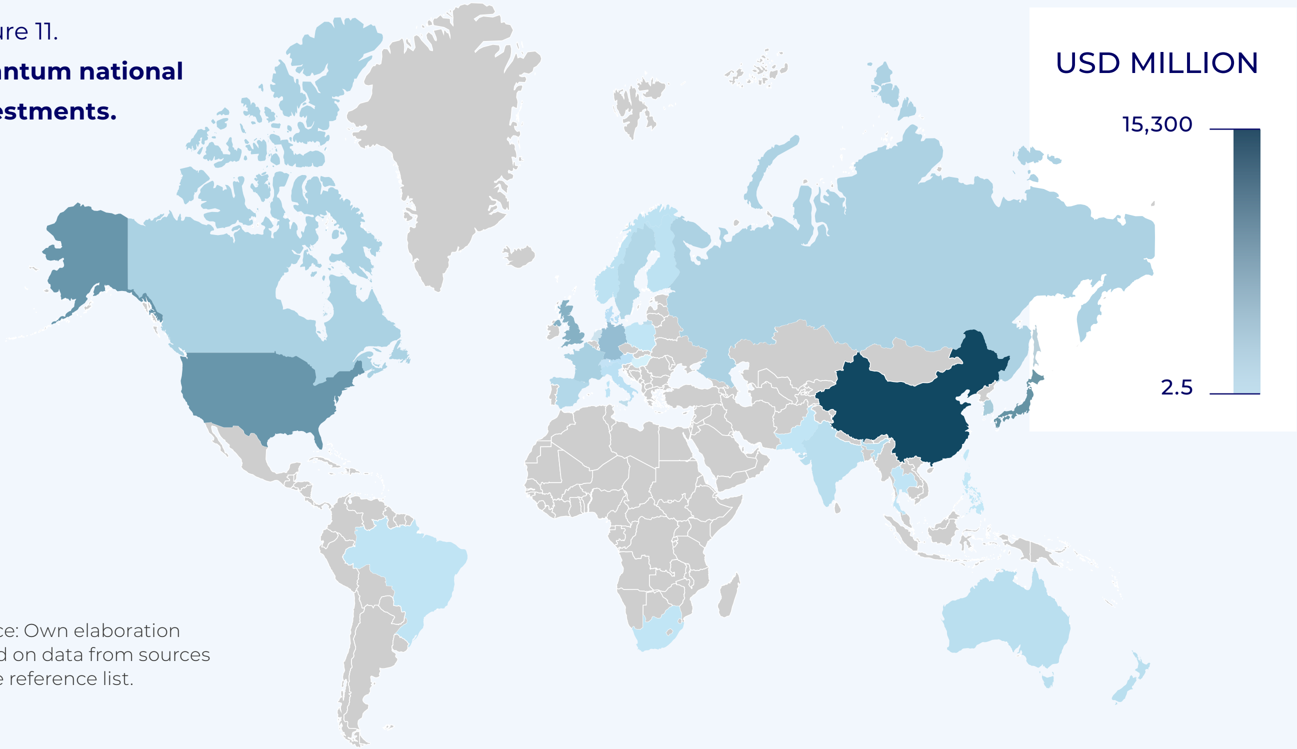
Figure 10. **National quantum strategies timeline.**



Source: Own elaboration based on data from sources in the reference list.

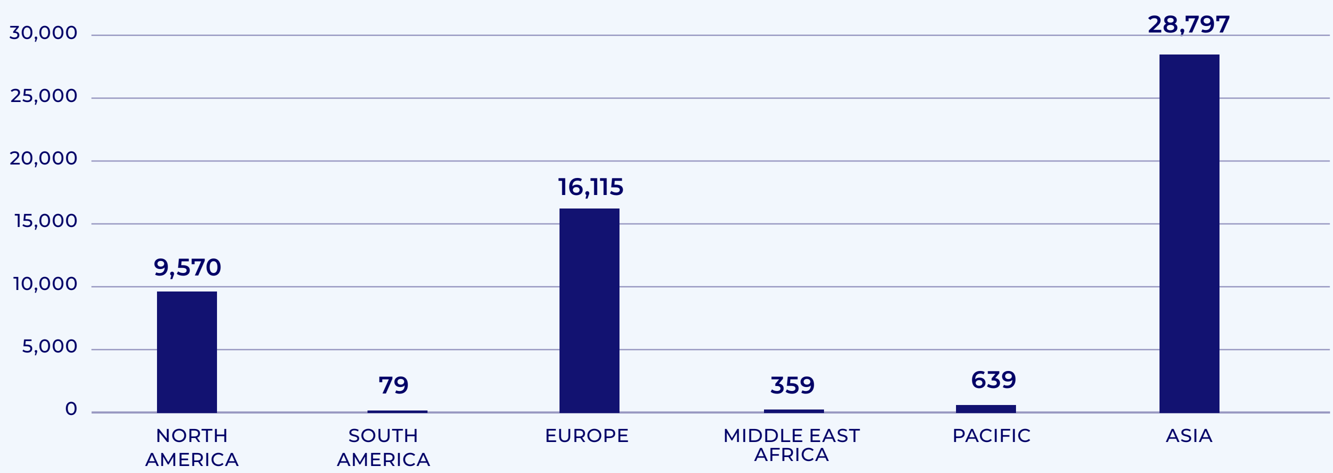
- **Asia-Pacific** (USD $ ~29.4) dominates global quantum investment, led by China's focus on communications and infrastructure (e.g., QKD backbones, satellites) and Japan's national program.
- **Europe** (USD ~$16.11B) ranks second, with broad-based funding across the EU and the UK. Germany leads with ~$3.4B, emphasizing high performance computer (HPC) integration.
- **North America** (USD $ ~9.6B) is third in public spending but leads globally in private venture capital and standards-setting, largely through big American tech firms (IBM, Google, Microsoft, AWS).
- **Latin America**, **Africa**, and **the Middle East** have modest but strategic investments, often linked to international partnerships and workforce development, but lack significant domestic manufacturing capacity.

Figure 11. **Quantum national investments.**



Source: Own elaboration based on data from sources in the reference list.

Figure 12. **Quantum investment by region in USD Million.**



Source: Own elaboration based on data from sources in the reference list.

2.4. DEFENSE APPLICABILITY

In less than a decade, defense has shifted from a marginal concern on the European agenda to a top strategic priority. Russia's act of aggression towards Ukraine has demonstrated that modern defense extends beyond conventional capabilities. Today, safeguarding electricity grids, internet networks, transportation systems, and even housing infrastructure is as critical as deploying tanks and troops. Hybrid threats, coupled with growing instability in Eastern Europe and pressure from the US, have redefined the very concept of security, leading NATO to call for a sustained and ambitious effort: increasing the defense spending target from 2% to 5% of GDP by 2035.[7]

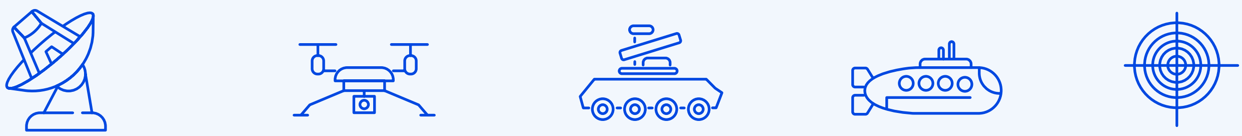
Defense is not only essential for a country's territorial integrity; it also safeguards strategic interests, sustains institutional stability, and underpins national sovereignty. In Europe, the industry directly supports over half a million jobs, with approximately 40% accounting to aeronautics and 60% to land and naval sectors, according to the European Commission.[8]

Industry investments act as a catalyst for innovation, driving advancements in emerging technologies, such as quantum computing.

The defense industry spans five domains, all of which require advanced technologies (*Figure 13*).

Within this context, quantum technologies are becoming a key component of the current tech and arms race between Europe, the US, and China. As the Sam Howell from the National Security Program at the Center for a New American Security notes: "The first country to operationalize quantum technologies will possess a toolkit of capabilities that can overwhelm unprepared adversaries." Mastery of quantum will allow a State to compromise corporate, military, and government infrastructures more rapidly than adversaries can implement effective defenses. The implications for intelligence, cyber warfare, and strategic planning are profound.

Figure 13. Defense industry domains



Space systems enable global surveillance, communication, and missile defense by leveraging satellite networks and orbital technologies.

The **air** domain focuses on aerial combat, mobility, and intelligence through aircraft, drones, and hypersonic weapons.

Land defense includes troops, armored vehicles, and robotics designed for ground combat, logistics, and electronic warfare.

Maritime operations rely on ships, submarines, and underwater drones for naval dominance, coastal defense, and sea-based power projection.

Cyber and digital warfare is based on technologies that act as cross-cutting enablers , providing critical tools for hacking, data protection, decision support, and AI-driven defense systems.

7 NATO. Defense expenditures and NATO's 5% commitment. NATO. 2025. Defence expenditures and NATO's 5% commitment | NATO Topic

8 European Council. EU defence in numbers. European Council. 2025. https://www.consilium.europa.eu/en/policies/defence-numbers

China has taken an early and sustained lead in this race. Since 2018, it has invested heavily in Quantum Technologies as part of its long-term national strategy for "innovation-driven" development, allocating USD $1.2 billion over five years. It has achieved global leadership in quantum communications, as demonstrated by the development of the world's longest quantum key distribution (QKD) network—the 1,200-mile Beijing-Shanghai backbone—and the groundbreaking Micius satellite, which extends quantum communication across greater distances. These advances enable unbreakable encryption, protecting sensitive data from future quantum decryption attacks, and laying the groundwork for secure, networked quantum military systems.

China's progress has highlighted how quantum breakthroughs can reshape both technological and military capabilities. This has influenced global defense agendas, with Europe now explicitly acknowledging the dual-use potential of quantum technologies in its strategic planning.

The defense industry is actively testing quantum technologies to unlock new capabilities, particularly as Europe's quantum strategy recognizes their civilian benefits alongside their defense applications

Figure 14 shows a breakdown of how quantum technologies are being applied.

Figure 14. **Defense use cases.**

SENSORS

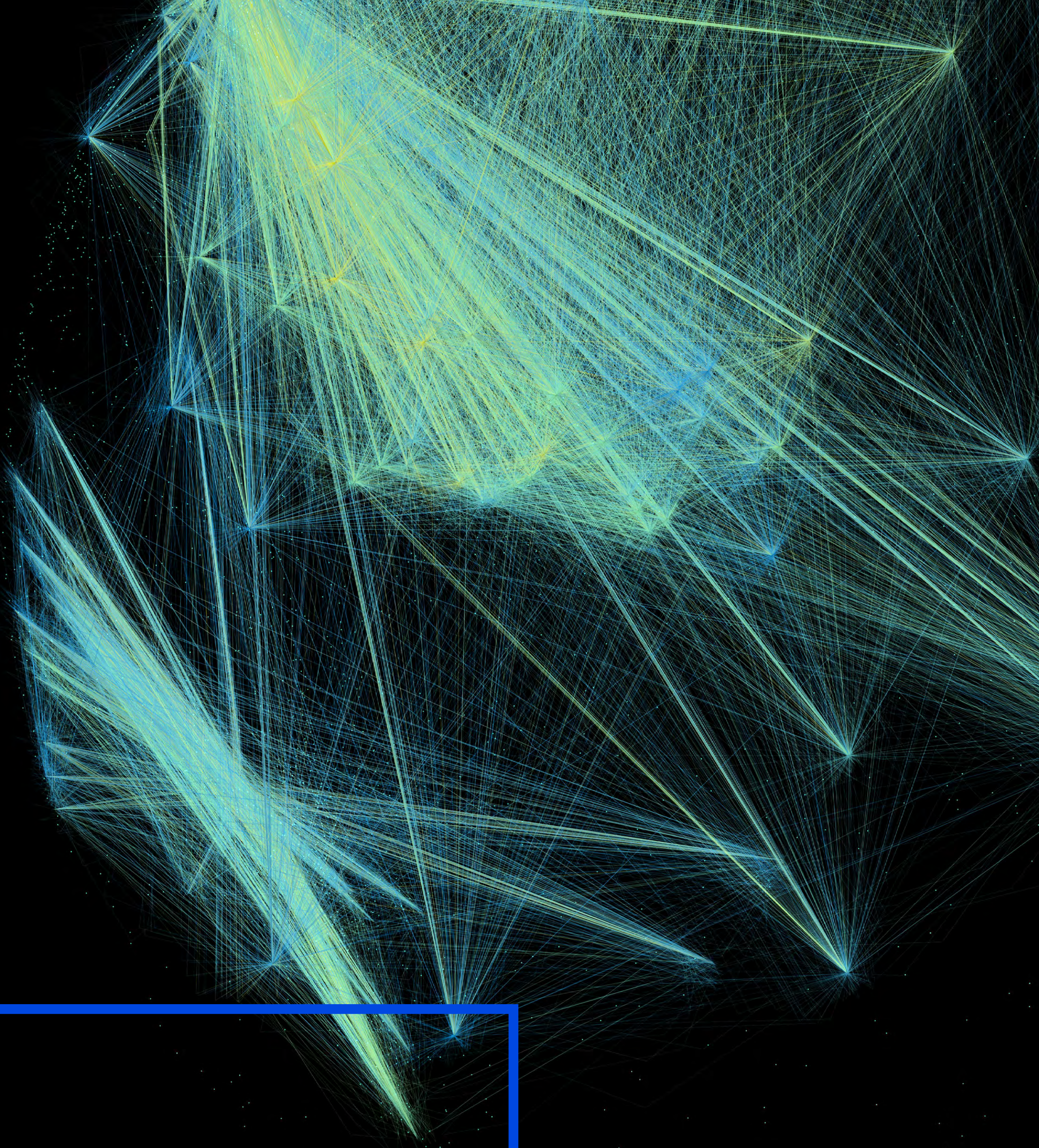
- Atomic clock for secure positioning, timing and navigation, reducing GPSdependency
- Help radars spot hard-to-detect "silent" objects distinguishing signal from noise.
- Submarine detection detecting minute changes in magnetic fields.
- NATO is exploring quantum Sensing for terrain analysis and autonomous systems for underground mapping.
- In-flight accurate airplane navigation without GPS reducing navigation errors fromtens of kilometers to tens of meters.

COMMUNICATIONS

- Secure satellite communications with real-world demonstrations connecting China, China with: Austria, South-Africa and Russia.
- Secure metropolitan network communications with real-world long-distance connection between government, research and corporate institutions, in Madrid, and Copenhagen.
- Adaptive ways of network organization using quantum cybersecurity in 5G networks tested by NATO.

