QUANTUM TECHNOLOGIES

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Quantum technologies have the potential to change the rules of the game, leading to a redefinition of business models, value chains and competitive positioning.

These technologies represent not only scientific progress, but also a strategic asset of utmost importance for the competitiveness of economic systems and the technological sovereignty of nations. The race to quantum computing, sensors and quantum communications is already defining new geopolitical and industrial equilibriums, calling on businesses, institutions and scientific communities to make a joint commitment.

Alongside the opportunities, there are responsibilities that cannot be ignored. The adoption of these technologies must be developed within a framework of sustainability, fairness and respect for ethical values. When properly harnessed, quantum power can contribute to ecological transition, efficient resource management and the construction of a more resilient and inclusive society.

Our task is to accompany this revolution with strategic vision and responsibility, while ensuring agility and speed of execution.

The report we present analyses the ecosystem and the market, the main players and emerging start-ups, the level of maturity of the technologies, use cases and industrial applications, providing a clear summary of the prospects and challenges that will shape the future of quantum technologies.

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Foreword

The scientific understanding of quantum effects is not new. The physicists Max Planck, Albert Einstein and others developed their theories 125 years ago and this year we are celebrating the United Nations Year of Quantum due to the 100th anniversary of quantum mechanics. But only in recent years the understanding and technology was developed, how to control quantum effects in a way, that they can be used in a practical application, like sensing, communication or computing.

Today, first quantum based sensors are in use in various industrial applications and in health care. The advantages of quantum communication are also used in first security related applications. Although quantum computing, where we expect the biggest commercial potential, only started to find its way out of research labs, universities and computer centers. Nevertheless, companies, like IQM, are already producing computers in batches and are shipping their products to first-movers in the quantum application arena. Quantum computing as a service is also available through cloud applications. Those solutions are used to develop new algorithms and for training and education of young scientists.

Relevant players are in the race for the first applications which create more commercial value than classical digital systems. There will be a market with more than one player, but to be profitable, it is important to be in the market early and offer relevant commercial solutions soon.
The relevance of quantum computing is not only defined by its ability to solve complex algorithms through parallel computing in a very short time, it will as well solve computing problems, which cannot be solved by any classical computers in a realistic timeframe. Some of those algorithms would take millions of years even on our biggest supercomputers or would require more transistors than we have atoms in the universe.

The application of artificial intelligence will benefit from quantum computing as well, the needed energy and time used by AI applications will be dramatically reduced.
Currently, we see a global competition in the development of quantum systems between China, US, Japan and Europe, which can be characterized by high investment. While about the activities and investment in China not much information is available, we see a strong will in Japan and Europe to invest and to develop some independence from US based companies.
The evolution of quantum computing in Europe has been shaped by a coordinated mix of research programs, public and private investments, and regulatory initiatives. Since the launch of the EU's Quantum Flagship program in 2018, Europe has built a vibrant ecosystem around quantum technologies, enabling companies to move from early-stage research into commercial expansion. The Quantum Flagship has been complemented by major EU-level initiatives such as the EuroHPC program, which funds six hosting sites for quantum computers, and the EU Chips Act, which seeks to strengthen Europe's capabilities in quantum chip technologies through a combination of public and private investment. More recently, the European Commission announced its Quantum Europe Strategy, which is expected to culminate in the Quantum Act in 2026, providing a comprehensive legislative framework for the sector.

Alongside these EU-wide programs, national governments have played a crucial role by funding large-scale projects. Finland, for instance, committed €20.7 million and €70 million to VTT's 5–20–50 and 300-qubit computer projects, while Germany's Federal Ministry of Education and Research (BMBF) has invested €40 million in integrating a quantum computer into the SuperMUC-NG supercomputer at the Leibniz Supercomputing Centre in Munich. These efforts reflect a deliberate strategy to anchor quantum computing development in Europe and position the region as a competitive player globally.

Early involvement of state investors such as Tesi, Finnish Industry Investment Ltd, and the European Innovation Council (EIC) are significant for the sector, as they signal both technological credibility and long-term policy commitment. Public capital helps bridge the so-called "valley of death" between fundamental research and commercial viability, giving startups the time and resources to generate revenue before later-stage venture investors step in. Compared with other regions, Europe's strength lies in its strong policy frameworks and public-private alignment, though it still faces challenges in scaling as quickly as its competitors.

The broader ecosystem benefits from Europe's strong academic foundations, a vibrant startup scene, and public-private collaborations that provide shared infrastructure and early customers. Upcoming policies such as the Quantum Act will be decisive in shaping both funding as well as economic security, particularly given the dual-use nature of quantum technologies. The success of Europe's ecosystem will therefore depend on how effectively companies and governments work together to balance innovation with national security concerns.

As the European quantum industry matures, it is likely to have a profound impact on innovation and competitiveness at both the regional and global level. Europe's model, which emphasizes strong research foundations, early public investment, and structured collaboration, has positioned it as a leader in shaping the global quantum landscape. If it can continue to channel sufficient private investment and accelerate commercialization, Europe can remain a central player in the global race for quantum technologies.

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01 /

Overview

Technologies commonly referred to as quantum technologies derive their name from the discipline known as **quantum theory or quantum mechanics**, as they are based on the functioning of matter at the subatomic and particle level described by this physical model, which was conceived in the early 20th century.

Unlike classical physics, which deals with describing the behaviour of the macroscopic world – from the laws of electromagnetism to the theory of general relativity – quantum theory focuses instead on interpreting the working of the microscopic world, which sometimes exhibits behaviour that is counterintuitive compared to the physical experience of the world to which we are commonly accustomed.

1.1 The Two Quantum Revolutions

Over the last century, humanity has witnessed two revolutions linked to the world of quantum physics applications, with significant technological implications.
While the first of these revolutions changed the interpretation of nature's behaviour, the second is changing the way we interact with it.

The first quantum revolution: a new interpretation of the microscopic world

The first quantum revolution began in the early 1900s, when physicist Max Planck proposed the idea that energy is not continuous, but rather discrete and separated into indivisible units called "quanta".

A few years later, in 1905, drawing inspiration from this very idea, Albert Einstein was able to scientifically justify the occurrence of the so-called photoelectric effect (i.e. the conversion of light into energy), hypothesising that light, in addition to being representable as a wave, also takes on the characteristics of a particle (the photon), a discovery that earned him the Nobel Prize in Physics in 1921.

