Finanziato dall'Unione europea NextGenerationEU

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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

NQSTI National Quantum Science and Technology Institute

Quantum for Italy 2025

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CONTENTS

List of Figures

Table of Boxes

List of Tables

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PREFACE: *NQSTI*, the *National Quantum Science and Technology Institute*

Claudio Pettinari
NQSTI President,
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Università degli Studi di Camerino

"Quantum science and technology is rapidly reshaping the frontiers of innovation, offering transformative potential across communication, computation, sensing, and secure information. In this dynamic context, Italy has taken a decisive step forward with the establishment of the ***National Quantum Science and Technology Institute*** **(***NQSTI***)** — a coordinated national effort designed to strengthen the country's leadership and competitiveness in the quantum domain, a consortium that was founded by 20 Italian entities, but is currently expanding.
Supported by PNRR investments, *NQSTI* has created an integrated ecosystem that connects universities, research institutes, and industrial partners. This network not only enhances access to state-of-the-art infrastructures but also promotes technology transfer, cross-disciplinary collaboration, and advanced training for the next generation of quantum scientists and engineers. A recent and relevant milestone achievement in this process has been the creation of **Quantum Technology Fabs** designed to support industry and academy researchers in prototyping and validation of quantum devices - a concrete foundation for long-term life and sustainability and innovation capacity.
Today, *NQSTI* represents both a scientific hub and a strategic instrument for national growth. Its coordinated model supports Italy's participation in the European quantum agenda and ensures alignment with international initiatives. Through its open and collaborative approach, *NQSTI* stands as a **fundamental bridge between research, industry, and policy**, providing expert insight and evidence-based guidance for building the future of quantum technologies in Europe".

The fall of 2021 saw the creation of a group of 23 experts from Academia and Research institutions, following the publication of the Italian government guidelines. These experts shared an analysis of the QST know-how available in the country, of the obstacles to its full valorization and translation into economic growth and sustainable development, and a vision of the main directions capable of bringing the radical innovation requested by the guidelines. This study was then shared with leading enterprises operating in Italy: new goals and needs completed the report. The analysis represented the starting point for the elaboration of the ***National Quantum Science and Technology Institute*** as a PNRR proposal. The *NQSTI* coordination's programs aim **to overcome the current structural weaknesses** of the Italian systems, such as fragmentation of research lines and organizations, scarcity of personnel, poor funding, inadequate digital infrastructure, and lack of exploitation of the existing facilities/laboratories.

NQSTI's vision is that the extraordinary PNRR funding must be used to update technical facilities and strengthen the QST community in the next few years, but even more importantly, it must be channeled to drive the national community into an ordinary and sustainable condition of increased impact, visibility, and capacity to modernize and support the competitiveness of the Italian economy.

The ***National Quantum Science and Technology Institute*** (*NQSTI*) is a consortium that intends to:

(i) team up Italian entities carrying out competitive and innovative research in the field of quantum science and technology (QST), and

(ii) stimulate future industrial innovation in the field, providing a forum in which novel ideas and opportunities are transferred to companies.

In order to ensure a long-term positive effect on the Italian economic growth and development, the whole innovation chain was considered: from the strengthening and coordination of the low-TRL research, to its translation into prototypes, favoring interfacing with industrial needs thanks to strong outreach and continued-education programs.

The ***National Quantum Science and Technology Institute*** long term goal is to contribute to the establishment in Italy of a Knowledge Transfer (KT) System for Quantum Technology i.e. to manage the activities and the processes through which knowledge, expertise and qualified personnel flow between the research system (institutes, universities, research centers) and the community of end users in the industrial sectors, in commerce, in the service and in the public sectors.

Serafino Sorrenti

NQSTI Honorary Chair

Chief Information Security Officer (CISO)