COUMPUTING

- Dynamic routing optimization independent of network density or real-time changes to optimize logistics in battlefield resource allocation
- Optimizing military satellite launches and space exploration by allocating resources and adjusting parameters in real time.
- Adjust weight, strength, thermal resistance, energy efficiency, performance and structures of different materials.
- Increase the reliability of the telecommunications network avoiding crosstalk by finding an optimal set of cells and frequencies to use.
- New electrolytes to maximize electrochemical storage by simulating lithium-air batteries with increased autonomy.
- Decipher currently unbreakable encryption used in secure military and intelligence communication
- Accurately predict air flows and sound wave propagation in different materials to improve aerodynamic design.
- Enable more accurate assessment and simulation of the potential impact of different flight scenarios to minimize disruptions.



3.
PROJECT SCOPE AND METHODOLOGY

3. PROJECT SCOPE AND METHODOLOGY

The first phase of the QPL project combined desk research with insights from Subject Matter Experts (SMEs) from the quantum ecosystem to assess the status of quantum technologies in Europe and identify the conditions for success.

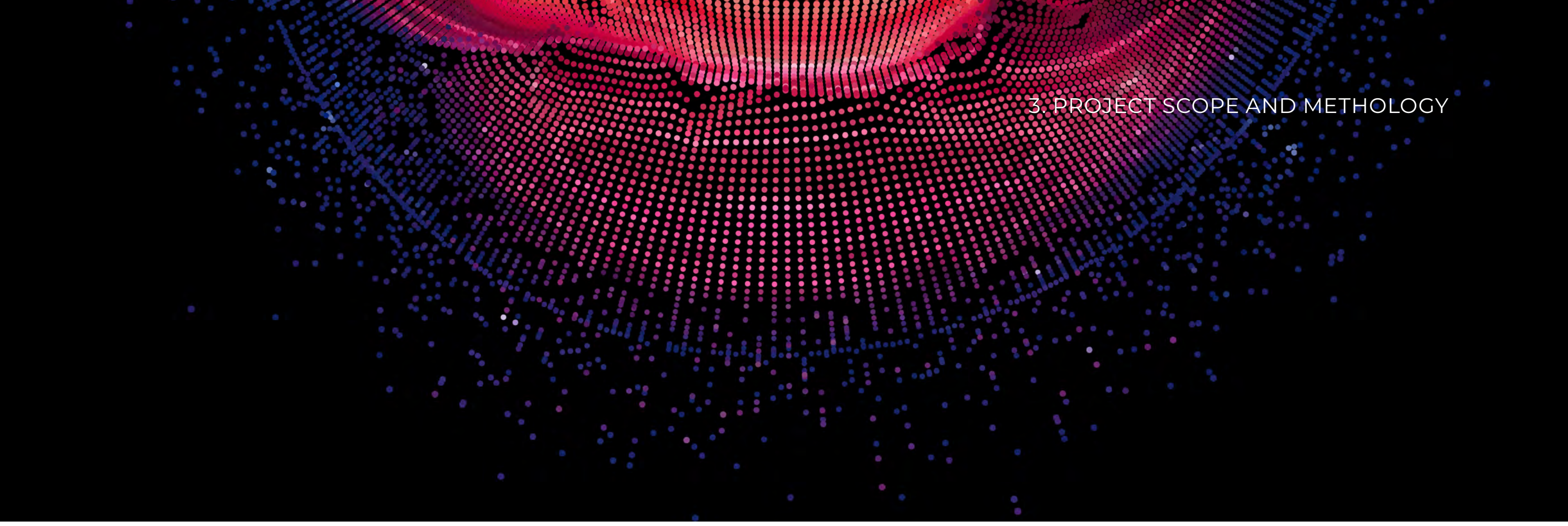
The analysis focused on the four quantum technologies highlighted by the Quantum Europe Strategy: communications, sensors, computing, and post-quantum cryptography. The **defense sector** was selected as the primary industry lens for the study due to its critical role in technological advancement, strategic autonomy, and dual-use applications.

The study was conducted from January 2025 to September 2025, with a detailed roadmap outlined in the appendix.

PROJECT METHODOLOGY

A total of 25 SMEs participated, drawn from academia, government and public institutions, the defense industry, and technology providers. All participants were selected due to their active involvement in the quantum ecosystem and reported a medium (3) to very high (5) level of professional engagement in the field (*Figure 15*). Their professional backgrounds are outlined in the Appendix.

Figure 15. **Quantum knowledge self-assessment**.



The geographic scope included five EU countries most relevant to quantum development, chosen based on program maturity, national investment levels, domestic quantum computing capabilities, participation in international initiatives, and respondent availability. These countries were Spain, France, Germany, Denmark, and Poland. No interviews were ultimately secured from Poland, as the country has only recently begun its work in this area and does not yet have representatives available to comment. Semi-structured interviews were conducted during the months of April and June 2025 to gather the SMEs' views across three key areas:

1. **Strategic Positioning and Governance:** feasibility of a "Quantum Valley" in Europe, key sectors and technologies to prioritize, the role of quantum in the EU's industrial strategy, member state alignment, and the main governance goals and barriers.

2. **Commercialization, and Autonomy:** EU's competitiveness in quantum technologies in terms of the adequacy and distribution of its investments, the timeline for commercialization, value chain vulnerabilities, geopolitical risks and the importance of consolidating a regional strategy to strengthen Europe's autonomy.

3. **Defense and Cybersecurity:** role of quantum technologies in EU defense strategy, their current level of advancement, the awareness of cybersecurity risks among policymakers, the barriers to achieving quantum-safe systems, and the timeline for implementing post-quantum cryptography.

Each interview was transcribed in full and analyzed through thematic coding. Responses were categorized, according to the predefined categories, allowing for both comparative insights across respondents and identification of emergent themes.

On July 3, 2025, the CGC organized a Foresight Workshop at the IE Tower with additional experts and policymakers from Spain to:

1. **Discuss the preliminary findings** of the desk research and interviews and the current state and landscape of quantum development and governance.

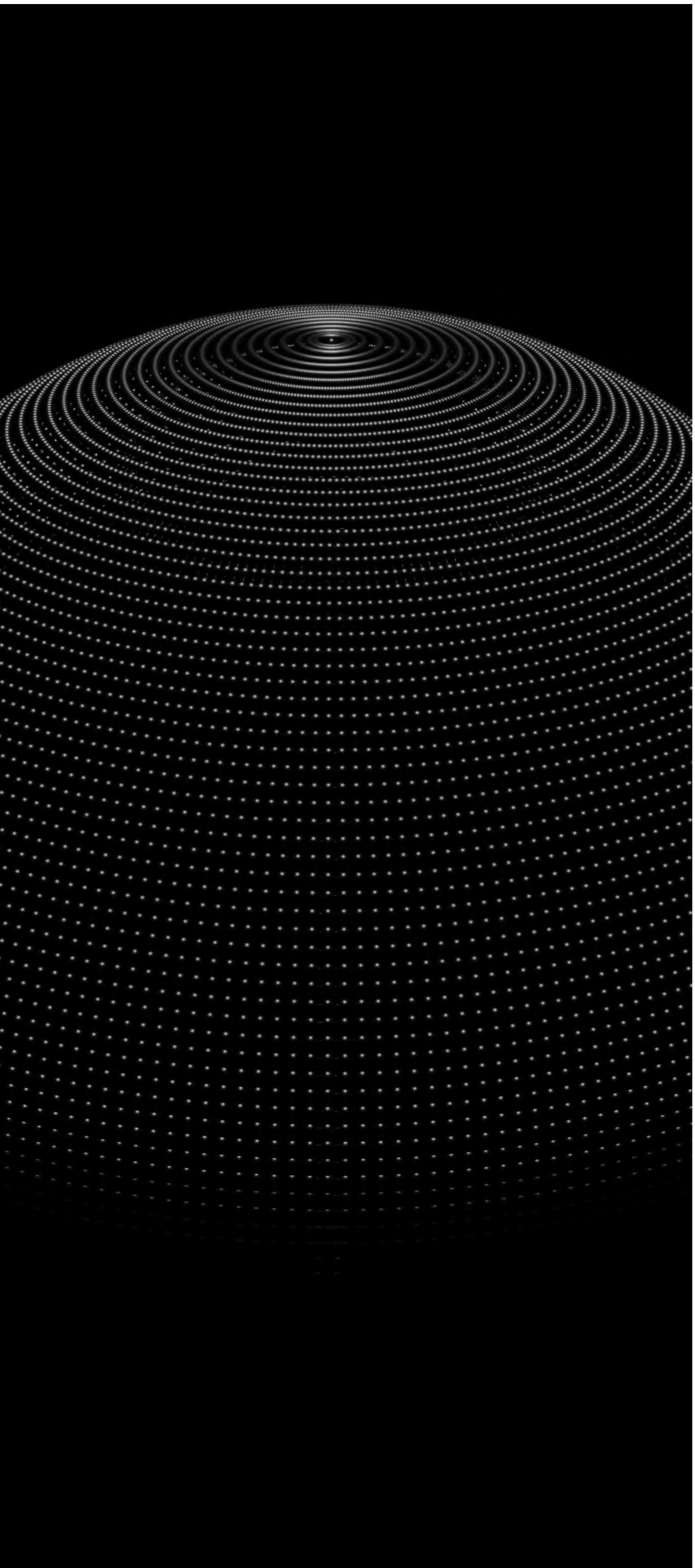
2. **Propose policy measures** to bridge the gap between the current state and a desired future scenario of European competitiveness in and through Quantum Technologies.

3. **Identify the needs of the European quantum industry**, and outline recommendations for improvement.

Participants in the workshop contributed both individually and in groups. Some questions were answered via the *Mentimeter* tool to capture real time feedback and polling, while others were addressed through squad-based brainstorming (2–7 participants) using design thinking techniques. This format facilitated both collective and divergent thinking, culminating in the development of a vision statement for Europe's quantum technology strategy in defense—capturing aspirations, bold changes, challenges, and enablers.

4. CURRENT SITUATION

4. CURRENT SITUATION



While quantum innovation is advancingworldwide, Europe's challenge lies in turning its scientific excellence into strategic autonomy and industrial strength. This section assesses Europe's quantum landscape based on expert insights gathered through interviews.

Europe sits at a crossroads in quantum technologies: a world-class research base and rising startup activity, but uneven national capabilities, fragmented governance, and a thin scale-up finance ecosystem. While public Research & Development (R&D) investment is strong, private capital, growth pathways, and cross-border coordination lag—dampening the continent's ability to turn science into industrial advantage. Based on the interviews, this section reviews expert perception on Europe's strategic positioning the current state of quantum development and governance across the EU.

> Even if quantum computing is not fully operational and does not currently pose a risk to cybersecurity systems, hackers may be capturing and storing today's data for decryption tomorrow.

4.1 EUROPE'S STRATEGIC POSITIONING AND COMPETITIVENESS

There are mixed feelings about Europe's position on quantum technologies. When asked about the feasibility of Europe becoming the "quantum valley of the world", ratings ranged from 2.5 to 5, with most falling between 3 and 4, indicating a range from "possible" to "likely" and reflecting cautious optimism. Most agreed that Europe has strong potential in quantum technologies, though few considered global leadership to be guaranteed or undisputed. This divergence likely stems from differing perspectives among participants: some approach the issue from a more policy-oriented "buy side," while others view it through a technological or market-driven lens.

The interviewees widely agree that Europe's main strengths are:

01/ Strong early-stage quantum research
with quantitative ratings between 3 and 4 (possible–likely), specifically because of strong early-stage research.

02/ A world-class academic base
with quantitative ratings between 2.5 and 5 (mostly 3-4), backed by the fact that in academia, Europe is a world leader.

03/ Significant public funding
with quantitative ratings between 4 and 5 and a clear consensus amongst interviewees that consider that there has been significant progress.

04/ Strong public programs at both national and EU levels
with quantitative ratings between 3 and 3.5 due to the lack of coordination.

At the same time, they pointed out two main weaknesses:

01/ Limited capacity to translate academic excellence into industrial development,
mainly due to the restricted availability of venture capital in Europe. While early-stage public funding and seed investment are relatively accessible, several experts emphasized that growth-stage financing remains scarce, creating a key barrier to scaling quantum technologies where there is a need for larger amounts of investments.

02/ Structural fragmentation and uneven capacities among Member States.
Countries such as Germany, France, the Netherlands, Finland, and Denmark were frequently identified as leaders, whereas others, including parts of Eastern and Southern Europe, have struggled to develop national initiatives and continue to operate on the periphery of the EU's quantum ecosystem.

Interviewees' assessments of Europe's potential to become a global quantum leader were consistent with their evaluation of its **current competitiveness**. On a scale of 1 to 5, most rated Europe between 3 and 4 (*Figure 16*).

Figure 16. Current competitiveness

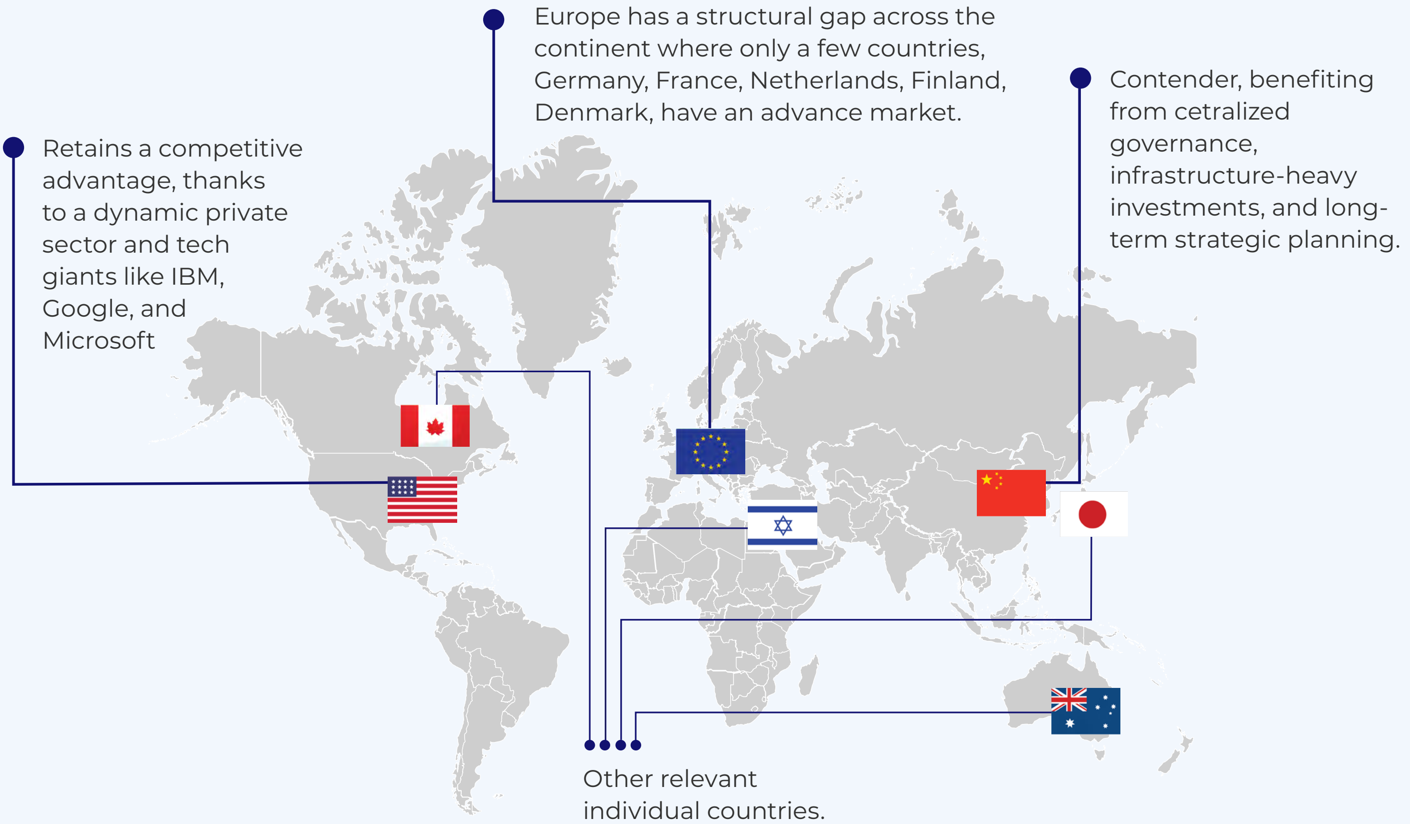
There was broad agreement that the **US** maintains a clear edge, driven by a dynamic private sector and major technology firms such as IBM, Google, and Microsoft. **China** was likewise identified as a leading contender, owing to its centralized governance, infrastructure-focused investments, and long-term strategic planning. Other countries highlighted as relevant players included **Canada, Japan, Australia, the United Kingdom, and Israel** (*Figure 17*).