From then on, scientists such as Niels Bohr, Werner Heisenberg, Erwin Schrödinger, Wolfgang Pauli, Paul Dirac and others laid the foundations of quantum mechanics, a theory capable of explaining some **seemingly counterintuitive behaviour** of matter at the subatomic level, including:

- **Wave-particle duality**: elementary particles, such as electrons and photons, exhibit both wave and corpuscular properties
- **Superposition:** an elementary particle can exist simultaneously in a combination of multiple states, each with a certain probability
- **Indeterminacy**: it is not possible to know simultaneously and with absolute precision certain pairs of properties of an elementary particle, such as, for example, its position and velocity
- **Entanglement**: elementary particles can "interconnect" (or become entangled), so that there is a correlation between their states that is preserved regardless of the distance between them

Out of these new theoretical assumptions, a first series of technological innovations emerged that proved decisive for the modern world: from silicon transistors, the basis of microprocessors, to lasers for accurate measurement of distances, also at an astronomical level, to magnetic resonance imaging used in diagnostics and fibre optics, on which the World Wide Web is based today.

In summary, the first quantum revolution enabled humanity to shed light on the fundamental structure of nature and to develop applications capable of exploiting quantum principles in an innate way, without directly controlling them.

The second quantum revolution: how to manipulate quanta

At the end of the 20th century, a second quantum revolution began, marking a significant leap forward not only in terms of understanding, but also in the control of the intrinsic behaviour of the subatomic world.
Nowadays, we no longer just take advantage of quantum phenomena in a pretty much spontaneous way, but we are getting better at manipulating them directly and precisely.

As a result of recent advances in engineering, it is possible to isolate and **control individual particles**, such as electrons and photons, preserving their quantum properties long enough to use them in a conscious and programmed manner.

This second quantum revolution actually paved the way for three large technology families known as **quantum technologies**:

- **Quantum Computing**, which encompasses both the creation of a new type of computer (Quantum Computer) based on the laws of quantum mechanics and the writing of new algorithms designed to be implemented and executed on this new type of machine, offering advantages in terms of both calculation times and the accuracy of expected outputs compared to traditional computers
- **Quantum Communication**, which uses entanglement to create new, ultra-secure communication protocols, while ensuring that any unauthorised interception attempts are immediately detected
- **Quantum Sensing**, which gives rise to sensors capable of measuring physical quantities such as magnetic fields, gravitational variations or infinitesimal temporal variations with extremely high precision, with applications in medicine, geology, navigation and fundamental physics

In summary, while the first quantum revolution allowed humanity to appreciate some of the spontaneous potential arising from the unique physical properties that characterise the microscopic world, the second is providing the tools to build new technologies, based on a better understanding and control of the natural phenomena governed by these principles.

Briefly analysed below, the three quantum technologies will be explored in more detail in Chapter 3.
For each technology, the main industrial sectors in which it is currently applied or most likely to be applied are also listed. An in-depth examination of industrial applications is the focus of Chapter 4.

1.2 Quantum Computing

Quantum computing is a computing model that exploits the laws of quantum mechanics to solve problems that are too complex, in terms of solution time, available computing space or energy resources, to be effectively handled by traditional computing architectures.
Unlike conventional computing, which uses the minimum unit of information known as a bit (which can take on the value of either 0 or 1), quantum computing uses **qubits** (quantum bits), which have significantly different properties.

The combined use of the three properties of qubits allows quantum computers to simultaneously process many solving scenarios and thus achieve better results than traditional computers, both in terms of speed and accuracy of output, while reducing computational resources and therefore the overall energy required for computation.

Types of qubit

Qubits can be engineered in many different ways, each with its own advantages and technical challenges:

- **Superconductive qubits**: these are made from superconducting materials cooled to temperatures close to absolute zero. They currently represent one of the most easily scalable platforms, to the extent that they form the technological solution underlying the quantum computers of companies such as IBM, Google, Amazon, D-Wave, Rigetti and IQM
- **Trapped-ion qubits**: these are made with ionised atoms suspended in electromagnetic traps and manipulated using laser pulses. Companies such as Quantinuum (a consortium that also includes the multinational Honeywell) and IonQ are investing heavily in this technology, which is valued for its reliability and consistency

QUBITS PROPERTIES

The functioning of qubits is based on the application of three fundamental physical principles:

SUPERPOSITION

A qubit, in addition to being in a well-defined basic physical state (0 or 1), can also be in one of an infinite number of configurations resulting from the combination of the basic states, each with a certain probability (for example, 0 and 1 simultaneously at 50%). This allows for an increase in the overall computational space available with the same number of elementary data processing units available (i.e. qubits instead of bits)

ENTANGLEMENT

Two or more qubits can become entangled in such a way that a change in the state of one immediately affects the other, regardless of the distance between them. This particular type of bond allows information to be encoded and transmitted much more efficiently and is also commonly known as "action at a distance"

INTERFERENCE

A qubit, as an elementary quantum system, combines corpuscular and wave characteristics, and is therefore subject to the physical principle of interference, which is exploited to amplify the probabilities of finding the correct answer to a problem encoded in it, destructively limiting the incorrect ones

- **Photonic qubits:** as the name suggests, qubits correspond to photons, which are used to encode and process information. In addition to being more stable and resistant to surrounding noise, photons are also ideal for long-range communication. It is no coincidence that promising start-ups such as PsiQuantum, funded by the US government among others, and Xanadu are following this approach
- **Neutral atom qubits:** these are made from non-ionised atoms, cooled and controlled using appropriate optical instruments. They strike a good balance between scalability and consistency. Among the companies pursuing this approach are QuEra in the US and Pasqal in Europe
- **Silicon spin qubits**: in this case, the qubits correspond to the spins of electrons confined in semiconductor structures, similarly to what happens in so-called quantum dots, which act as pixels in QLED TVs. The main advantage of this approach is its substantial compatibility with ordinary chips, which are also silicon-based. Unsurprisingly, Intel is among the companies investing most heavily in this area
- **Topological qubits**: the idea behind this technological solution is to use exotic quasiparticles (non-Abelian anyons) to represent qubits. Microsoft is the main proponent of this approach that, while promising intrinsic fault tolerance, is still in the theoretical research phase and has not yet been tested
- **Nitrogen-Vacancy Centre**: qubits correspond to point defects in the crystal lattice of a diamond, where a nitrogen atom replaces a carbon atom near a vacancy. Although this technology has the advantage of providing high stability even at room temperature, scalability depends on the number of impurities in the diamond. Companies such as Quantum Brilliance and SaxonQ are exploring this approach, particularly with a view to selling small quantum computers for installation in data centres

Each of the methods for creating qubits described above is evaluated on the basis of four key properties:

- **Scalability**: possibility of increasing the number of qubits without significantly increasing the size of the quantum chip that contains them, while maintaining the overall reliability of the system
- **Speed**: ability to increase the system's calculation frequency in order to ensure a greater number of operations performed per unit of time
- **Fidelity**: probability that the system will remain accurate in performing physical/logical operations on qubits without incurring failures/errors
- **Coherence**: ability to extend the time during which qubits retain their characteristic quantum properties, which are by nature ephemeral as they are subject to various types of external perturbations (e.g. magnetic or thermal)

The main challenge is to increase all of the above dimensions without the growth of one negatively affecting the others, in order to achieve reliable and useful processing architectures on a large scale.

01 / Overview

Industrial applications

Although the technology is still in its infancy, its potential is already apparent in many areas:

- **Pharmaceutics and materials science**: accurate simulation of chemical compounds and complex materials. This can accelerate the discovery of new medicines, catalysts and complex molecular structures, a task in which even the most powerful classical computers prove inefficient
- **Finance**: investment portfolio optimisation, risk management, predictive analytics and stochastic simulations. Quantum computing can drastically reduce the time required for highly complex analyses, while increasing the accuracy of results
- **Logistics and transport**: solving problems such as better route planning, resource allocation or strategic planning, potentially in real time
- **Energy**: modelling of complex systems such as those designed to prevent failures in electrical networks, improving efficiency and ensuring operational stability
- **Artificial Intelligence**: some machine learning applications could benefit from quantum approaches both to accelerate the training of supervised models and to improve the quality of predictions of unsupervised ones or the choices made by an agent trained by reinforcement learning

In addition to promising a significant reduction in processing time when solving certain problems and a higher quality of output solutions, in some cases quantum computing even makes it possible to tackle **problems that classical computers cannot manage**, which, unfortunately, can also prove to be negative.

A potential threat to cryptography

These inaccessible problems include the factorisation of integers with an arbitrary number of digits into prime numbers.

The well-known RSA public key cryptographic protocol is based on the impossibility for a traditional computer to perform this decomposition in a reasonable amount of time. Since 1977, the year it was conceived, the protocol has helped to protect, among other things, web communications and financial transactions. However, as early as 1994, computer scientist Peter Shor devised a quantum algorithm that allows even very large integers to be broken down into prime factors in exponentially less time than the best classical technique. Therefore, a sufficiently powerful quantum computer could **break current cryptographic protections**, threatening much of global digital security and necessitating replacement with newly developed cryptographic systems that are resistant to this type of attack, known as Post-Quantum Cryptography (PQC).

A Survey on Post-Quantum Cryptography: State-of-the-Art and Challenges

1.3 Quantum Communication

Quantum communication is a technology that encompasses a set of quantum telecommunication systems that primarily leverage the principle of entanglement to create essentially secure data transmission channels which, for certain applications, are more efficient than traditional information exchange systems.

The new frontier of inviolable communications

Compared to traditional communication protocols, this type of system guarantees intrinsic security (i.e. guaranteed by the medium used for transmission rather than by a software algorithm), the ability to detect any interception attempts, and better transmission capacity for the same amount of time and bandwidth available.

Unlike traditional data transmission systems (where data travels from sender to recipient encoded in the form of binary electrical pulses), **quantum communication systems use photons**, which allow the exchange of information even in superposition states (thus increasing the amount of data sent per unit of time, given the same transmission capacity of the channel used) and pieces of information not locally correlated (i.e. information that can also be sent non-sequentially on different channels, while maintaining the same information content).

In an increasingly interconnected world subject to growing cyber threats (including those potentially posed by future quantum computers, as discussed above), classical cryptography methods based on difficult mathematical problems could become vulnerable.

Besides Post-Quantum Cryptography, which is a logical solution to the problem, **Quantum Key Distribution** (QKD) is a possible strategy for secure and physically guaranteed data transmission.

Quantum Key Distribution is a technique that allows two interlocutors (traditionally called *Alice*, the sender, and *Bob*, the recipient) to exchange a secret key by exploiting the properties of quantum mechanics. The first protocol designed for this purpose is BB84, named after its creators Bennett and Brassard, who proposed it in 1984. This protocol ensures that any attempt to intercept the key will result in the inevitable alteration of the key itself, thus rendering the intercepted information unusable to the attacker and at the same time revealing the unauthorised attempt of theft to the recipient of the communication.
More recent and efficient developments of the BB84 protocol are the Ekert protocol and so-called Quantum Teleportation, which employ more advanced forms of entanglement between the photons used for key transmission.

Entanglement and teleportation in quantum key distribution for secure wireless systems

The QKD protocol does not directly transmit messages, but rather provides a set of inviolable encryption keys to be used for exchanging data over conventional channels. This system has already been tested in various real-world contexts, including via satellite repeaters and fibre optic channels, paving the way for a future distributed quantum communication network (Quantum Internet).

Another advantage of using quantum communications lies in the so-called **Superdense Coding**, a technique that allows **multiple bits of information to be transmitted simultaneously for each photon** used in the transmission.

In a classic communication, a single bit transmits at most one binary piece of information (0 or 1). Instead, with superdense coding, the sender can send two classical bits using a single photon, if this is entangled with another photon already held by the recipient.
This mechanism increases communication efficiency and shows how entanglement can be exploited to maximise the transmission capacity of channels.
When combined with the right network infrastructure, it is possible to create high-density, ultra-low latency hybrid communication systems, which are useful in contexts with particularly demanding transmission requirements.

Industrial applications

Already in the short term, quantum communication is one of the most promising areas in terms of tangible applications.

Sectors that can benefit the most include:

- **Defence and security**: military, governmental and institutional intelligence intrinsically protected from even sophisticated attacks, including those perpetrated by sufficiently powerful quantum computers in the future
- **Financial services**: security of banking transactions and sensitive communications concerning customers exchanged between central banks, financial institutions and insurance companies
- **Telecommunications and critical infrastructure**: creation of quantum networks to ensure greater communication efficiency and substantial security for data transmitted on an international scale
- **Healthcare**: secure sharing of medical data and confidential information relating to clinical or pharmaceutical research
- **Cloud and datacentres**: improvement of transmission capacity and integrity of information exchanged in client-server mode, particularly in multi-tenant and distributed contexts

Despite still being an evolving technology, especially in the field of free space communication, concrete implementations already exist in which quantum communication has been used productively.

Among the leading technology providers, it is worth mentioning the Canadian EvolutionQ, the US-based QuSecure, the Swiss IDQuantique, as well as the Italian QTI - Quantum Telecommunication Italy, recently acquired by Telsy, the TIM Group's centre of expertise for communications security and cybersecurity.

1.4 Quantum Sensing

Among quantum technologies, quantum sensing is responsible for the creation of **ultra-sensitive measurement sensors** designed to detect minimal variations in physical quantities such as time, gravity, magnetic field intensity, acceleration and temperature.

From a metrology point of view, this means, on the one hand, the possibility of obtaining much more accurate measurements of physical quantities that can already be detected using conventional sensors, but, on the other hand and above all, the possibility of measuring physical quantities that cannot otherwise be detected with the instrumentation currently available.
Therefore, this type of instrumentation allows critical problems to be addressed in contexts where measurement sensitivity is crucial, such as in the detection of very weak magnetic fields in the human brain or low-intensity gravitational fluctuations in geophysics.
The calculation of elapsed time can also benefit from quantum atomic clocks, whose greater accuracy enables the construction of new generations of GPS systems.
In a nutshell, quantum sensing represents a new generation of metrology technologies capable of pushing the limits of standard sensors, revolutionising the methods of remote observation, navigation and monitoring.