Within Europe, interviewees noted uneven capacities and fragmentation in the quantum technology competitiveness of its member states. Countries such as **Germany, France, the Netherlands, Finland, and Denmark** are frequently identified as leaders, while others, including some in Eastern and Southern Europe, are seen as struggling to develop national initiatives and sufficient financial resources. These five countries were repeatedly mentioned across interviews as Europe's most mature quantum ecosystems. Germany and France combine strong institutional coordination and industrial partnerships; the Netherlands and Finland stand out for their cross-border infrastructure and experimental approaches; and Denmark for its collaborative links between academia and industry. In contrast, Eastern and Southern European countries remain largely research-focused, reflecting uneven development of national programs and funding mechanisms.

One example that was observed first-hand was the impossibility to find country representatives to talk to in Poland, despite our best efforts to locate experts to have them participate on this project.

While Europe's quantum landscape is anchored by a few highly advanced ecosystems—Germany, France, the Netherlands, Finland, and Denmark—these countries differ in their approach. Germany's DLR Quantum Initiative and France's unified national plan combine strong state coordination with industrial partnerships. The Netherlands and Finland emphasize cross-border research infrastructure and early market experimentation, while Denmark excels in academic–industry collaboration and sensing applications.

Figure 17. **Geographic quantum regions.**



In contrast, Southern and Eastern European countries often lack sustained national programs, long-term funding, and industrial anchors. Their participation in the quantum value chain remains concentrated in academic research rather than commercialization or hardware production. These asymmetries not only reflect different levels of economic capacity but also reveal the absence of a cohesive European strategy to leverage complementary strengths across regions.

Europe faces a siloed work environment in which collaboration occurs in research but not so much in innovation. This is because each country operates independently with its own quantum strategy and no unified approach. Moreover, collaborations sometimes take place abroad, through bilateral agreements with non-EU countries. This structural fragmentation is a challenge since it hinders Europe's ability to compete with more dynamic ecosystems.

DIVERGENT STAKEHOLDER PERSPECTIVES

The interviews revealed that perceptions of Europe's quantum competitiveness vary notably by stakeholder group.

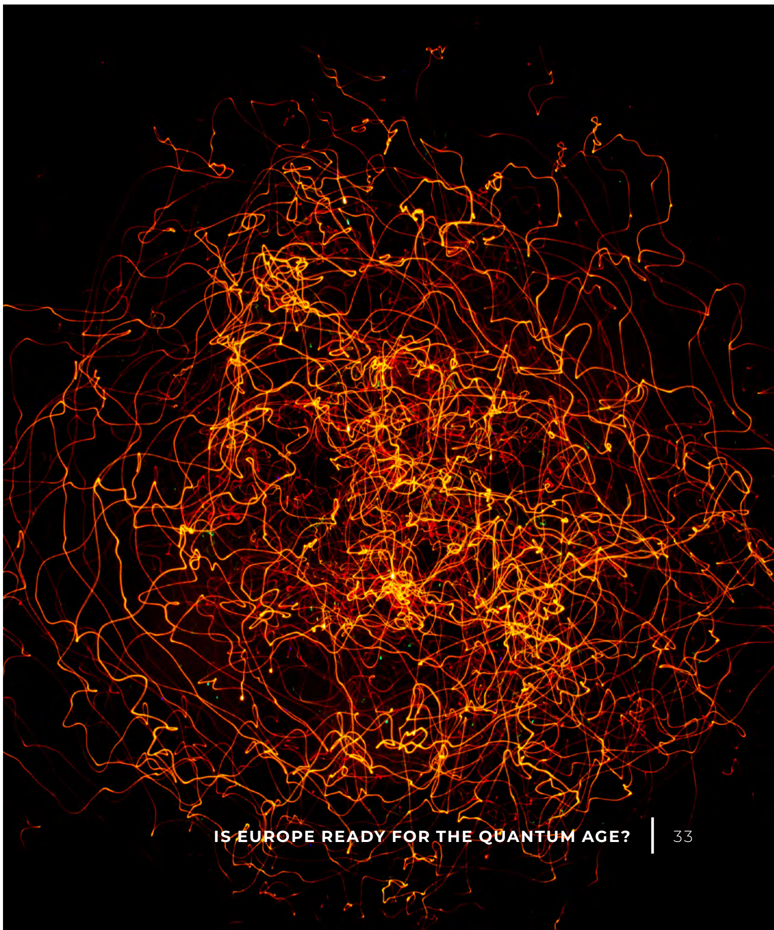
- **Researchers** emphasized the strength of Europe's academic ecosystem and called for continued long-term investment in fundamental science, cautioning against premature industrialization.
- **Policymakers** focused on the need for coherent governance and greater coordination between national and EU-level initiatives to reduce fragmentation.
- **Industry representatives** expressed concern over the scarcity of late-stage venture capital and limited incentives for scaling quantum startups.
- **Defense and security experts** viewed quantum as strategically critical but highlighted institutional inertia and a lack of coordination between civilian and military research.

This diversity of perspectives underscores that Europe's challenge is not scientific capability but **alignment**—bridging the differing priorities of academia, policymakers, and industry to create a common path from research to market impact.

Interview ratings on cross-country coordination reinforce this interpretation. When asked to assess alignment between EU Member States, most respondents rated it between 3 and 3.5 out of 5—moderate but incomplete *(Figure 18)*. The need for a dedicated European coordination mechanism, comparable in ambition to the US.

Figure 18. **EU member states alignment.**

A US DARPA (Defense Advanced Research Projects Agency)-type model was repeatedly highlighted as essential to bridge research, policy, and market priorities. This aligns with growing calls for governance structures capable of translating scientific excellence into coherent industrial outcomes.



INTERVIEW EXCERPTS ON EUROPE'S QUANTUM POSITIONING

"The main challenge I would say is integration and inclusion, and this has different dimensions. If we speak about the dimension at the geographical level, it means that we must make sure that the sort of participation divides between widening countries and the other countries of the European Union is closed. This is really bringing in danger of creating different development speeds within the European Union and impairing both of the political momentum in this direction, but also the capacity and the possibility to tap into talent, all the talent that we have."

–Research-Academia (Germany)

"I think Europe ticks a lot of boxes, in terms of public support, academic research, end users, and corporates that can adopt quantum computing. Where we're a bit weak is on the investment side. We have a solid ecosystem for early-stage funding, but once a company starts to grow, it becomes difficult to find growth investors."

–Technology Provider (France)

"The US has an advantage through its financial ecosystem and consolidated computing industry."

–Technology provider Provider (Spain)

"Europe currently lags behind the level of investment seen in the United States and China, particularly in private funding, although it leads in public investment. Therefore, while the initiative has solid potential, it is expected to become part of a broader network of hubs rather than a singular, dominant center."

–Quantum Consortium (Spain)

"There's too much uniformity in national strategies and not enough differentiation. For instance, a small country could exploit second-mover advantages, relying on R&D investments made elsewhere. There's not enough explicit thinking about how to make collaboration concrete. Many strategies mention cybersecurity, transportation, defense, navigation, materials, etc., but there's little on implementation. The UK, for instance, showed that openness in quantum research leads to higher-impact citations. But we need more practical mechanisms to make the whole greater than the sum of its parts."

–Policymaker (Europe)

"It is feasible to achieve that pact for quantum technologies and to ensure that Europe has a certain level of leadership in this field. However, it requires, on the one hand, a great deal of commitment and, on the other, strong coordination — and Europe is not always particularly good at coordination. In many cases, especially when so much is at stake as with quantum technologies, we end up competing heavily among ourselves. To truly become a powerful international player, much stronger coordination among Member States and less internal competition will be necessary."

–Policymaker (Europe)

"It's necessary for Europe to become a leader in this technology, and I believe it has the potential to do so because we have many excellent universities, strong research institutions, and a growing number of startups in the quantum field. What we lack is sufficient venture capital and jointly coordinated initiatives."

–Defense Agent (Germany)

4.2. EUROPE'S GOVERNANCE AND INVESTMENTS

On a positive note, interviewees recognize that Quantum Technologies are clearly gaining visibility at EU level, and are increasingly being positioned as a **strategic priority** within the current landscape. Interviewees confirmed this, emphasizing that visibility and policy commitment at the EU level are very high (4–5/5), but alignment across national strategies remains moderate (3–3.5/5). While flagship initiatives such as the *Quantum Flagship*, the forthcoming *Quantum Act*, and *EuroQCS* were praised, participants stressed that the lack of a unified operational mechanism limits their combined impact. There was a broad consensus that coordination structures are still fragmented, and that more strategic instruments—like the proposed Quantum Pact—will be needed to align resources and long-term priorities.

This perception is reinforced by initiatives such as:

01/ Initiatives such as the *Quantum Flagship* and the *Quantum Act*.

02/ Broader strategic documents such as the *Competitiveness Compass*.

03/ Sustained public investment in research and early-stage development.

The public side of the investment particularly through the European Commission and Member States is relatively strong, generally rated between **4 and 5 out of 5** (*Figure 19*) with flagship initiatives, recovery funds, and national programs contributing to this.

Figure 19. **Level of public investment.**

1	2	3	4	5

Despite this strong foundation, respondents highlighted a set of structural challenges that limit the effectiveness of Europe's governance and investment mechanisms. These challenges reflect the tension between high-level commitment and uneven national implementation.

The challenges described by stakeholders across research, policy, and industry reveal a persistent gap between strategic ambition and practical implementation. Despite visible progress, Europe's governance structure still reflects asymmetries in national capacities, short-term funding cycles, and varying political commitment. These governance gaps translate directly into investment inefficiencies and uneven technological progress.

Interviewees highlighted some major **investment challenges** hindering Quantum Technologies development in Europe:

01/ Uneven national strategies: Significant variation exists across member states when it comes to the distribution, structure and long-term sustainability of investments. While some countries pursue ambitious plans, others have yet to establish national programs, creating fragmentation and unequal progress.

02/ Weak private investment ecosystem: Europe's deep-tech venture capital market lacks the scale and risk appetite needed to support high-growth quantum startups.

03/ Limited exit opportunities: The scarcity of Initial Public Offering (IPOs) and major acquisitions restricts the growth potential of quantum startups and discourages private investors.

04/ Inadequate scale-up mechanisms: Few dedicated tools and incentives exist to bridge the gap between research and commercialization, hindering industrial adoption and market creation.

05/ Variable effectiveness of public funding: Outcomes often depend on how well resources are allocated and strategic priorities identified.

In particular, the following areas (*Figure20*) were the most frequently identified as those that need further investment, ordered by relevance and emphasis:

Figure 20. **Further investment areas.**

01/ Infrastructure and Application-Driven Development

Europe lacks shared infrastructure such as cleanrooms, testing environments, lab-to-fab transitions and targeted support for industrial use-case validation. Greater investment in these resources would lower barriers for smaller actors, foster cross-border collaboration and enable business adoption. There is also a need for closer collaboration with large industrial or economic groups to identify specific quantum use cases.

02/ Long-Term Perspective and Continuity

Short-term and inconsistent funding cycles undermine Europe's ability to retain talent and support scale-up efforts. Long-term, predictable investment frameworks, such as the EU's multiannual budget cycles, are needed. Companies require consistent support to develop build teams, develop IP, and plan long-term.

03/ Efficient Allocation, Traceability, and Avoidance of Double Funding

Funding is often concentrated in a few member states, with instances of double funding at both national and EU levels. More rigorous evaluation mechanisms, better traceability of outcomes, and greater coordination between the different administrations is needed and may be achieved through the Quantum Pact.

04/ Basic and Applied Research

Despite growing pressure to industrialize, the current development stage of quantum technologies requires to maintain strong support for fundamental research. Investment in universities and research centers remains critical to sustaining Europe's long-term competitiveness.

Interviews revealed **no clear consensus on which quantum technologies Europe should prioritize** or how to structure a coherent strategy. Participants were divided between focusing on specific applications (e.g., computing, communications, sensing) and investing in enabling infrastructures that support multiple domains. Each Quantum Technology requires its own development timeframe and **strategic priorities**, yet **they all contribute to a broader, interdependent quantum ecosystem**, in which progress in one domain reinforces the others. Neglecting any risks weakening Europe's overall development capacity and competitiveness in quantum.

> This ecosystem approach requires recognition of different maturity levels while ensuring balanced support across all domains. Strategic prioritization is therefore less about ranking technologies by importance than about sequencing their development coherently and integrating their contributions into a common agenda.

There are **priorities and governance challenges in the quantum ecosystem**, with a moderate perception of alignment between EU countries (*Figure 20*). While many interviewees rated the current level of alignment between EU countries as moderate, typically around 3 to 3.5 out of 5, "moderate", their responses reveal deeper structural tensions between the discourse of coordination and the reality of fragmented national strategies.

Figure 20. Alignment between EU countries.

1	2	**3**	4	5

While there are efforts to develop coordination mechanisms, such as industrial alliances and shared infrastructure initiatives (e.g., EuroQCS), crucial decisions—where to locate infrastructure, how to structure funding mechanisms, and which national champions to support—remain primarily in the hands of individual EU Member States.

These governance imbalances are clearly reflected in the way public investment is distributed and managed across Europe. While funding levels are widely considered substantial—typically rated 4 to 5 out of 5 by interviewees—its effectiveness depends heavily on allocation, continuity, and coordination between Member States and the European Commission.