Industrial applications

Quantum sensing is already a near-production technology in numerous areas:

- **Healthcare**: devices for generating neurological scans, useful, for example, as a tool for preventive and non-invasive diagnostic investigation of diseases affecting the nervous system
- **Geology and environmental surveys**: quantum gravimeters to detect underground voids, aquifers or volcanic activity
- **Defence and security**: long-range unidentified object detection and automated navigation systems based on untraceable quantum radars/sonars
- **Precision manufacturing industry**: manufacture of sensors for nanomachines to make their action monitored and programmable
- **Aerospace and autonomous mobility**: tools for orientation and localisation in signal-free environments such as outer space

Major technology providers include the Australian Q-CTRL, the US-based SandboxAQ, and the Italian Quantum Ket, which specialises in the production of geophysical and biomagnetic quantum sensors.

1.5 The Year of Quantum

Awareness of the strategic importance of quantum technologies is also growing at institutional and supranational level.
2025 has been proclaimed the centenary year of quantum mechanics, prompted by the United Nations, which accepted the invitation of scientists from around the world to highlight this event.
The United Nations emphasises how all the technologies and theories born out of quantum physics contribute to both the economic and social development of humanity.

The International Year of Quantum Science and Technology initiative identifies six macro areas on which researchers, institutions and policymakers should focus their attention, efforts and investments:

- **Health and Wellbeing**: develop diagnostic imaging and support the creation of new medicines and vaccines
- **Reduced Inequalities**: make quantum solutions accessible to everyone thanks to an open science approach
- **Industry and Infrastructure**: develop new materials
- **Economic Growth**: ensure the security of the economic and financial infrastructure
- **Climate Action**: environmental monitoring and development of new climate models
- **Clean Energy**: design new low-cost solar cells and low-emission lighting systems

International Year of Quantum Science and Technology (IYQ)

02/

2025 Market and Ecosystems

Chapter 1 presented the fundamentals of quantum technologies and the main application families. This second chapter focuses on the evolution of the global quantum market, analysing its structure, key players and growth prospects.

In many respects, the quantum technology ecosystem represents a competitive battleground between countries and groups of countries for dominance over the technology and its entire value chain. The impact that quantum technology will have on many industrial, scientific and economic sectors will indeed be transformative and disruptive.

The international quantum market is experiencing a growing role for public and private investment.

Market data, including growth trends and competitive dynamics among the main ecosystems (divided into North America, Europe and Asia), suggest that multiple market and industrial challenges will need to be addressed over the next 5–10 years. Governments and public bodies around the world are promoting the emergence of industrial supply chains in the quantum sector by creating initiatives and technology parks, public-private partnerships and medium- to long-term development strategies.

The chapter closes with a reflection on the future prospects of quantum technologies, concentrating on the theme of technological sovereignty and global competitiveness.

2.1 Market

The quantum technology market is transitioning from the laboratory to industry, with sustained growth in public and private investment. According to the McKinsey *Quantum Technology Monitor - June 2025* report, the industry is still in the early stages of its life cycle. However, projections indicate significant economic potential, with applications ranging from health to finance, energy to mobility, and many other sectors. Based on the tangible technological potential, the quantum market is divided into three fundamental pillars: quantum computing, quantum communication and quantum sensing.

Technology	Value in 2025 in USD billion	Expected value in USD billion
Quantum computing	1.2 – 1.4	9.5 (2034)
Quantum communication	1.3 – 1.4	13.0 (2034)
Quantum sensing	0.3 – 0.4	1.2 (2032)

Sources: Future Market Insights, Precedence Research, Fortune Business Insights

The **quantum computing** segment is currently attracting most of the media attention and investment, despite remaining technologically immature in many of its architectures. However, it is also the sector with the greatest potential for value creation, even though most applications are only expected to be in prototype form.

According to analysts, quantum computing and quantum communication are currently the two segments with the highest market value, with roughly equivalent estimates of between $1.2 and $1.4 billion in 2025. However, quantum computing is the area attracting the most attention from investors and the media due to its potential for industrial transformation.
Average annual growth is between 23% and 31%. Applications focus on the simulation of chemical systems and materials, complex optimisation in industrial and financial contexts and integration with artificial intelligence. Furthermore, particular importance is given to the Quantum-as-a-Service (QaaS) model, which allows access to quantum resources via cloud platforms (see Chapter 4).

The **quantum communication** sector, focused on quantum cryptography and secure data transmission, is also expanding rapidly. The market is valued between $1.31 billion and $1.41 billion in 2025 and could exceed $13 billion by 2034, with annual growth exceeding 28%. This area is strategic for applications in defence, finance, public administration and telecommunications.

Quantum sensing, although less well known to the general public, already has practical industrial applications. With a current value of approximately $377 million and a forecast of $1.2 billion by 2032, it is used in sectors such as healthcare, defence, navigation in environments without GPS coverage and precision agriculture.

With more than $15 billion, China leads in public investment in quantum technologies

According to McKinsey, up to April 2025, a total of more than **$54 billion in public funds** have been invested in support of quantum technologies. China's leadership stands out ($15.3 billion), followed by the European Union with $8 billion, Japan with $7.4 billion, the USA with $6 billion and Canada with $2.5 billion. Alongside these, Australia, the UK and South Korea are also pursuing ambitious national programmes, while there are also significant state initiatives in the US, such as the $500 million in Illinois and a $1-billion plan in Maryland to support the development of quantum infrastructure.

Private investment is also growing rapidly: in 2024, there was approximately $2 billion in venture capital funding for quantum start-ups and scale-ups, up 50% from the previous year. This figure reflects renewed momentum in the sector following the slowdown after the peak in 2022, with investment volumes remaining around 6 times higher than 2019 levels. According to the McKinsey report, the global quantum technology market is estimated to reach a total value of $198 billion by 2040.

Quantum technology development is concentrated in three major geographical areas: North America, Europe and Asia. Each of these has initiated substantial public and private investments, supported the launch of start-ups and outlined national strategies to consolidate a competitive advantage in an emerging sector considered to have a high economic impact.