Stakeholders repeatedly stressed that while early-stage support is strong, Europe's private investment ecosystem remains weak, particularly in scale-up finance, exit opportunities, and industrial risk capital. **Two opposing visions shape the debate on investments in EU**: either channel investment toward the most advanced Member States to accelerate global leadership or distribute resources more evenly to close technological gaps across Europe. This highlights a broader strong internal conflict between countries with different developmental speeds: those with more advanced technological capabilities and those lagging behind. Effective governance will require strategies that both leverage the specific strengths of each national ecosystem and the imperative to close existing technological gaps across Member States.

> The goal must be to establish a coherent strategy throughout Europe and to clarify which technologies should be further developed, as well as which nation is doing what to establish a joint agenda setting in different technology fields.

Several experts also drew attention to inefficiencies in current funding flows, noting recurring patterns of resource concentration in leading countries such as Germany, France, and the Netherlands. This often results in double funding of similar research streams and limited traceability of outcomes. Interviewees called for more transparent evaluation frameworks, longer-term continuity beyond recovery fund cycles, and a better balance between strategic specialization and inclusive participation across regions.

Interviewees identified three main risks if EU Member States fail to develop a coordinated quantum governance agenda:

01/ Irreversible Lag

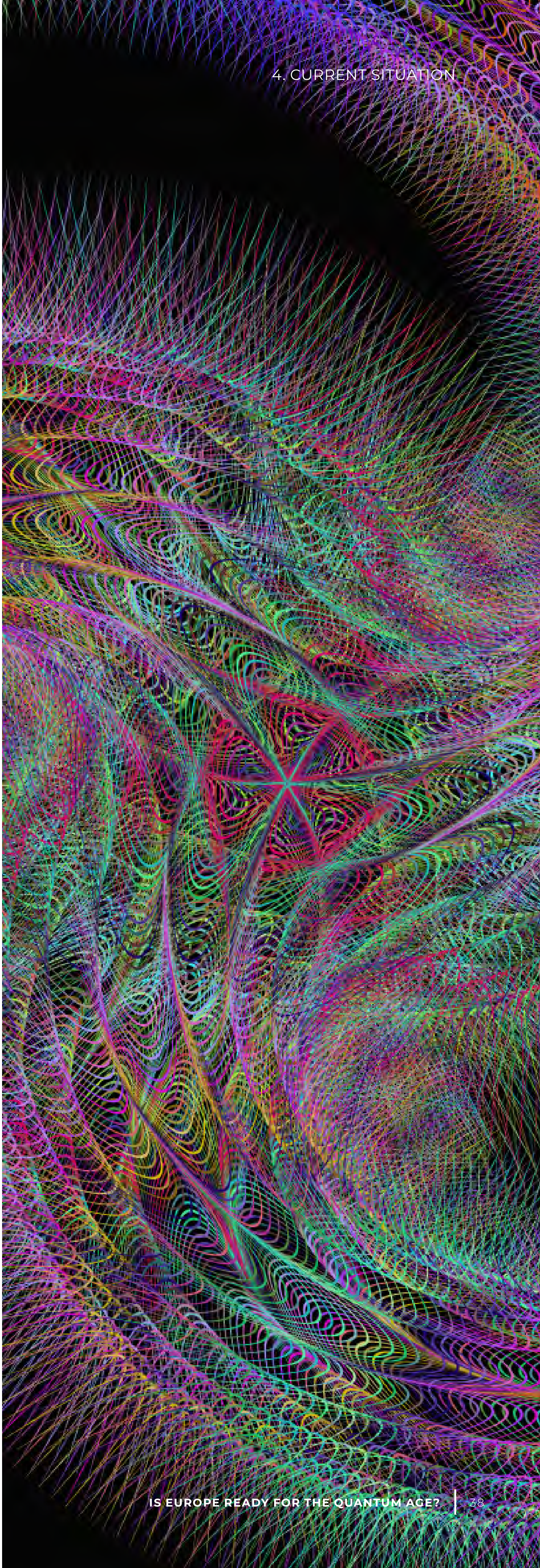
Failure to establish leadership now could permanently lock Europe out of the quantum race. Once global competitors consolidate investments, infrastructure, and innovation, catching up becomes extremely difficult.

02/ Increased Fragmentation

Without a consolidated strategy, divides among member states grow. Some countries may continue to advance rapidly while others are left behind. This fragmentation undermines cohesion, limits cross-border collaboration and reduces impact.

03/ Loss of Strategic Assets

If Europe has weak support structures for startups it leads to their acquisition by non-European actors, and the absence of long-term opportunities and investment leads researchers and developers to seek work abroad. There is a risk of losing technological and human assets.



INTERVIEW EXCERPTS ON EUROPE'S GOVERNANCE AND INVESTMENTS

"Europe is altogether investing a very high amount between the Commission and the Member States. But what we need is one unified strategy, one aligned strategy with longer-term planning. What we need is a longer-term framework, like a 7-year budget cycle, which national governments don't have. Synchronizing these timelines and mobilizing funds like EIC and EIB can really help us not miss the train."

–Research-Academia (Germany)

"There is enormous quantum talent in Europe, so the capabilities are very high. Governments can do a lot to support this, but we need a cohesive plan and decision-making processes guided by technological development—not by national interests. That is both a challenge and an opportunity for Europe. Even with strong implementation, one key disadvantage remains: Europe has traditionally lagged behind in private investment, which is essential for any technology to truly thrive."

–Research-Academia (France)

"The companies have been delivering on their own, that's for sure. But the adoption of such projects will take a bit longer than maybe what everyone expected at the beginning. Even though you have something that's working, it remains very technical and very difficult to implement. You also have to make connections with industry and end users. All the companies are doing proof of concept with large corporates, but still, it will take time to go from proof of concept to actual business case that generates value within companies. I think we still need a couple of years for corporate and industrial actors to understand how they can generate value from these products."

–Technology Provider (France)

"At the European level, there is enough money, but there are also countries with a lot of national investment, so there is double funding, often with little oversight. One of the reasons for the Quantum Pact is to better synchronize resources between what the European Commission provides and what the Member States do.
At the project level: Germany, the Netherlands, and France are the main players in all areas. That is very difficult to avoid. They are also the countries with the highest local investment, which in a way reinforces what Brussels provides. They have allocated more money to large-scale and high-intensity projects. I'm not sure that's the most efficient approach, because the results aren't always visible."

–Quantum Consortium (Spain)

"There are some areas that are weak. Not Europe's fault per se—but things to be mindful of.
The whole supply chain in material science, for instance: we rely on Ukraine, Africa, China for rare earths, minerals, gases. And talent—we should definitely be able to create, educate, and upskill our own. We're already self-sustained in research, so we should just keep funding the basic research. And we must make sure we have trusted global partners."

–Quantum Investor (Denmark)

"No country can fully dominate the quantum ecosystem. Collaboration is necessary. Nationalism is seen by industry leaders as the biggest bottleneck. Supply chains are multi-dimensional. Europe should be cautious not to isolate itself."

–Policymaker (Europe)

4.3. COMMERCIALIZATION PATHWAYS AND DEFENSE APPLICABILITY

Despite high levels of public investment and research activity, the translation of quantum science into commercial impact remains slow. Interview findings highlight that limited industrial maturity, insufficient standardization, and the absence of demonstrable applications are the main barriers to scaling. Many respondents identified the need for shared infrastructure, industrial testbeds, and application-driven funding programs to accelerate progress from laboratory prototypes to market-ready technologies.

Quantum business value timelines and profitability vary considerably across subfields resulting in highly divergent timelines that depend on breakthroughs, with general-purpose, application-ready quantum computing not yet feasible at scale (*Figure 22*).

Interviews provided detailed estimates for commercialization horizons: quantum sensing is expected to reach widespread adoption within 2–10 years, quantum communication within 5–15 years, and quantum computing within 10–30 years.

These timelines reflect different maturity levels—sensing as the most imminent, communication as strategic but mid-term, and computing as a long-term breakthrough opportunity.

Two critical gaps affect **quantum technology commercialization:**

(1) Industrial maturity and standardization to scale production

(2) Proven applications that demonstrate a clear quantum advantage.

Until both are addressed, adoption and investment will remain cautious.

Respondents agreed that Europe's first tangible value from quantum technologies will arise where public and strategic demand already exist—primarily defense, cybersecurity, and high-performance industrial sectors. However, industrial readiness and standardization gaps continue to delay broad adoption, underscoring the need for demonstration projects that validate quantum advantage in real-world use cases.

Figure 22. **Industry maturity and adoption timeline.**

QUANTUM SENSING

- Imminent with high potential for near-term deployment
- Sensing applications in sectors like aviation, navigation, or health will be the first to generate real-world value

(2–10 years)

QUANTUM COMMUNICATION

- Strategic and mid-term Mature and ready
- Some value is already being generated, particularly through public procurement and defense-related use

(5–15 years)

QUANTUM COMPUTING

- Long-term with huge but uncertain potential
- Systems sold for research. Early value will come from some applications (e.g. optimization, pharma modeling)

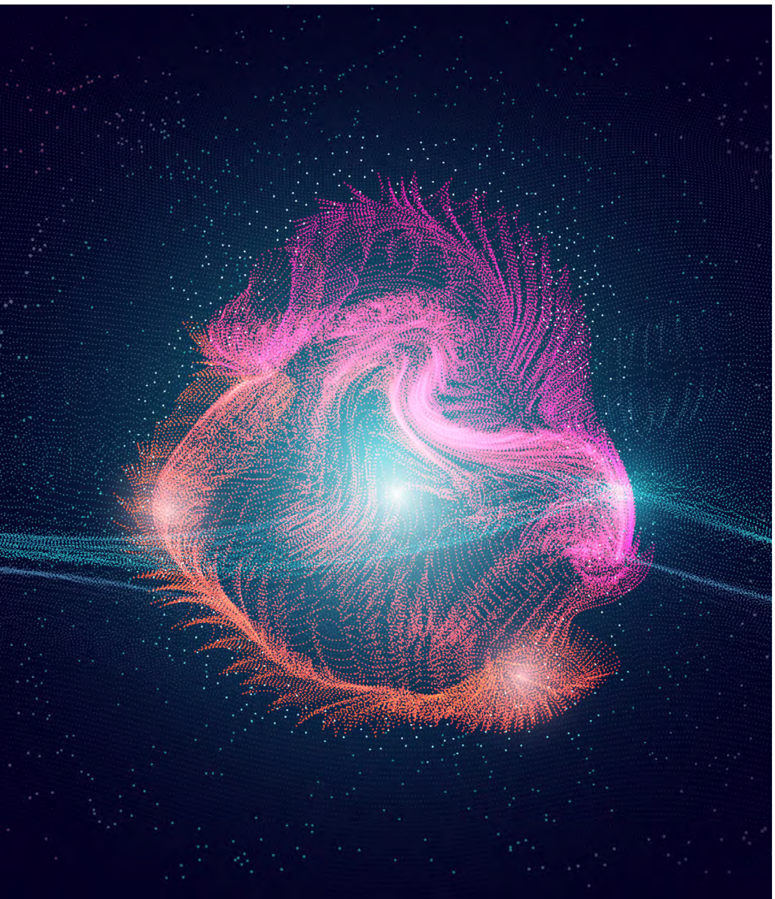
(10–30 years)

The first **potential impact for quantum technologies** will be in:

01/ *Defense and Cybersecurity*
This is the most immediate and strategically prioritized area, with quantum communication (via projects such as IRIS2 and EuroQCI) driving secure data transmission and protection of critical infrastructure.

02/ *Economic Competitiveness*
Quantum computing is a lever to strengthen Europe's technological autonomy and industrial leadership, with potential to enhance capabilities in optimization, machine learning, and material science. Success could generate major economic benefits.

03/ *Industry-Specific Applications*
Fields such as pharmaceuticals, chemistry, logistics, and materials science are expected to benefit significantly from quantum tools. Early use cases include drug discovery, advanced simulations, and high-precision sensing.



Europe aims to reduce geographic reliance in its quantum value chain but encounters structural limits in hardware, as even individual components (such as optical fiber) could become bottlenecks if demand grows quickly.

- Europe's top concern is its dependence on US and East Asian suppliers **for quantum chips, semiconductors, lasers, and control hardware.** These risks include export restrictions or trade conflicts that could disrupt supply and competition from cheaper imports (especially from China) that could undermine European suppliers, a vulnerability that overlaps with the broader semiconductor sector and motivates initiatives like the European Chips Act.
- **Critical materials** such as niobium, germanium, ultra-pure silicon, rare earth elements, and helium-3 highlight Europe's heavy reliance on external suppliers despite some local reserves, with geopolitical risks—including the war in Ukraine, tensions with China, and dependence on the US—exposing Europe to potential disruption. These materials are needed to build quantum chips and cool down the computers through the dilution refrigerators and to operate computers with control electronics.

Experts see the **potential impact of the US protectionist measures** as a double-edged sword for Europe's quantum sector. On one hand, they risk delaying research, disrupting supply chains, and weakening transatlantic collaboration. On the other, they could serve as a catalyst for Europe to strengthen its autonomy, diversify global partnerships, and invest in its own ecosystem, potentially leading to greater resilience and talent retention.

Across interviews, **defense and cybersecurity consistently emerged as the most immediate and strategically prioritized domains** for quantum technology development in Europe. Experts broadly agreed that these areas will be the first to demonstrate concrete societal and strategic value, though most rated Europe's current readiness as moderate—between 3 and 3.5 out of 5—reflecting early integration but limited operational deployment.

On the **impact of quantum technologies for the defense sector**, interviewees broadly agreed that they will become increasingly important in defense, especially over the long term. While technological maturity varies across subfields, several areas show strong potential for strategic use. A summary is shown in *Figure 23*.

Figure 23. **Quantum applicability in defense.**

QUANTUM SENSING

- Submarine detection
- GPS-independent navigation
- Precision targeting via gravimeters, magnetometers

A high-priority area for defense applications, with strong potential to enhance navigation and to detect concealed or hard-to-reach threats.

QUANTUM COMMUNICATION

- Unbreakable encryption
  – Satellite
  – Drones
  – Naval platforms

The most mature and immediately applicable defense technology, providing unbreakable communication links essential for secure operations.

QUANTUM COMPUTING

- Cryptanalysis
- Optimization for logistics
- Planning and simulation of defense systems
- Design of new materials or weapons systems

A key enabler of future defense capabilities, with long-term potential to solve complex computational problems and ensure technological sovereignty.

In the near term, **quantum communications and sensing** stand out as the most relevant. Secure communication methods—particularly quantum key distribution (QKD)—are already in development and, in some cases, deployment, providing unprecedented protection against interception.

However, these technologies still face significant hurdles. Their reliance on extreme stability and cryogenic environments creates major challenges for deployment in dynamic field conditions, limiting the near-term scalability of quantum sensing and communications in defense operations.

The **current maturity of quantum technologies in the defense sector** is still moderate. Europe remains in the early stages of integrating quantum technologies into its defense sector, with progress between a 3 and 3.5 (*Figure 24*). Some initiatives are underway, with challenges due to a lack of coherent planning, stable funding, and cross-institutional coordination as key barriers to progress.

Figure 24. **Quantum applications maturity in defense.**

1	2	3	4	5

A critical factor to progress is the sector's high bar for technological maturity. Unlike civilian applications, defense projects typically require Technology Readiness Level (TRL) 8 , meaning that components must already be tested, validated, and deployed in real operational environments before considered viable.

Another development hurdle is **secrecy with potentially excessive classification** might actually hinder innovation and collaboration. For example, the US Department of Defense initially kept quantum sensor research classified, only to later reverse course and open it up to the broader research community.

Interview insights also highlighted the growing urgency of post-quantum cryptography. Most respondents converged on 2030 as the target year by which quantum-safe systems should be fully implemented across critical infrastructures, while others warned that preparation should begin earlier to avoid transition bottlenecks. The main barriers identified were transition complexity, lack of finalized standards, and uneven awareness across EU institutions.

Policymakers across Europe are becoming increasingly aware of **cybersecurity risks and the shift to post-quantum cryptography** due to the challenges posed by quantum technologies to existing cryptographic systems that require a move to new systems. However, the level of preparedness remains uneven across the EU: high-level agencies such as defense ministries, the European Commission, and NATO are generally well-informed; nevertheless, the understanding and sense of urgency vary significantly across national administrations and even within institutions.

> European policy still tends to follow the lead of the US, particularly the standards set by National Institute of Standards and Technology (NIST), rather than developing a distinct European approach. The absence of a coordinated EU-wide migration plan toward post-quantum systems is a gap.

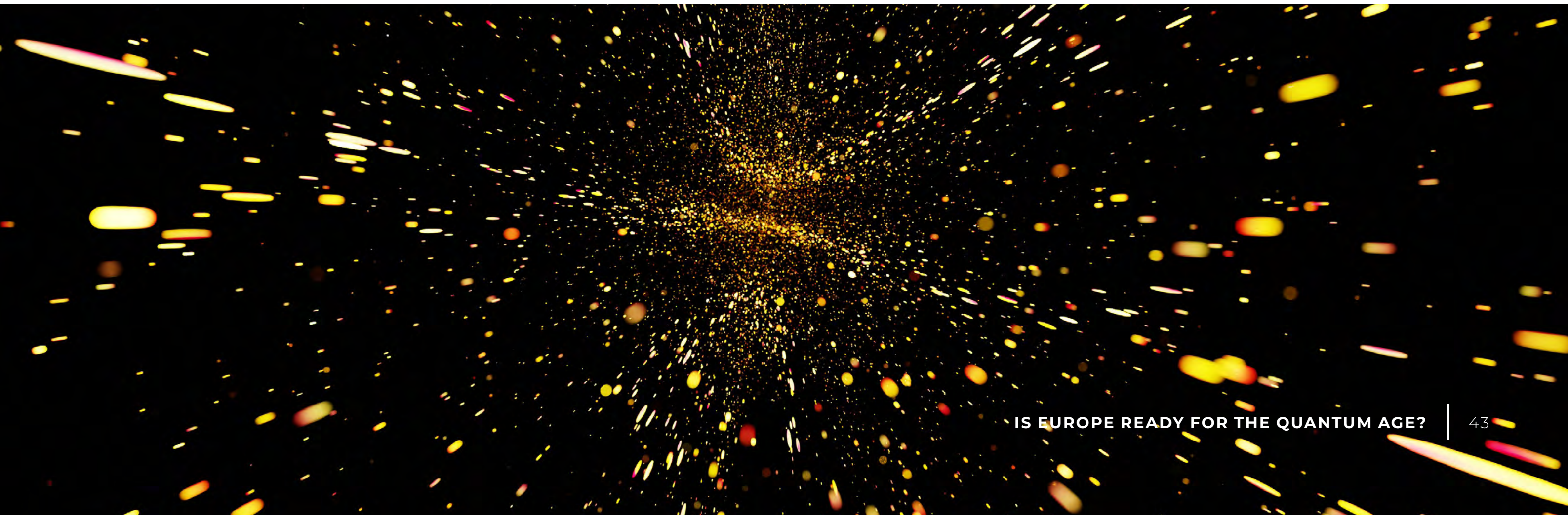
Although the timeline for post-quantum cryptography is 2030, or even later, some experts consider that there is a need for more immediate action since the accelerating pace of quantum research and unexpected breakthroughs in hardware suggest that waiting could be a strategic miscalculation.

There are three identified barriers for the implementation of post-quantum cryptography:

01/ *Time and Transition Complexity*
Changes must be implemented simultaneously and across all layers of communication systems to be effective.

02/ *Lack of Standardization and Protocol Stability*
The field is still waiting for final decisions from the US NIST.

03/ *Awareness Gaps and Uneven Political Will*
This uneven political will and knowledge base hampers coordinated action and delays the initiation of necessary reforms.



INTERVIEW'S EXCERPTS ON COMMERCIALIZATION PATHWAYS AND DEFENSE APPLICABILITY

"Quantum sensing is the area closest to the market and where the greatest potential can be realized. Quantum communications as well, especially for ensuring privacy and confidentiality. The greatest economic potential lies in quantum computing, but it is also where we are least likely to compete with the billion-dollar investments from China and the US. That is why one of Europe's opportunities is to consolidate value chains for the production of quantum technologies with European suppliers and industries."

–Policymaker (Spain)

"Quantum communications for secure communications, including for defense, is pretty much advanced. It's already commercially available and developed and deployed. Quantum sensing is not far from there, single-photon imaging is quite advanced, and other methods are being developed for space-based detection of submarines and similar defense-related applications. Quantum computing is currently the least advanced but is already being considered for its dual use potential, and export control measures reflect this growing importance."

–Research-Academia (Germany)

"Well, it's just that you have to change all the internet protocols. And this is not something that one can do overnight. And at the same time, one would have to do it overnight because it only works if it is available everywhere. Otherwise, it will not have sufficient strength. So that's a bit the challenge that we have: the breadth, the pervasiveness of security in classical communications and the need to replace that with these new kinds of algorithms which, if you wish, is only a deployment question, but a non-trivial one."

–Research-Academia (Germany)

"In the defense sector, only TRL 8 technologies are used. These are products that have gone through all necessary tests and are already deployed in field conditions by operational units. Even if validated in labs or testbeds, devices must demonstrate operational performance before scaling up to mass production. This is standard in defense applications—vehicles, aircraft, communications systems all follow this path. For quantum, only mature components, already in use in the market, are viable candidates."

–Defense Agent (Spain)

"Quantum technologies are included in defense, although still in an early stage. NATO already has an active initiative on quantum technologies and is collaborating with the sector. There is clear awareness of their future importance, and the first steps are being taken. This line of work is expected to be progressively strengthened, especially in areas such as cybersecurity and advanced computing."

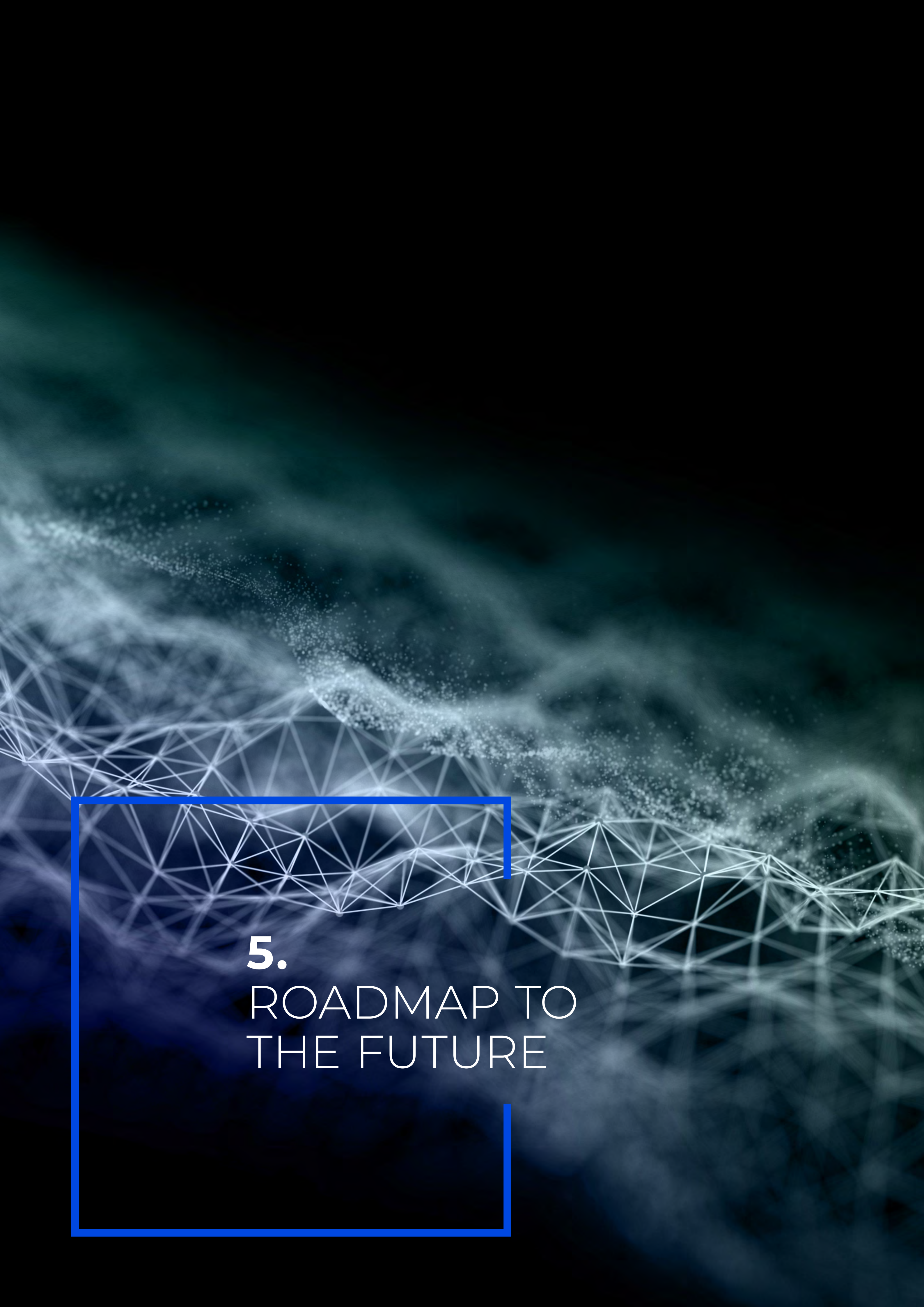
–Technology Provider (Spain)

"Most of the national quantum strategies mention defense, cybersecurity, and national security as areas of application. But it's not always clear how these priorities are being concretely implemented or coordinated across countries."

–Policymaker (Europe)

"If I go by internal discussions, this should have started five years ago. Replacing hardware systems takes a long time, especially in areas like ships, aircraft, and other embedded devices. We never know when a cryptographically relevant quantum computer will arrive, but if it comes in 2030, we won't be able to replace all systems in just a month or two. This kind of transition takes many years."

–Defense Agent (Germany)



5. ROADMAP TO THE FUTURE

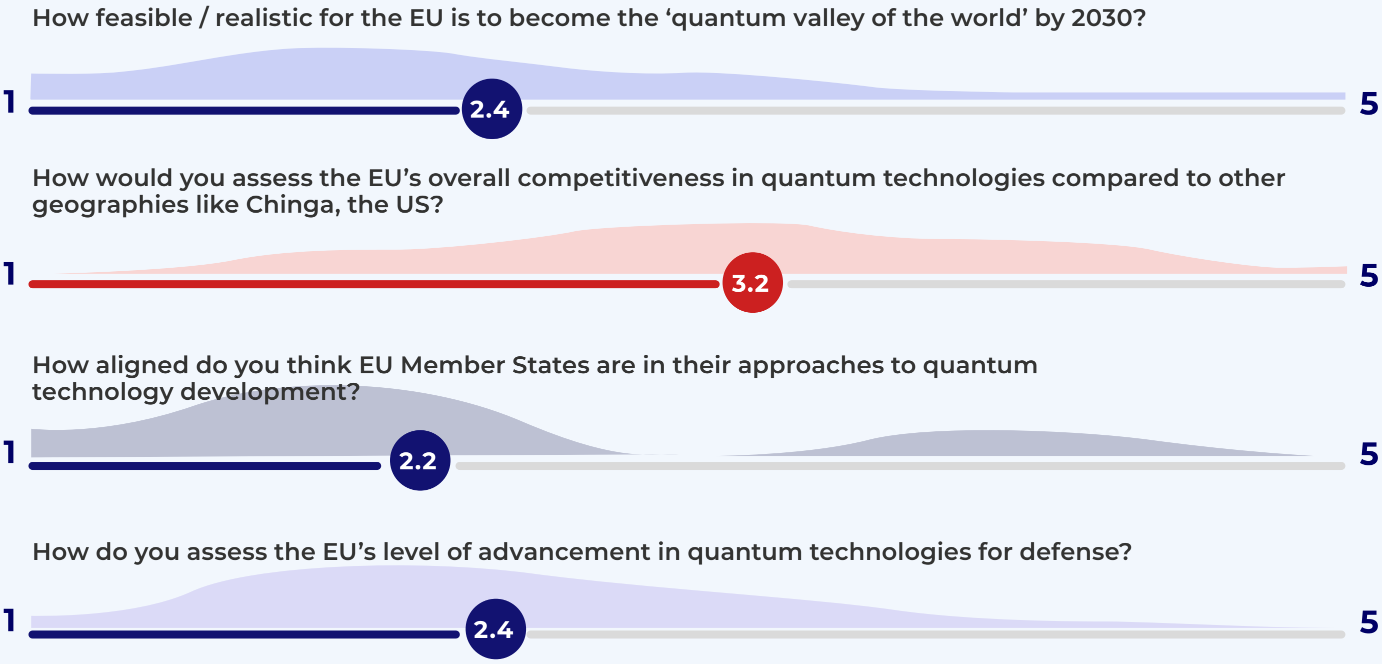
5. ROADMAP TO THE FUTURE

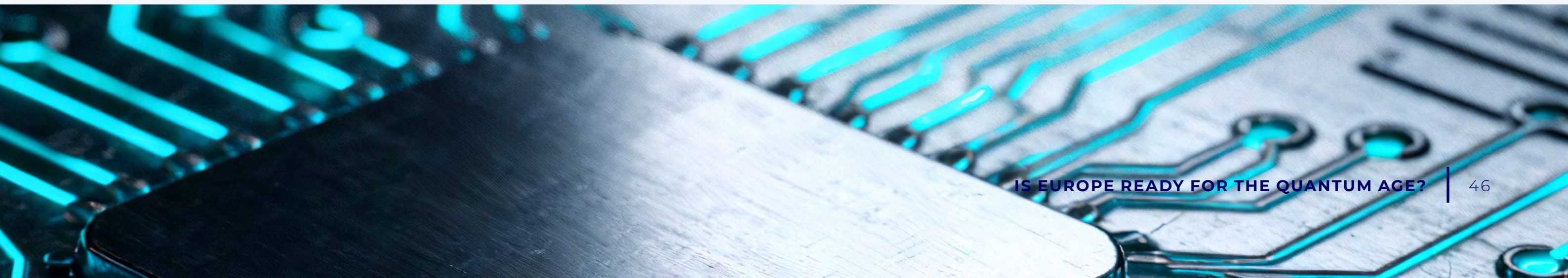
The project culminated in a high-level workshop with 12 SMEs to discuss preliminary findings from the desk research and interviews, review the current state of quantum development and governance in Europe, and identify actionable measures to strengthen European competitiveness in and through quantum technologies.