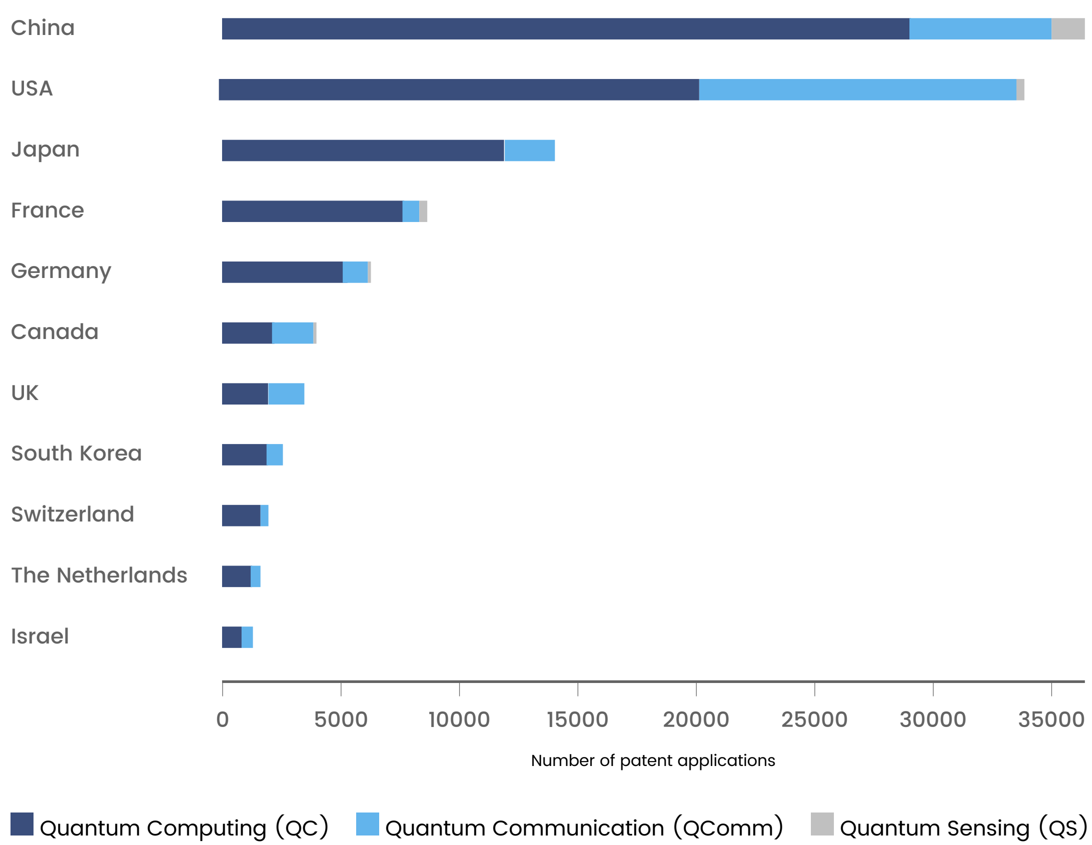
The United States has earmarked $6 billion in public funds for research and development of quantum technologies, most of which has been channelled through federal programmes, research organisations and government agencies.
The US market is marked by a high level of private investment. Between 2015 and 2023, over 50% of all global venture capital investment in quantum technologies was concentrated in the United States. The US has the largest number of active start-ups in the sector, with more than 100 companies operating in the field of quantum technology.
In the quantum computing sector in particular, the United States is the ecosystem with the highest market value: approximately $1.44 billion in 2025.

Canada has also earmarked $2.5 billion in cumulative public funds for the quantum sector. The country maintains a prominent role in academia and has a growing presence of start-ups, especially in quantum sensing and quantum communication. Between 2015 and 2023, Canada received about 5% of venture capital investments globally.

Shifting the focus to the European Union, investments exceeded more than $8 billion in public funds for quantum technologies, placing the EU in second place globally. This figure includes both centralised programmes (e.g. *Quantum Flagship*, funded

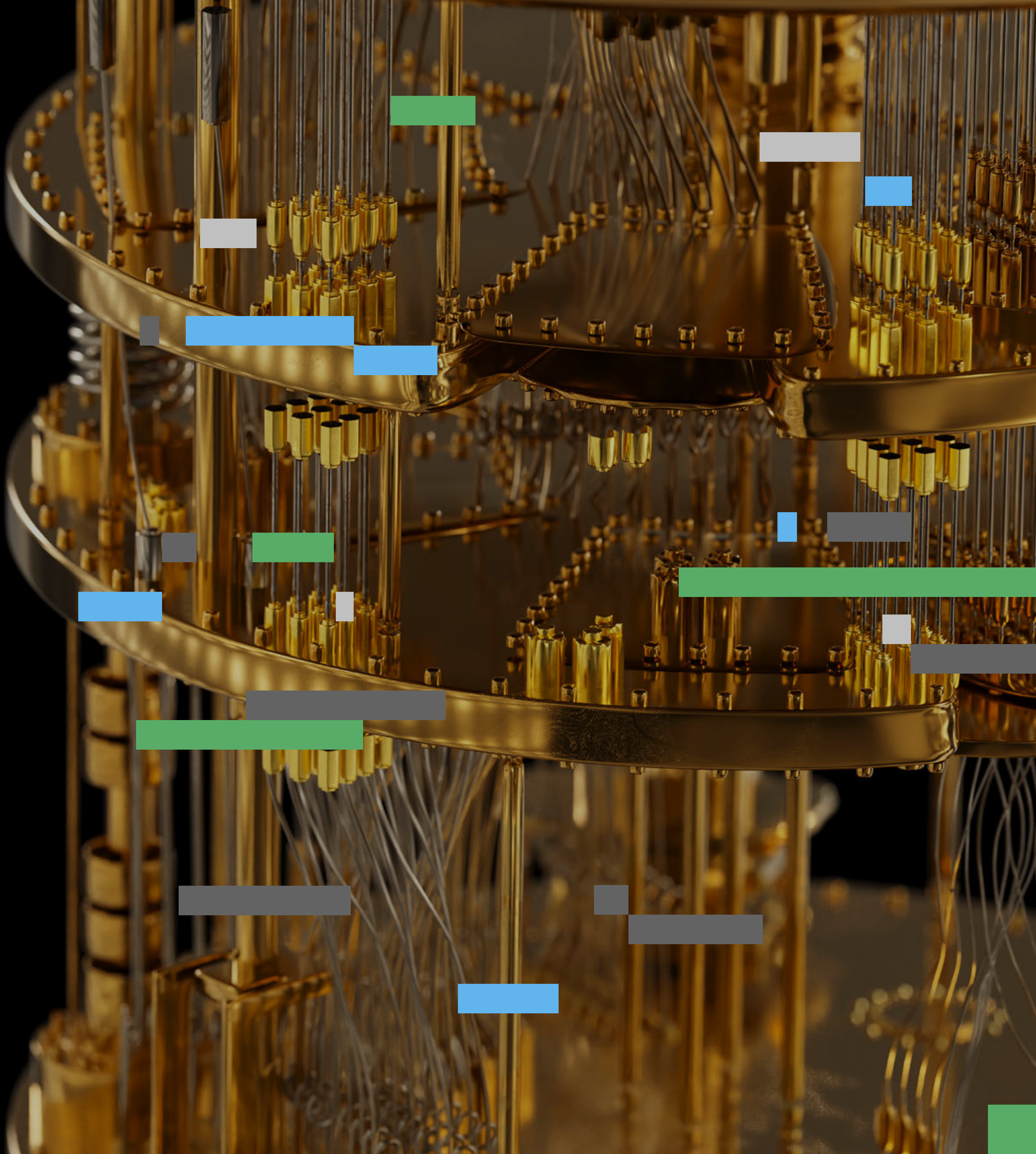
with over €1 billion) and national projects of individual Member States. The European EuroQCI programme, for example, aims to create a secure continental quantum communication network by 2027. The resources allocated at EU level and by individual Member States for this infrastructure exceed €500 million.
According to McKinsey, the level of private funding in Europe remains low compared to other global clusters. Between 2015 and 2023, the continent attracted about 16% of total global venture capital investment, about one-sixth of that of the United States. As of September 2025, Europe has over 100 start-ups operating in the quantum sector, with a strong concentration in countries such as Germany, France, the Netherlands, Finland, Italy and Spain. Germany is the strongest market in terms of size and industrial capacity, followed by France. However, there has also been growth in the Italian ecosystem, with an increasing number of initiatives related to quantum sensing, photonics and Horizon Europe programmes.

Patent applications in quantum technologies by country and area (2000-2024)
Source: LINKS Foundation analysis based on McKinsey data



03/

Technologies



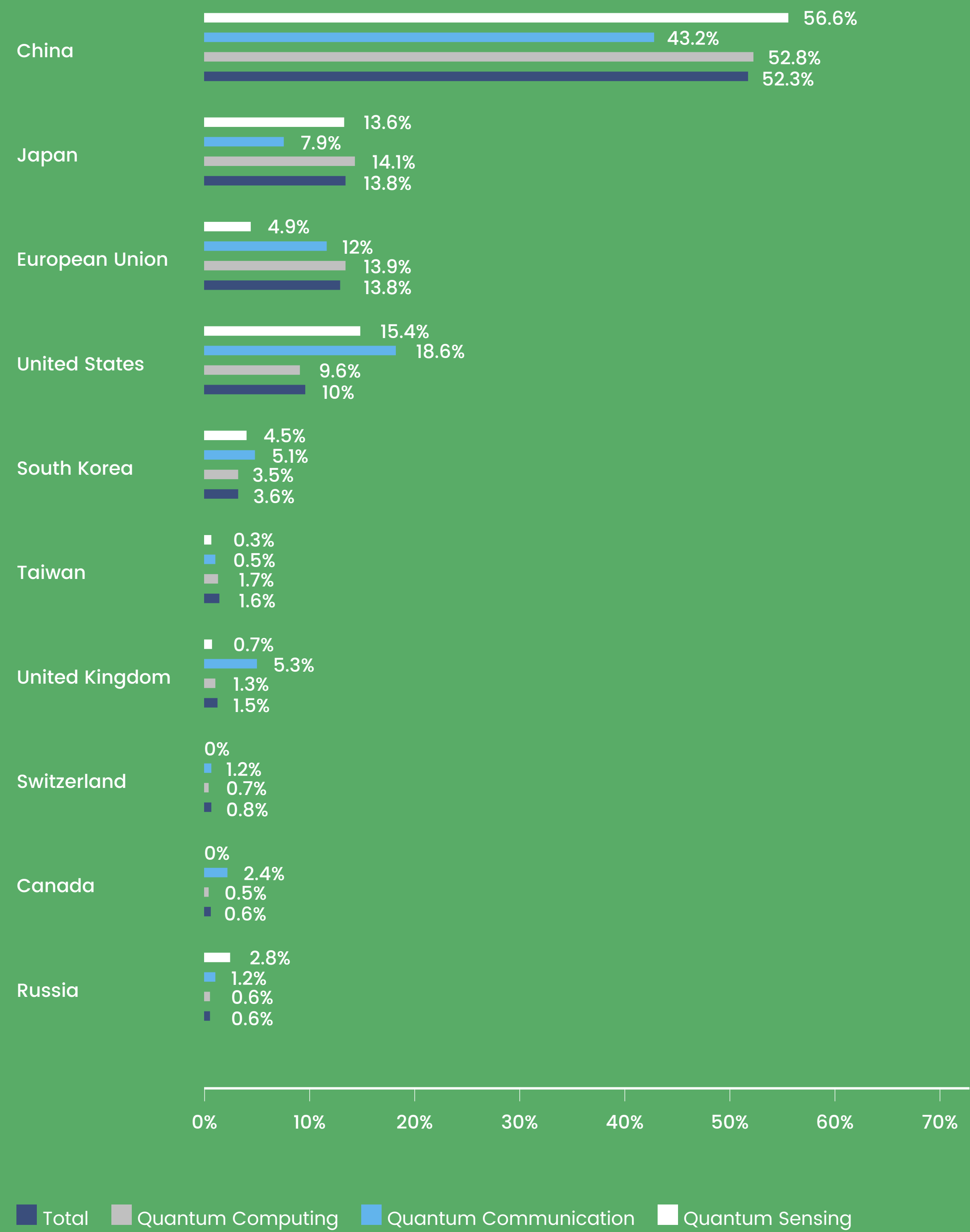
As discussed in Chapter 2, in the sensor, communications and computing sectors, the market can be considered attractive in terms of turnover, geographical distribution and number of players involved.

Quantum technologies are often associated with frontier technologies, far removed from practical applications. The reality is quite different, as many of them have gone beyond the confines of laboratories to enter industrial sectors.

In many respects, the three quantum macro-categories represent three killer applications that enable the sector to expand and reach the critical mass that fuels innovation.

From 2000 to 2022, the data available on patents granted in the three quantum sectors show how research and innovation in this field are concentrated among a few major global players: China, Japan, the European Union and the United States account for 89.9% of patents.

Quantum technology patent share from 2000 to 2022, by segment and country
Source: Statista



3.1 Quantum Sensing

The industrial sectors that are making the most use of these sensors are those that require highly accurate data analysis, potentially in special or extreme conditions. Adopting sensors that exploit the properties of quantum mechanics offers some significant practical advantages over traditional sensors: **higher precision, greater sensitivity and detection speed, miniaturisation**.

In general, quantum sensors provide high performance in the measurement of physical quantities, and in particular:

- **Time** and **frequency**
- **Gravity** and **variations of the gravitational field**
- **Magnetic fields**
- **Electric fields**
- **Accelerations** and **rotations**
- **Quantum optical properties of light**

Quantum sensors show great promise for a wide range of applications in the medical, chemical-pharmaceutical, energy, geodesy and geographical scanning sectors, as well as for environmental monitoring, navigation in the logistics and transport sectors, and space and defence-related activities. The industrial development of this branch of technology will revolutionise sectors that need ultra-precise data to enable new services.