The group evaluated Europe's readiness to become a quantum player by 2030, its current level competitiveness when compared to other geographies, intra-EU alignment, and progress in defense applications (*Figure 25*).

Like the SMEs who participated in the interviews, the workshop participants agreed that Europe possesses world-class science, talent, and relevant institutions —most notably the *Quantum Flagship*—yet continues to lag behind the US and China in turning research excellence into industrial strength and sovereign capabilities. Fragmentation across Member States, slow and bureaucratic funding mechanisms, and limited political prioritization risk were seen as structural barriers. As one participant noted, "Europe risks becoming irrelevant by osmosis, not by failure."

Figure 25. **Feeling of EU's quantum state.**





Furthermore, while views differed on the level of alignment among EU Member States, there was consensus that the challenge is not only technical but institutional: Europe needs more decisive, long-horizon leadership and streamlined decision-making to transform its scientific assets into competitive advantage.

Experts also identified several structural **headwinds and tailwinds** shaping Europe's trajectory as shown in *Figure 26*. Addressing the former while leveraging the latter will determine whether Europe can translate its strong scientific base into sustained strategic advantage.

Figure 26. **Europe's trajectory.**

HEADWINDS (-)

- **Fragmentation**
  Persistent technological, fiscal, and regulatory divisions hinder scaling and cross-border collaboration.
- **Lack of unified prioritization**
  Absence of an EU-wide list of critical technologies leads to duplication and misalignment.
- **Weak industrial champions**
  Europe lacks large-scale "quantum Airbuses" capable of competing globally.
- **Investment-to-impact gap**
  Public funding remains high, but late-stage investors, defense sandboxes, and TRL-8 test facilities are scarce.
- **Talent leakage**
  Highly skilled graduates migrate to deeper talent markets due to weak retention incentives.
- **Supply chain exposure**
  Dependence on non-EU chips, components, and rare materials exposes Europe to geopolitical risk.

TAILWINDS (+)

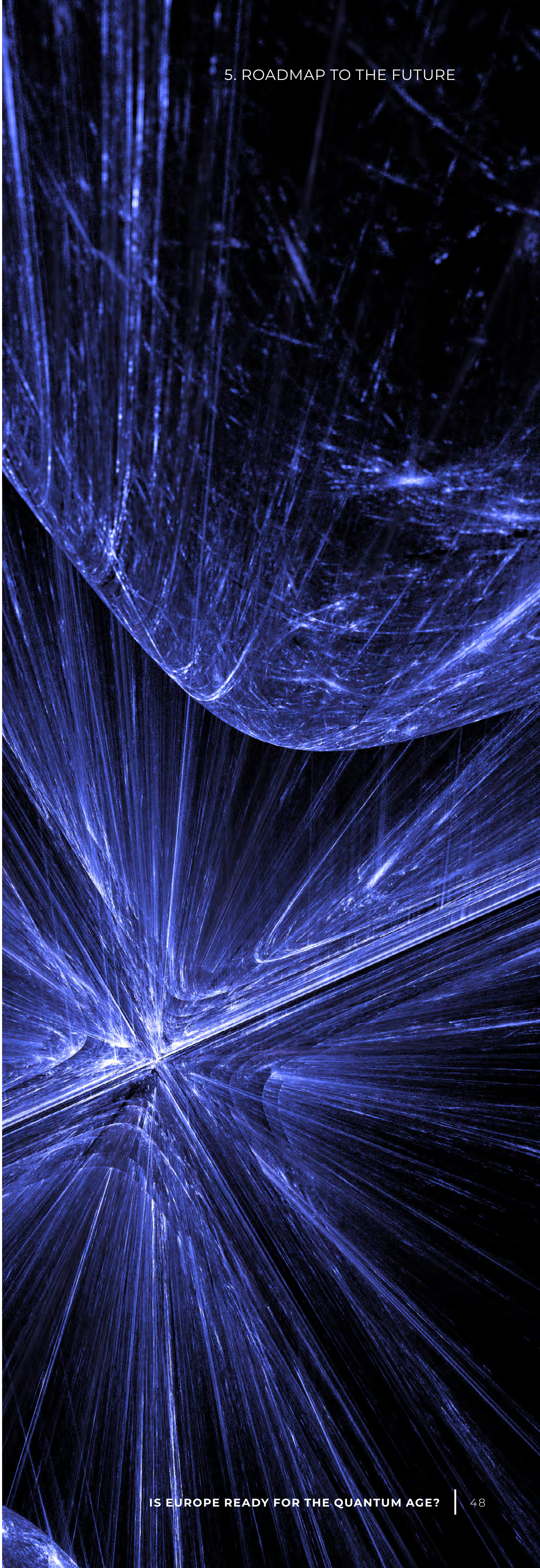
- **Research excellence**
  Europe's scientific foundations are among the world's strongest, supported by leading universities and institutes.
- **The Single Market**
  Offers unparalleled potential for scale if regulatory barriers are reduced and funding access is streamlined.
- **Public–private collaboration**
  Successful precedents in aerospace and semiconductors show how government–industry partnerships can drive innovation.
- **Existing initiatives**
  Programs such as the Quantum Flagship, EuroQCS, and QCI provide a foundation for coordination and infrastructure.
- **Global lessons**
  Models from NASA, South Korea, and Canada highlight how long-horizon, results-based investment accelerates innovation.
- **Techno-diplomatic positioning**
  Europe's neutrality and credibility can turn science and technology into geopolitical leverage.

5.1. VISION 2040: A SOVEREIGN QUANTUM EUROPE

Following a foresight-driven discussion, the workshop group articulated a long-term vision for a *Sovereign Quantum Europe by 2040*—an integrated, globally competitive ecosystem with coherent governance, strong industrial capacity, and strategic autonomy. More specifically, by 2040 Europe should aim to:

- **Achieve full sovereignty** across the quantum value chain, from hardware and software to materials and manufacturing.
- **Operate as an integrated ecosystem**, linking communications and sensing networks with the world's largest interoperable multi-platform quantum computer.
- **Adopt a unified defense posture**, embedding quantum encryption, sensing, and computing into a common European security architecture—enhancing intelligence, cybersecurity, and situational awareness.
- **Become a global exporter of trust**, delivering reliable quantum solutions that reflect Europe's social and environmental standards and set a global benchmark for trustworthy quantum innovation.
- **Build a cohesive talent community**, capable of attracting and retaining the world's best scientists, engineers, and entrepreneurs.

> "Europe risks becoming irrelevant by osmosis, not by failure."
>
> —SME Participant during the Foresight Workshop (2025).



5.2. STRATEGIC PRIORITIES FOR ACTION

Delivering on this vision will require addressing the structural barriers that fragment Europe's quantum ecosystem while consolidating its scientific and institutional strengths. Building on workshop insights, **five strategic priorities** were identified to guide coherent European action:

01/ Governance and Sovereignty:

- Ensure *coherent implementation of the EU Quantum Strategy* across Member States, with aligned national roadmaps and shared performance metrics.
- Empower a *high-level quantum board and permanent secretariat* to coordinate efforts, monitor progress, and prevent duplication across member states.
- Create *independent advisory bodies*, modeled on RAND or MITRE, to provide long-term strategic guidance and foresight.

02/ Policy and Investment:

- Build two to three European *hyperscale champions* with global reach.
- Launch *Plan 10×10*—a long-horizon investment pool for European deep-tech startups.
- Create *defense sandboxes* and testbeds to validate dual-use applications.

03/ Infrastructure and Supply Chains:

- *Onshore* semiconductor and critical material production.
- Develop a *multi-platform quantum hub* interconnecting European computers.
- Establish trusted *international partnerships* to ensure supply chain resilience.

04/ Talent and Culture:

- *Anchor talent* through mobility visas, "European pride" retention programs, and civil-service rotations into industry.
- Expand *upskilling funds* and education reforms.
- Foster a *risk-tolerant innovation culture*, through flexible, experiment-driven funding mechanisms (i.e."money to fail").

05/ Technology Convergence and Diplomacy

- Integrate *quantum, AI, and cyber* into mission-oriented R&D programs.
- Use *science as a diplomatic lever,* to compete against the US and China through cooperation with like-minded countries.
- Position Europe as a neutral yet strategic *techno-diplomatic power.*

5.3 EXECUTION ROADMAP

To operationalize this strategy, participants proposed a three-horizon roadmap with concrete milestones (*Figure 27*). Each phase builds upon the other, aligning governance, investment and diplomacy to progressively build autonomy and industrial capacity.

Figure 27. **Implementation and Milestones.**

SHORT-TERM (2025–2030)

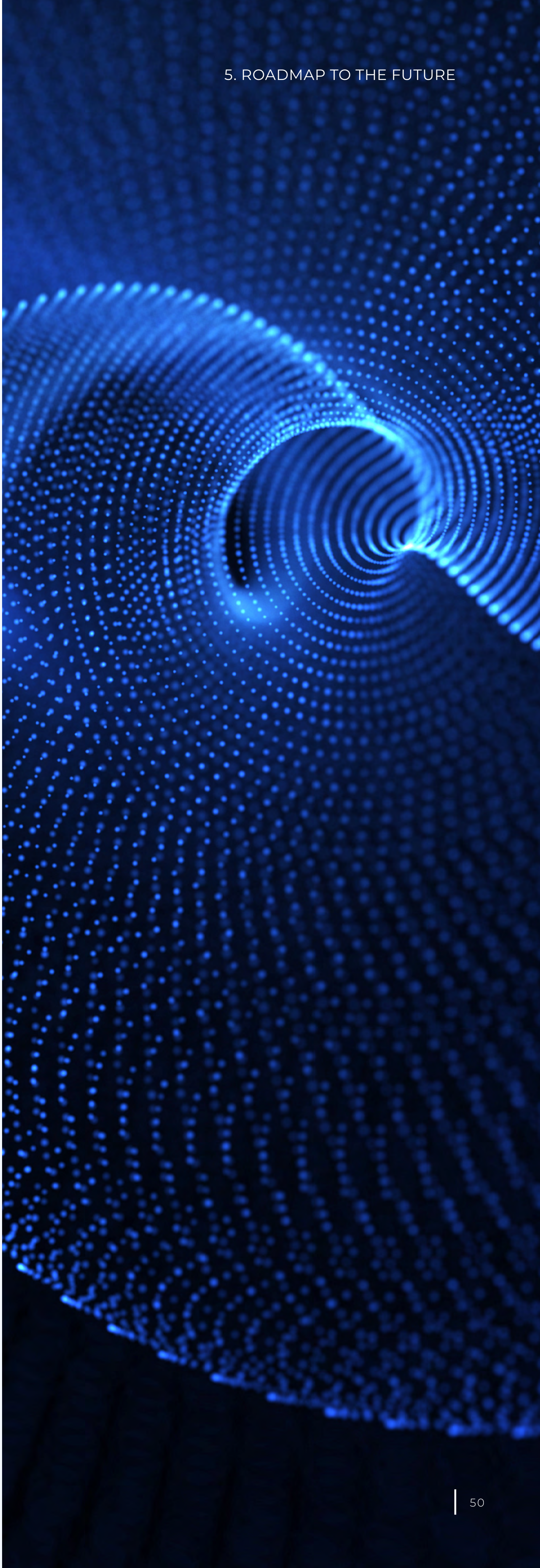
- Consistent implementation of the Quantum Europe Strategy and alignment of national plans.
- Launch of defense sandboxes and a quantum hub platform.
- Introduction of talent mobility schemes and retention programs.
- Stronger cross-Member State coordination and reduced regulatory fragmentation

MEDIUM-TERM (2030–2035)

- Two hyperscale European quantum champions operational.
- Onshore supply-chain capacity established.
- Quantum capabilities integrated into EU defense posture.
- Expanded interoperability framework across platforms and Member States.
- Strengthened EU techno-diplomatic engagement globally.

LONG-TERM (2035–2040)

- Largest interoperable quantum computer network worldwide established.
- Europe recognized as a trusted exporter of quantum solutions.
- Cohesive quantum talent community anchored within the EU.
- Quantum capabilities embedded across Europe's strategic, economic, and defense architecture.



IS EUROPE READY?
CONCLUSIONS AND OUTLOOK

Quantum technologies are emerging as the foundation of future power. Europe's readiness to master them will determine its geopolitical relevance, economic competitiveness, and its ability to uphold democratic values in a world increasingly defined by technological sovereignty.

Europe enters the race with a formidable scientific base, strong public investment, and flagship institutional programs that already coordinate talent and infrastructure across the continent. Yet it still struggles to scale: national fragmentation, limited private investment, and slow governance mechanisms undermine its capacity to translate knowledge into capability. **Europe is scientifically ready but strategically incomplete.**

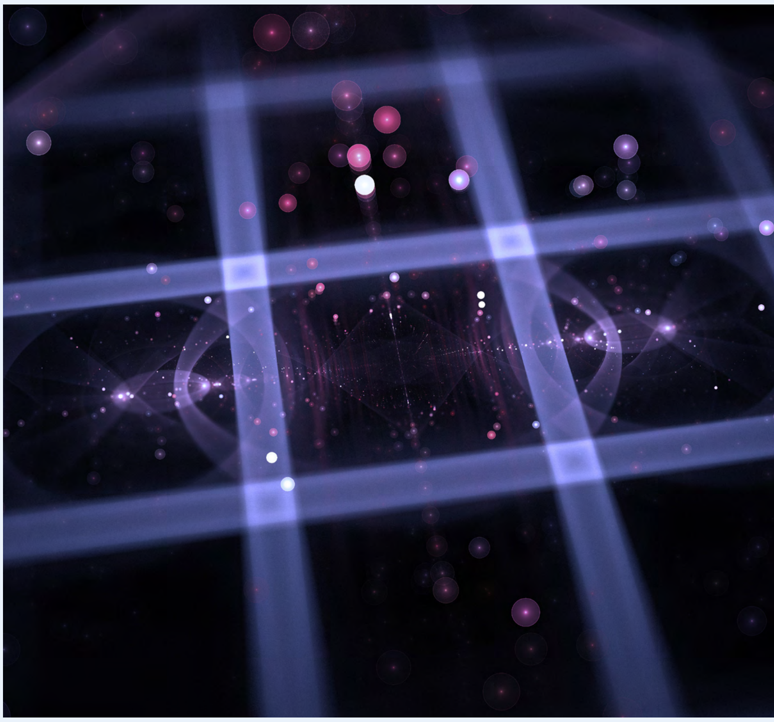
Turning excellence into sovereignty and capacity to lead will require more than scientific capability—it will demand political courage, institutional alignment and industrial ambition. Member States must follow the EU Quantum Strategy coherently, coordinate investments through shared European mechanisms, and empower institutions capable of ensuring continuity beyond political cycles.

> A stronger industrial backbone—anchored by a few globally competitive champions, deeper public–private collaboration, and resilient supply chains—will be key to scaling innovation.

In doing so, Europe must navigate three fundamental tensions that define its quantum trajectory. First, **sovereignty versus cooperation**: full self-sufficiency is neither realistic nor desirable, and strategic autonomy must coexist with trusted international partnerships. Second, **innovation versus protectionism:** efforts to safeguard critical assets must not stifle the openness and collaboration that fuel discovery and market growth. Third, **integration versus fragmentation:** without coherent governance, the Union risks deepening internal divides—allowing some Member States to advance while others fall behind.

Europe's defense posture should also evolve. A more agile, mission-oriented framework—similar to DARPA—could accelerate dual-use innovation and ensure that frontier science translates into strategic advantage. Sustained talent mobility, open research networks, and active techno-diplomacy can further position Europe as a trusted and values-driven quantum power.

Ultimately, **quantum is not optional**: it is a strategic necessity. The next decade will determine whether Europe becomes a sovereign quantum leader capable of shaping global norms and standards or remains a research-driven follower. The foundation exists; what is needed now is unity, urgency, and the resolve to act.



NEXT STEPS —
CONTINUING THE WORK

This report provides a first integrated view of Europe's quantum landscape and readiness. To consolidate and expand its findings, several potential action lines are proposed for the continuation of this analytical effort.

01/ Broaden Country Coverage

Extend the analysis to include additional national profiles—notably in Germany, France, Denmark, Poland, and the Netherlands—and add comparative insights from key non-EU quantum leaders such as the United States, the United Kingdom, Japan, and Canada.

02/ Refine the European Operational Model

Build on the findings to propose a European Quantum Operational Model for policymakers, drawing lessons from the Airbus and CERN experiences. This would provide a practical structure for coordination, shared infrastructure, and public–private engagement.

03/ Deepen the Defense and Security Dimension

Analyze how DARPA operates in the United States and explore how a similar mission-oriented, agile approach could be adapted for quantum technologies in Europe's defense ecosystem.

04/ Enhance Coordination and Methodology

Recommend measures to strengthen collaboration under the Quantum Flagship, focusing on budget coordination, alignment of national interests, clear goals, and structured evaluation processes.

APPENDICES

APPENDIX 1: DATA COLLECTION

Set of artifacts developed and used to gather information from the SMEs during the project through one-on-one interviews and a group workshop.

INTERVIEWS

As a key player in the quantum technology sector, you are invited to take part in this industry interview with the goal of understanding why this upcoming technology is important for Europe, and how it is being approached. The results of this interview will be utilized for a report on the Quantum Policy Lab (QPL) program with the goal of equipping public and private decision-makers with analysis, skills, and foresight to address the governance of quantum technologies. The QPL is a collaborative project between the Center for the Governance of Change (CGC) at IE University and the Centre for Future Generations (CFG). This interview covers quantum technologies broadly, including sensors, communications and computers, as well as post-quantum cryptography (PQC).

Screening questions

- Could you please state your name and organization?
- On a scale from 1 to 5, where 1 is the least and 5 is the most, how closely does your role relate to quantum technologies?

A. CURRENT VISION OF QUANTUM TECHNOLOGIES AND QUANTUM GOVERNANCE IN THE EU

01 In June 2024, 21 EU Member States signed the European Declaration on Quantum Technologies, committing to making Europe the "quantum valley" of the world.

- On a scale of 1 to 5 how feasible do you think that goal is, and why?
- How do you see this ambition contributing to European 1. competitiveness, 2. economic security and 3. defense, 4. geopolitical strength? Could you please mention the areas you consider the most critical?

02 Which quantum technologies do you think the EU should prioritize through its strategies and initiatives, and why? Could you mention them in order of priority?

03 How would you define the role of quantum technologies in the EU's broader technological and industrial strategy?

04 What should the goal of EU quantum governance be, and what do you think are the most critical policy areas the EU should focus on to strengthen quantum technology governance?

05 On a scale of 1 to 5, how aligned do you think EU Member States are in their approaches to quantum technology development? Where do you see the biggest divergences or challenges?

06 Where do you see the biggest divergences or challenges?

07 What do you see as the biggest barriers to advancing quantum technologies for the EU as a region?

B. PERCEPTIONS OF EU'S COMPETITIVENESS AND VULNERABILITIES IN QUANTUM TECHNOLOGIES

01 On a scale of 1 to 5, how would you assess the EU's overall competitiveness in quantum technologies compared to other geographies like China, the US or other geographies? Which country do you think is ahead in quantum technologies worldwide and in the EU?

02 What do you think about the EU's level of economic investment in quantum technologies?

- On a scale of 1 to 5, with 1 being very low and 5 being very high, how would you rate it?
- How well do you think this investment is allocated across different areas?
- Where do you think the EU should focus its investments on Quantum (e.g., research, infrastructure, workforce training, other)?

03 How soon do you expect quantum technologies to create business value? And which technologies do you think will be the most profitable, 1. Sensors 2. Communications 3. Computers?

04 What do you think could drive or delay commercialization in quantum technologies? 1. Sensors 2. Communications 3. Computers

05 Do you believe there is a consensus among EU policymakers on the need to reduce dependencies on specific geographies in quantum technologies? Is there a specific country in particular that is a powerhouse?

06 In your view, which parts of the quantum value chain are most vulnerable to foreign dominance? Why?

07 What do you think are the main threats the EU could face if a regional strategy for Quantum is not reached in the following years?

08 What additional measures or polices should the EU consider strengthening its strategic autonomy and global position in quantum technology?

C. PERCEIVED THREATS AND OPPORTUNITIES OF QUANTUM TECHNOLOGIES FOR DEFENSE

01 What do you think will be the role and the impact of quantum technologies for defense?

02 How would you define the role of quantum technologies in the EU's security and defense strategy?

03 How do you assess the EU's level of advancement in quantum technologies for defense in a scale of 1 to 5?

04 Which quantum technologies and applications do you think will be more relevant for defense, and why? Could you mention them at a level of importance?
1. Sensors
2. Communications
3. Computers

05 How well-informed do you think EU policymakers are about cybersecurity risks related to quantum technologies, and how well do you think the EU is approaching post-quantum cryptography?

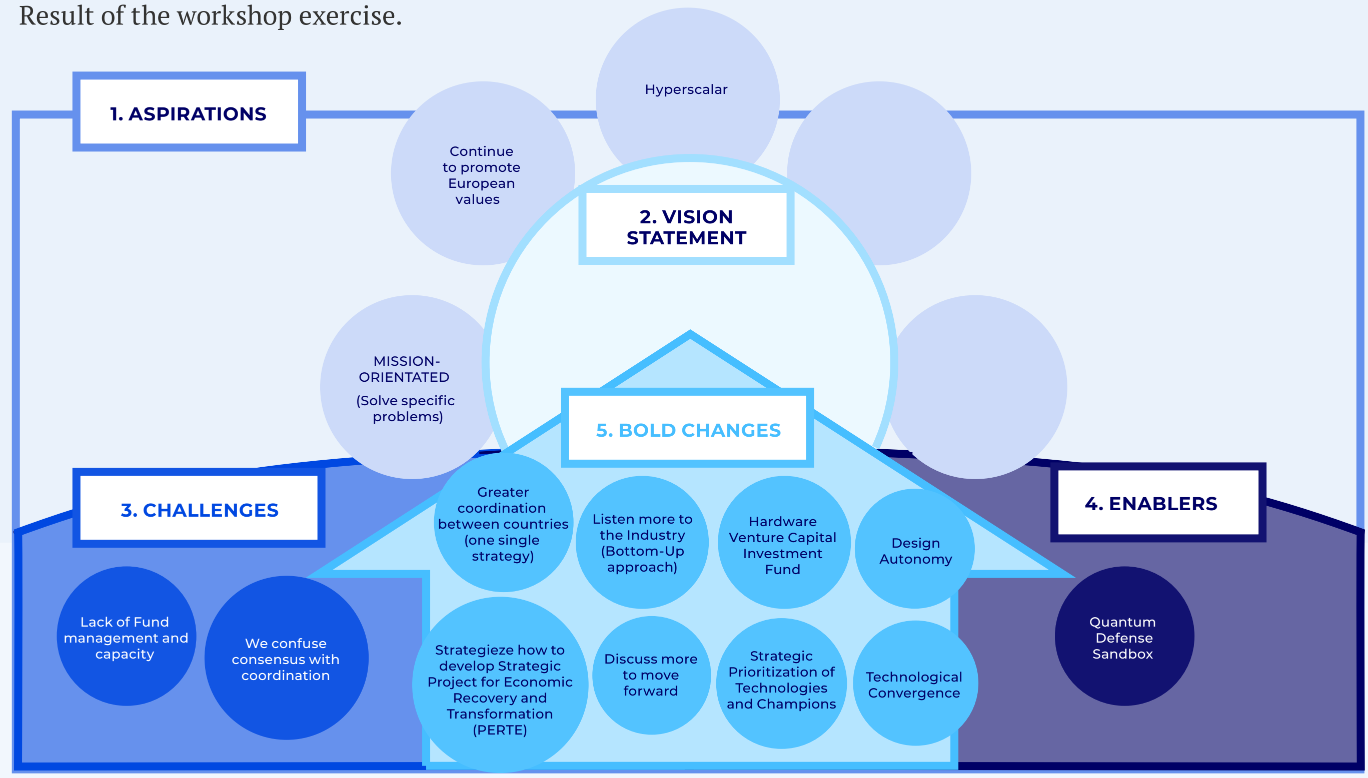
06 What barriers do you see to achieving quantum-safe cybersecurity in the EU?

07 In December 2024, 18 EU Member States signed the joint statement "Securing Tomorrow, Today: Transitioning to Post-Quantum Cryptography". In your view, by when (what year) should the EU have implemented post-quantum cryptography across different sectors? 1. Government systems, 2. Critical infrastructure, 3. Broader economic sectors. Is Europe going fast enough in PQC migration in relation to the US?

08 How do you think President Trump's foreign policies towards the EU, such as 25% tariffs, will affect the development of quantum technologies in Europe?

WORKSHOP

Result of the workshop exercise.



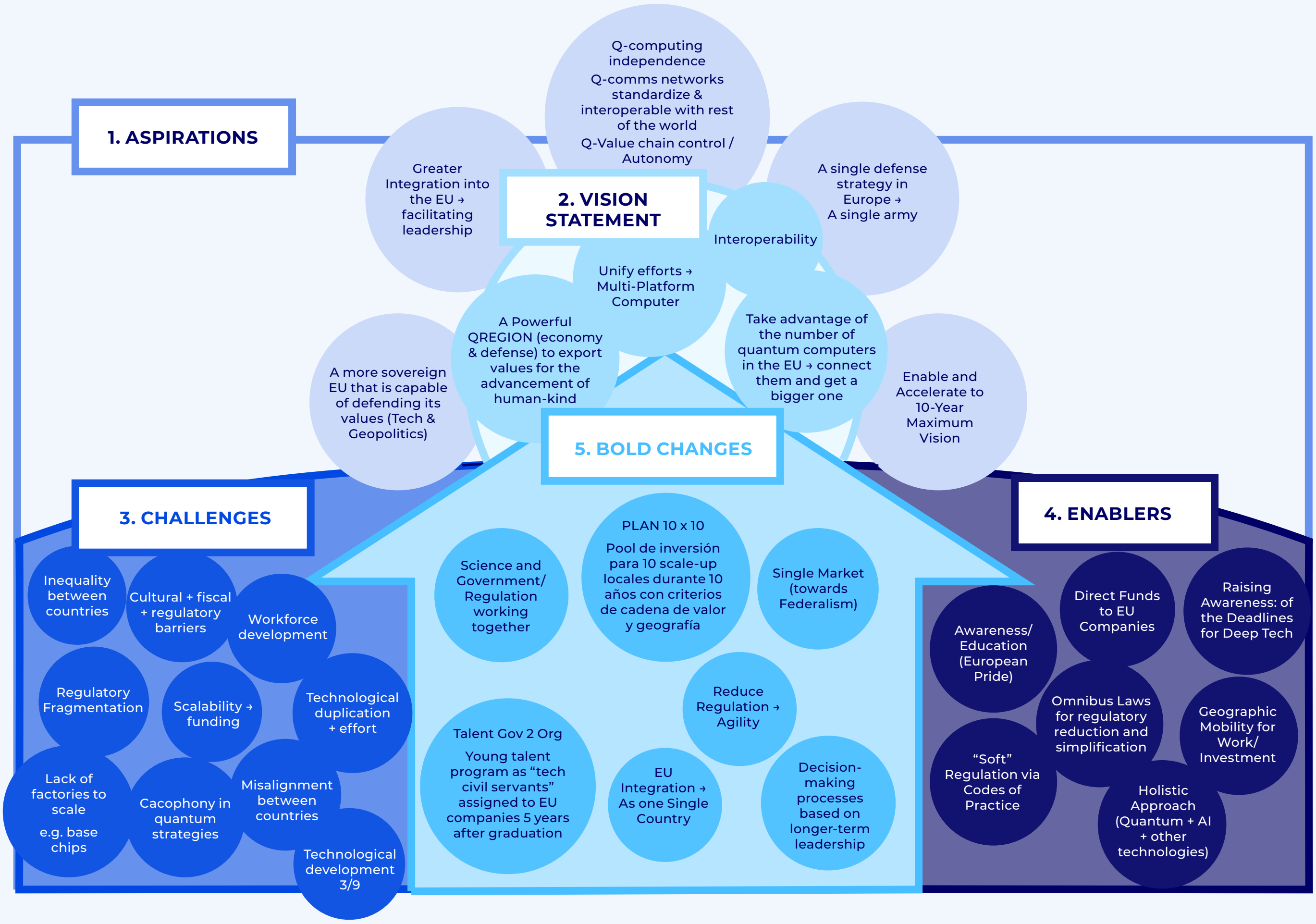


Figure 28. **Vision statement.**

APPENDIX 2: COUNTRY ANALYSIS

A set of countries has been chosen due to their strong involvement in quantum technologies, either through their research work, technology developments, national investments or involvement in the defense industry.

Note: The analysis is non-exhaustive and dated September 2025. The figures are estimates, as some investment plans include related technologies such as HPC and AI, and the rapidly evolving quantum technology landscape may render parts of the analysis outdated or limited.