QUANTUM SENSOR PROPERTIES

Greater sensitivity
Quantum sensors can detect extremely weak signals

Higher precision
They enable measurements with greater accuracy than conventional limits

Detection speed
They allow fast acquisition and real-time monitoring

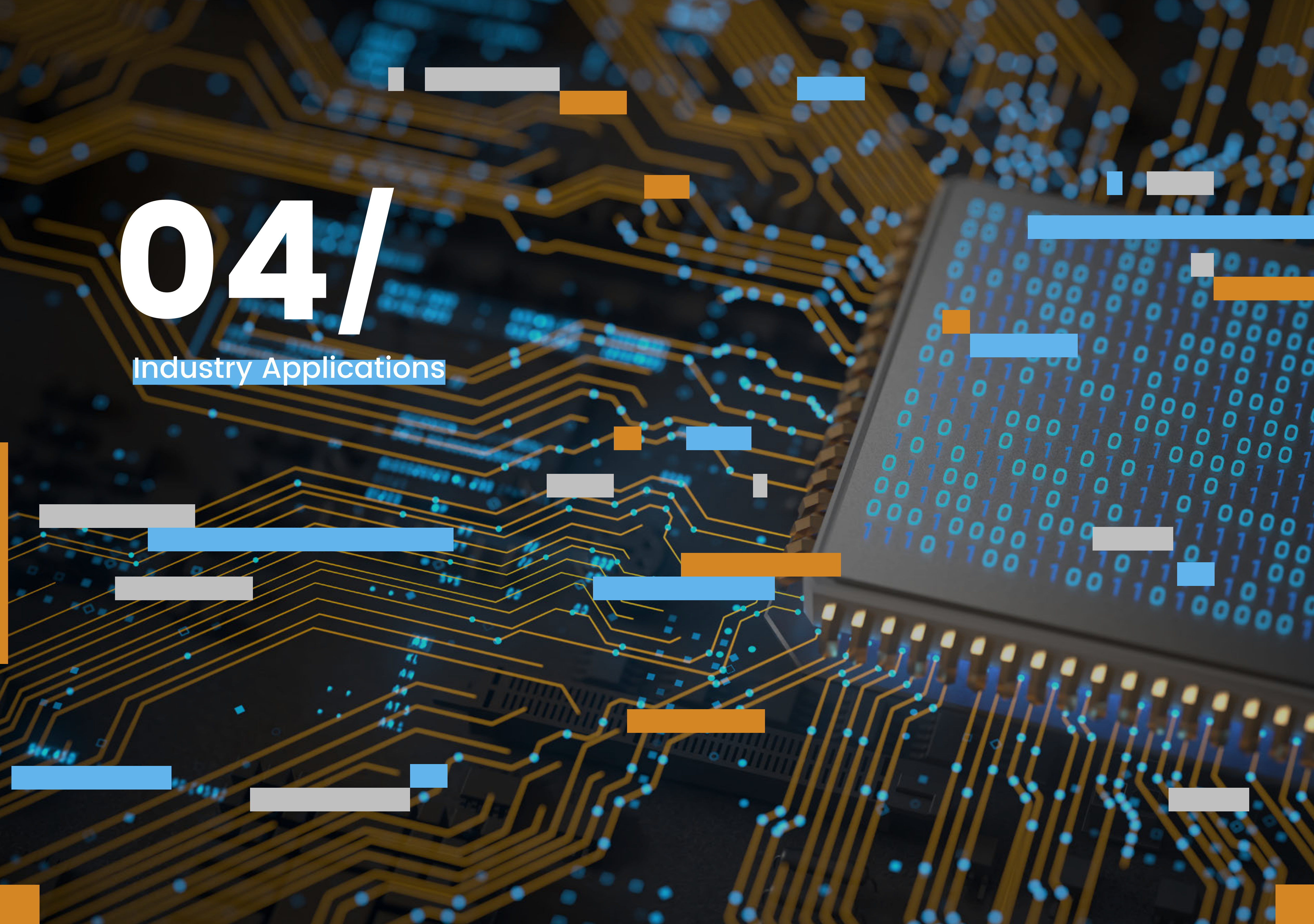
Operational cost-effectiveness
They require lower costs and fewer resources than conventional sensors

Source: internal production

Measured size	Measuring tools	Areas of application	Main uses
Time and frequency	Atomic clocks	Navigation, telecommunications, finance	Ultra-precise synchronisation, timestamping
Gravity and variations of the gravitational field	Interferometers, atomic gravimeters	Geophysics, natural resources, volcanology, archaeology	Surveying underground structures, 3D maps without excavation
Magnetic fields	Magnetometers	Medicine, industry, defence	Brain imaging, non-destructive testing, advanced monitoring
Electric fields	Atomic sensors with various technologies	Diagnostics, advanced electronics	Local variation detection, component monitoring, maintenance
Accelerations and rotations	Gyroscopes, quantum accelerometers	Logistics, transport, space exploration	Autonomous navigation, GNSS backup, precision orientation
Light and photonic states	Optical interferometers	Metrology, secure communications, physical tests	Ultra-precise optical measurements, quantum imaging, optical sensing

04/

Industry Applications



In recent years, quantum technologies have been the subject of much discussion about their potential positive impact in certain industrial and economic sectors.
The debate intensified in 2019 with Google's claim of quantum supremacy (see Chapter 3). The previous chapter presented the target market for the three main quantum technologies from which new industrial applications are emerging, namely quantum sensing, quantum communication and quantum computing.

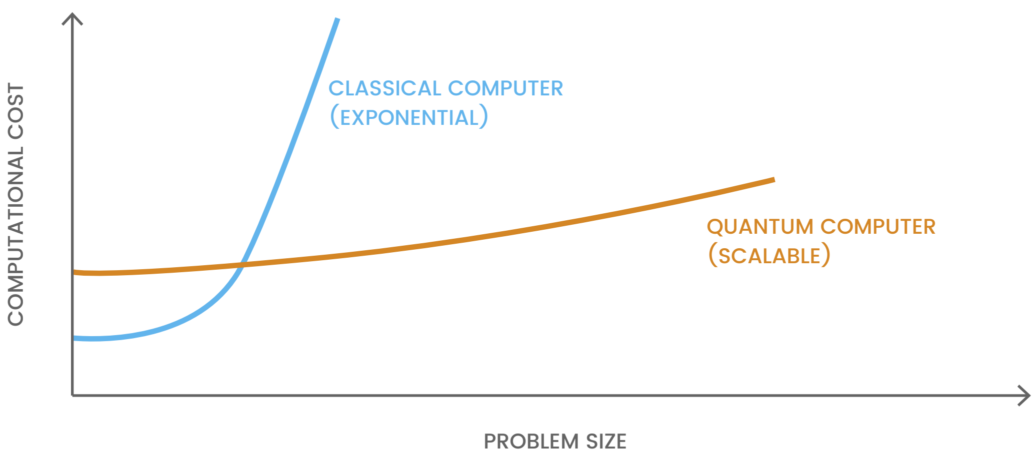
The scope of application for these technologies is gradually expanding to include industrial sectors other than those for which they were originally conceived and designed. This trend is common to many emerging technologies capable of solving complex problems: for example, consider the use of graphics cards (GPUs), initially designed to improve the fluidity of video images, now widely used in machine learning and artificial intelligence.