EUROPEAN UNION

All EU member states and the associated countries are working on the program of Quantum Technology Flagship program under Horizon 2020 and Horizon Europe which includes more than 230 institutions involved and budget of €1 bn over 10 years. There are different European Joint programs which are enhancing the current state of art at European level, programs include EuroHPC Joint Undertaking—Quantum Computers Hosting Sites, European Quantum Communication Infrastructure (EuroQCI), Quantum Computing and Simulation (EuroQCS) Infrastructure Project, Quantum Internet Alliance (QIA), OpenSuperQ and OpenSuperQ+ (Quantum Superconducting Computer Platform), Quantum Secure Network Partnership (QSNP), High Performance Computing and Quantum Simulation (HPCQS), Quantum Flagship Ramp-Up & Horizon Europe Quantum Calls, Quantum Education Coordination Action Academy, Quantum Europe Strategy,

DENMARK

- Research: Denmark has 7 well-known quantum institutions including Aalborg University, Aarhus University, Danish Technological Institute (DTI), Dansk Fundamental Metrologi (DFM), Technical University of Denmark (DTU), University of Copenhagen (UCPH) Niels Bohr Institute and Center for Quantum Devices (QDev), University of Southern Denmark.
- Hardware: Denmark is building its own 25-qubit superconducting quantum computer by 2026 under the DanQ project at the Niels Bohr Institute and aims for a fault-tolerant system by end of 2034. The QuNorth "Magne" quantum computer (€80 million) and Quantum Foundry P/S fabrication facility strengthen hardware capabilities.
- Investments: $448 M Denmark hosts NATO's DIANA accelerator site the Deep Tech Lab; it has the Novo Nordisk Foundation Quantum Computing
- Start date: 2023.

FRANCE

- Research: France has 6 well-known quantum institutions including, CEA (French Alternative Energies and Atomic Energy Commission), Centre national de la recherche Scientifique (CNRS), INRIA (Institut national de recherche en sciences), Paris Centre for Quantum Computing (PCQC), Strasbourg University, Université de Grenoble, Universite Paris. France boasts a Nobel price recipient in quantum technologies in 2022 Alain Aspect, for his work on quantum entanglement.
- Hardware: Three startups are racing to create a quantum computer Pasqal, Alice & Bob and Quandela. It is also building a national quantum computer aQCess (Atomic Quantum computing as a service).
- Investments: $2.07 B. France boasts a dedicated fund dedicated to quantum technologies, Quantonation Ventures.
- Start date: 2021

GERMANY

- Research: Germany has 6 well-known quantum institutions including DLR Quantum Computing Initiative (QCI), Fraunhofer-Gesellschaft's Competence Center Quantum Computing, Helmholtz, Leibniz Supercomputing Centre, Max Planck Society for the Advancement of Science, Technical University of Munich. There are also several quantum clusters with different institutions that collaborate to advance quantum technologies for computing, secure network, industry solutions, adding more quantum research-focused universities:

Mattera and light for quantum computing (ML4Q), and Munich Center for Quantum Science and Technology (MCQST).

- Hardware: Germany was the first European country to install a quantum computer, with IBM, and is creating its own quantum computers within the framework of the DLR Quantum Computing Initiative.
- Investments: $3.45 B. Germany boasts the largest European national investment in quantum technologies
- Start date: 2018

POLAND

- Research: Poland has 6 well-known quantum institutions including the National Laboratory of Atomic, Molecular and Optical Physics, International Centre for Theory of Quantum Technologies (ICTQT), National Laboratory for Quantum Technologies , Military University of Technology, Warsaw University of Technologyor Quantin research group among others.
- Hardware: The country recently announced the creation of a quantum computer infrastructure in Poland by the Warsaw University of Technology, they will also host AQT quantum computer as part of EuroHPC program.
- Investments: $2.5 M. Poland recently announced their national investments and participation in the EuroHPC program.
- Start date: 2024.

NETHERLANDS

- Research: The Netherlands has 7 major quantum institutions including QuTech (TU Delft & TNO), University of Amsterdam (Quantum.Amsterdam), Leiden University, Eindhoven University of Technology (TU/e), Radboud University, University of Twente, and CWI (Centrum Wiskunde & Informatica). These are united under the Quantum Delta NL national program.
- Hardware: The Quantum Delta NL initiative supports spin qubit and photonic-based quantum computers through QuTech (superconducting & semiconductor approaches) and QuiX Quantum (photonic platform).
- Investments: $1.11 B Netherland's Quantum Delta is focused on supporting the complete ecosystem by providing companies with the infrastructure necessary to build quantum computers.
- Start date: 2021

SPAIN

- Research: Spain has 8 well-known quantum research institutions including Barcelona Supercomputing Center-National Supercomputing Centre (BSC-CNS), CESGA (Centro de supercomputación de Galicia), CSIC (Consejo Superior de Investigaciones Científicas), Donostia International Physics Center, ESA (European Space Observatory), ICFO (Institut de Ciències Fotòniques), IMDEA Nanoscience, UCM (Universidad Complutense de Madrid), UPM (Universidad Politécnica de Madrid).
- There are also several quantum clusters with different institutions that collaborate to advance quantum technologies adding other quantum research-focused universities: Quitemad, mathQI, or IFISC (Institute for Cross-Disciplinary Physics and Complex Systems), MadQuantum-CM, amongst others.
- Hardware: Spain is creating a quantum computer to be hosted in the IFISC (Institute for Cross-Disciplinary Physics and Complex Systems) and hosting IBM Quantum System Two in the Basque Country (2025)
- Investments: $1.27B Spain recently launched a national quantum plan expanding its prior investment.
- Start date: 2021

APPENDIX 3:
LIST OF SUBJECT-MATTER EXPERTS (SME) THAT PARTICIPATED IN THE PROJECT

Europe

- Policymaker from the Organisation for Economic Co-operation and Development (OECD)
- Policymaker from Quantum Flagships

Spain

- Technology Provider from Qilimanjaro
- Quantum Consortium member from the Barcelona Supercomputing Center (BSC)
- Defense Agent from the Ministry of Defense
- Policymakers from the Ministry for Digital Transformation and Public Service
- Research-Academia from the Spanish Research Council (CSIC)

Germany

- Defense Agent from the DLR Quantum Computing Initiative
- Research-Academia from the Peter Grünberg Institut
- Research-Academia from the European Center for Quantum Sciences (CESQ)

France

- Technology Provider from Quantonation
- Technology Provider from Pasqal

Denmark

- Quantum Investor from the Novonordisk Foundation
- Research-Academia from the University of Copenhagen

WORKSHOP SMEs

- Member from Telefónica
- Member from the Ministry of Defense
- Members from the Ministry of Science, Innovation and Universities
- Member from the Cluster for Technological Innovation and Talent in Semiconductors at the Madrid City Council (CITT-CHIP)
- Member from IE University and Microsoft
- Member from Europavia
- Member from Bullnet Capital
- Member from IQM Quantum Computers
- Member from the European Quantum Flagship

GLOSSARY

CORE QUANTUM CONCEPTS

- **Quantum Mechanics:** The branch of physics that studies nature at atomic and subatomic scales using principles like quantization, wave mechanics, and uncertainty.
- **Hilbert Space:** A mathematical framework that provides the foundation for formulating quantum theory.
- **Dirac Notation (Bra–Ket):** A symbolic representation of quantum states within Hilbert space.
- **Superposition:** A quantum property allowing particles or qubits to exist in multiple states simultaneously.
- **Quantum Entanglement:** A phenomenon where particles become correlated so that the state of one instantly determines the state of another, regardless of Quantum Parallelism: The ability of quantum systems to process many possible outcomes simultaneously.
- **Quantum Advantage:** The point at which quantum computers solve problems significantly faster than classical computers.
- **Qubit:** The fundamental unit of quantum information that can exist in a superposition of 0 and 1.

QUANTUM TECHNOLOGIES

- **Quantum Computer:** A machine that encodes and processes information in qubits using quantum principles.
- **Quantum Sensors:** Devices that detect extremely small physical signals, such as magnetic fields or gravitational variations.
- **Quantum Communications:** Secure information transfer using quantum properties to prevent interception.
- **Quantum Key Distribution (QKD):** A cryptographic method that uses quantum mechanics to create secure communication keys.
- **Quantum Random Number Generator (QRNG):** A device that produces truly random numbers based on quantum processes.
- **Post-Quantum Cryptography (PQC):** Classical cryptographic methods designed to resist attacks from quantum computers.
- **Secure Quantum Cryptography (SQC):** Cryptography leveraging quantum properties like the no-cloning theorem to guarantee unbreakable security.

QUANTUM HARDWARE TYPES

- **Superconducting Qubits:** Artificial atoms made from materials like niobium or aluminum that conduct electricity without resistance.
- **Trapped-Ion Qubits:** Real atoms confined and controlled using electromagnetic fields.
- **Photonic Qubits:** Qubits encoded in photons, or particles of light.
- **Diamond Qubits (NV Centers):** Qubits created by defects in diamond lattices with nitrogen atoms.
- **Neutral Atom Qubits:** Ultracold neutral atoms arranged in configurable optical arrays.
- **Quantum Dots:** Semiconductor nanostructures that confine electrons to create qubits.
- **Topological Qubits:** Qubits formed from exotic quasiparticles like Majorana fermions that are resistant to noise.

POLICY AND STRATEGY

- **Quantum Flagship:** The EU's large-scale research initiative to advance quantum technologies across Europe.
- **European Quantum Strategy:** A 2025 plan to make Europe a global leader in quantum by 2030 through infrastructure, education, and governance.
- **International Year of Quantum Science and Technology (IYQ 2025):** A UN initiative marking the centenary of quantum mechanics to raise global awareness of quantum's impact.
- **Quantum Policy Lab (QPL):** A joint initiative by IE University's CGC and ICFG to assess European quantum policy gaps and challenges.
- **EuroQCI:** European programs for quantum communication and computing infrastructure.

SECURITY AND STANDARDS

- **CRYSTALS-Kyber:** A lattice-based post-quantum algorithm for key encapsulation.
- **CRYSTALS-Dilithium:** A lattice-based post-quantum algorithm for digital signatures.
- **FALCON:** A lightweight lattice-based post-quantum signature scheme.
- **SPHINCS+:** A hash-based signature scheme resistant to quantum attacks.

MATERIALS AND INFRASTRUCTURE

- **Helium-3 (^{3}He):** A rare isotope used in dilution refrigerators for quantum cooling.
- **Silicon-28 (Si-28):** Isotopically pure silicon used in qubit fabrication.
- **Tantalum (Ta):** A material used in superconducting qubit construction.
- **Niobium (Nb):** A superconducting material critical for quantum processors.
- **Indium (In):** A material used for interconnects in quantum chips.
- **Ytterbium (Yb) Isotopes:** Elements used in trapped-ion quantum computers.
- **Strontium (Sr) Isotopes:** Elements used for atomic clocks and ion-trap qubits.
- **Aluminum (Al):** A superconducting material for quantum circuits.
- **Germanium (Ge):** A semiconductor used in quantum dot and silicon-based qubits.

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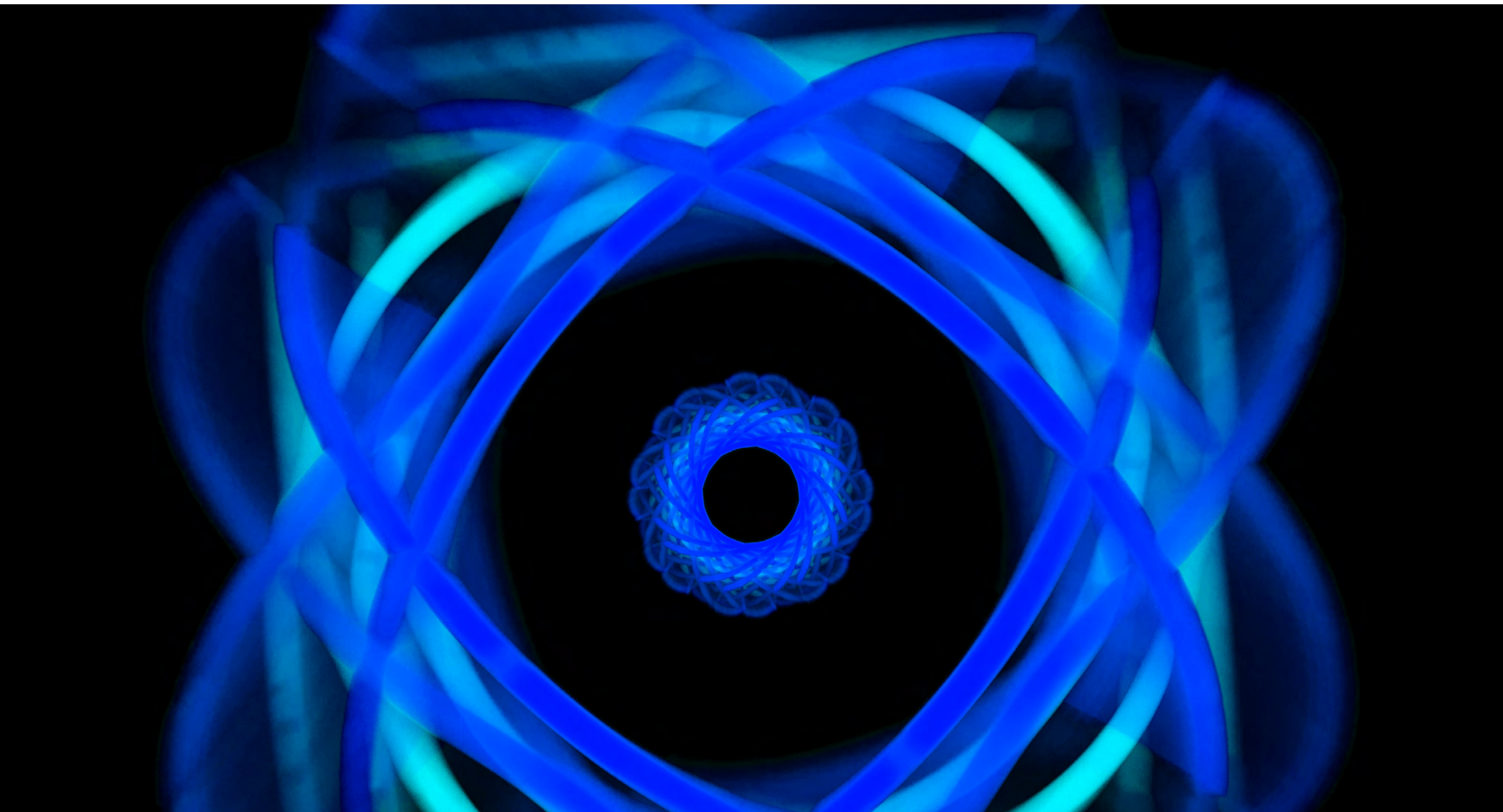

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