In terms of the cross-industry applicability of quantum technologies, while quantum sensing and quantum communication naturally focus on specific sectors (respectively biomedical, military and geodetic for the former, cybersecurity and telecommunications for the latter), quantum computing, on the other hand, makes it possible to tackle problems that cannot currently be tackled within a reasonable time frame and at a reasonable cost in a variety of industrial sectors, from chemicals and pharmaceuticals to logistics, automotive and energy supply, and financial services.

The varying degrees of technological maturity, the specific characteristics of each industry and, finally, the availability of funding have a significant impact on the cross-industry use of quantum technologies.
Quantum computing best expresses its potential compared to traditional computing systems in highly complex contexts because of its high efficiency, which translates into lower computational costs.

Potential of Quantum Computing

Qualitative comparison of the computational cost of simulating a quantum system with a classical computer vs. a quantum computer



Healthcare, chemistry and materials science are considered among the industrial sectors where the potential of these technologies will materialise most rapidly.

These are very broad fields, featuring a large number of enabling technologies for their development, both from a research and industrial production perspective. For these three sectors, quantum technologies will have a disruptive impact in the medium term (5–10 years): quantum sensing enables new ultra-precise measurement systems, while quantum computing opens the door to extremely complex and detailed simulations that can be performed quickly or even almost in real time.

Computing power will become an enabler to create new businesses and accelerate the discovery of metabolic processes, biological interactions between molecules, and **new drugs and materials**. Furthermore, the combination of several technologies such as quantum sensing and computing will make it possible to create **digital twins of complex objects**, including from a biological point of view, in order to better understand their functioning, evolution and thus be able to intervene with new therapeutic or advanced predictive maintenance approaches.

Energy and transport networks will also benefit from quantum technologies to increase efficiency, safety and resilience in stressed conditions. In particular, quantum computing promises a significant impact in terms of **sustainability**, thanks to the optimisation of complex systems involving a large number of variables such as, for example, those related to managing energy and transport networks. Quantum computing will also make an important contribution to the optimisation of transport and logistics, improving **route planning and traffic management**, dynamic allocation of resources in complex systems and the synchronisation of supply chains. The direct benefits will be tangible: reduced operating costs, increased reliability and lower logistics-related emissions.

Finally, financial institutions, both public and private, were among the first to recognise the disruptive and transformative role of quantum technologies due to their impact on security and industry resilience. Interest has focused on quantum communication, due to its relevance in developing **advanced cryptography** systems, and on quantum computing, as a useful tool for improving the analysis of large volumes of data and strengthening financial risk management mechanisms.
The use of quantum communication mostly concerns the implementation of secure protocols and the adoption of Quantum Key Distribution techniques to protect information flows. Quantum computing, with its computing power characterised by flexibility and speed of execution of operations, is seen as a new technological step for optimisation processes, fraud detection, anti-money laundering activities and analysis of large databases to promote monitoring or investment activities.

#use case
Quantum Computing as a Service

Quantum Computing as a Service (QCaaS), leveraging Cloud Computing infrastructures, represents an enabling service for access, experimentation and development of quantum computing, especially in a fragmented technological environment where hardware availability is still rather scarce.
In this scenario, QCaaS enables companies, universities and research centres to test quantum algorithms and implement applications by remotely accessing real quantum machines or simulators, without the need to own on-site or manage physical hardware, which is still relatively expensive and complex to maintain independently.
Therefore, Cloud Computing breaks down barriers to entry, making quantum technology democratic and scalable. This approach allows companies of all sizes to compare the performance of different quantum hardware and to experiment with algorithms on multiple platforms without any particular vendor constraints.
However, it must be considered that the absence of common international standards is a significant obstacle to software portability and interoperability among different systems. Each provider adopts its own framework, languages and specific APIs (e.g. IBM's Qiskit, Google's Cirq, Microsoft's Q#), making code reuse and comparability between platforms difficult.

The three major cloud operators leading the QCaaS offering are:

- Google Cloud, which provides access to its Sycamore platform via Cirq, as well as IonQ, AQT and Pasqal, and high-performance quantum simulations
- Amazon Web Services (AWS), with the Amazon Braket service, which allows access to multiple quantum technologies from manufacturers such as IonQ, Rigetti, QuEra and IQM
- Microsoft Azure Quantum, which offers an integrated architecture for accessing quantum machines from selected partners (Quantinuum, Rigetti and Pasqal) and incorporates a development environment (Q#) focused on modularity and scalability

Amazon Braket – AWS Quantum Computing

Microsoft Azure Quantum

Google Quantum AI

The availability of these platforms as services not only accelerates experimentation and research, but also enables the creation of a growing ecosystem that includes start-ups, public laboratories, hardware suppliers and software developers. Thus, QCaaS becomes the infrastructural bond of a rapidly evolving sector, which does not yet have a predominant technology but holds great potential for transformation.

About Intesa Sanpaolo Innovation Center
Intesa Sanpaolo Innovation Center is the Gruppo Intesa Sanpaolo company dedicated to frontier innovation. It explores future trends and scenarios, develops multidisciplinary applied research projects, supports startups, accelerates business transformation for companies according to the criteria of Open Innovation and the Circular Economy, facilitates the development of innovative ecosystems and disseminates innovation culture, in order to make Intesa Sanpaolo the driving force behind a better informed, inclusive and sustainable economy.
The Innovation Center, with its headquarters on the 31st floor of the Intesa Sanpaolo skyscraper and its national and international network of hubs and laboratories, is a relationship facilitator for the other stakeholders of the innovation ecosystem – such as businesses, startups, incubators, research centers, universities, national and international institutions – and a promoter of new forms of entrepreneurship and their access to risk capital, with the support of venture capital funds, thanks also to the Neva SGR subsidiary.

About LINKS Foundation
Leading Innovation and Knowledge for Society is a private research and innovation organisation founded by Politecnico di Torino and Fondazione Compagnia di San Paolo. It contributes to a development process based on the principles of social cohesion and sustainability, with the aim of fostering progress in scientific and technological research as well as the cultural and professional growth of society. The founding values guiding LINKS' work are the production, attraction, preservation, critical elaboration, and transfer of knowledge in the fields of engineering, architecture, and other polytechnic sciences, also through technology transfer activities and services supporting the local ecosystem. The Foundation pursues goals of social utility, promoting the civil, cultural, and economic development of the contexts in which it operates. LINKS acts as a platform for transferring knowledge from academia, research centres, and scientific literature towards industry, public administration, cultural institutions and third-sector organisations. Its role is to support the maturation of technologies and innovative solutions, achieving impact through the work of researchers with strong technical and scientific expertise.

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