Presidency of the Council of Ministers of the Italian Government

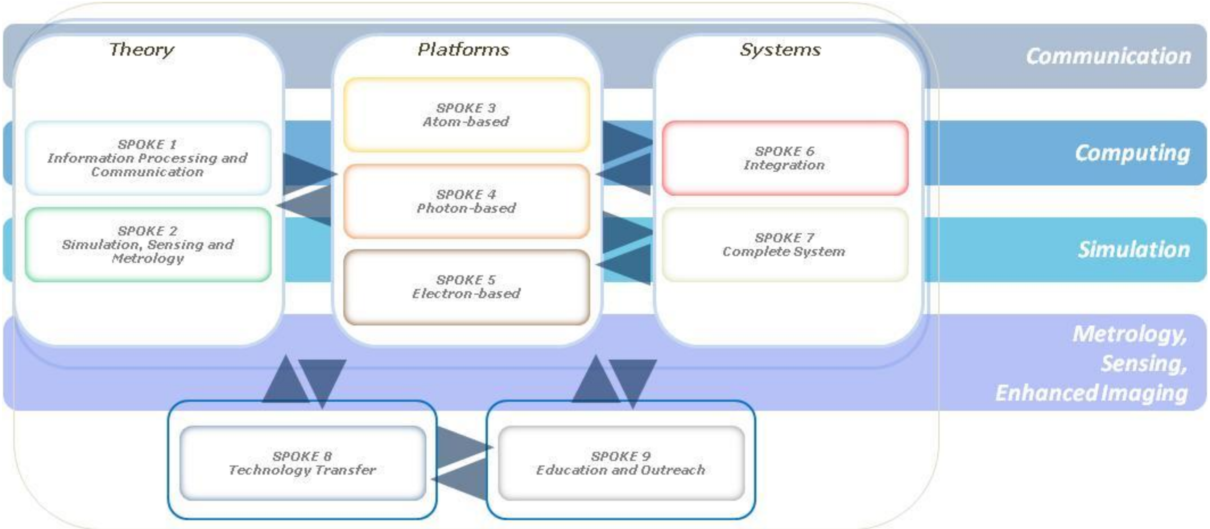
"The ***National Quantum Science and Technology Institute*** **(*NQSTI*)** constitutes a precious national asset for the advancement of quantum technologies in Italy. Its **coordinated structure, scientific excellence, and deep understanding** of both the national and international quantum ecosystem make it an **indispensable partner** to the vigorous governmental initiatives currently shaping this strategic domain.

Thanks to its technical competence and **extensive network**, *NQSTI* serves as an **authoritative interface** between the research community, industry, and policy makers. In this pivotal phase of the digital transition, it plays a crucial role in supporting the integration of quantum-driven innovation into Italy's technological and industrial fabric.

This document is a tangible example of how ***NQSTI*** can serve as a **reliable and timely source of information and analysis** to assist policy makers in monitoring progress and shaping informed strategies for the future of quantum technologies in Italy".

Within *NQSTI,* the goal is to create a dedicated **single-point provider for SMEs** where they will be able to find educational programs for their existing staff, new QST-trained personnel, and opportunities to innovate products and processes by participating, through dedicated open calls, in collaborative projects with our project participants. ***NQSTI*** **aims particularly to effectively connect low-TRL research with companies' R&D divisions**, either by leveraging on the existing industrial infrastructure or by stimulating the creation of new companies.
NQSTI **is organized in 9 Spokes**: the first 2 dedicated to establishing the theoretical and conceptual framework of the systems to be developed, and the following 3 dedicated to the technological platforms needed to implement those concepts defined in terms of the quantum of choice (atoms or molecules, photons, electrons), Spoke 6 dedicated to the integration of the developed devices into functional modules, Spoke 7 dedicated to research on system architectures. Spokes 8 and 9 are transversal Spokes dedicated to Technology Transfer and Education and Outreach, respectively (see *figure 1*).

Figure 1. The NQSTI Spokes' structure



Overall, the Partnership comprises 20 participants (public, non-profit entities, and private companies). The Hub was set up in the form of a limited liability consortium (SCARL) with the involvement of all public participants and is hosted in CNR central seat in Rome.
Its mandate is:

- ensure the coordination and management of the overall program towards the Italian Ministry of Research (MUR) and the Spokes, according to the agreement with the MUR and European/national rules for expenditures;
- monitor Spokes and participants, address gender-equality issues and diversity management;
- provide recommendations on the most appropriate solutions for achieving the selected research results;

- coordinate and promote interactions among "Spokes" and with stakeholder organizations;
- provide centralized program management support (e.g., periodic workshops, website hosting, etc.);
- promote educational programs and workforce development.

Within the Hub organization described above, *NQSTI* is scientifically coordinated by a steering committee formed by the Spoke leaders and chaired by Professor Fabio Beltram. Each Spoke is organized with a scientific coordination team comprising all activity leaders, and managing coordination is ensured by the Participants' representatives.

Fabio Beltram
NQSTI Scientific Coordinator
Full Professor of Experimental physics of matter and applications
Scuola Normale Superiore

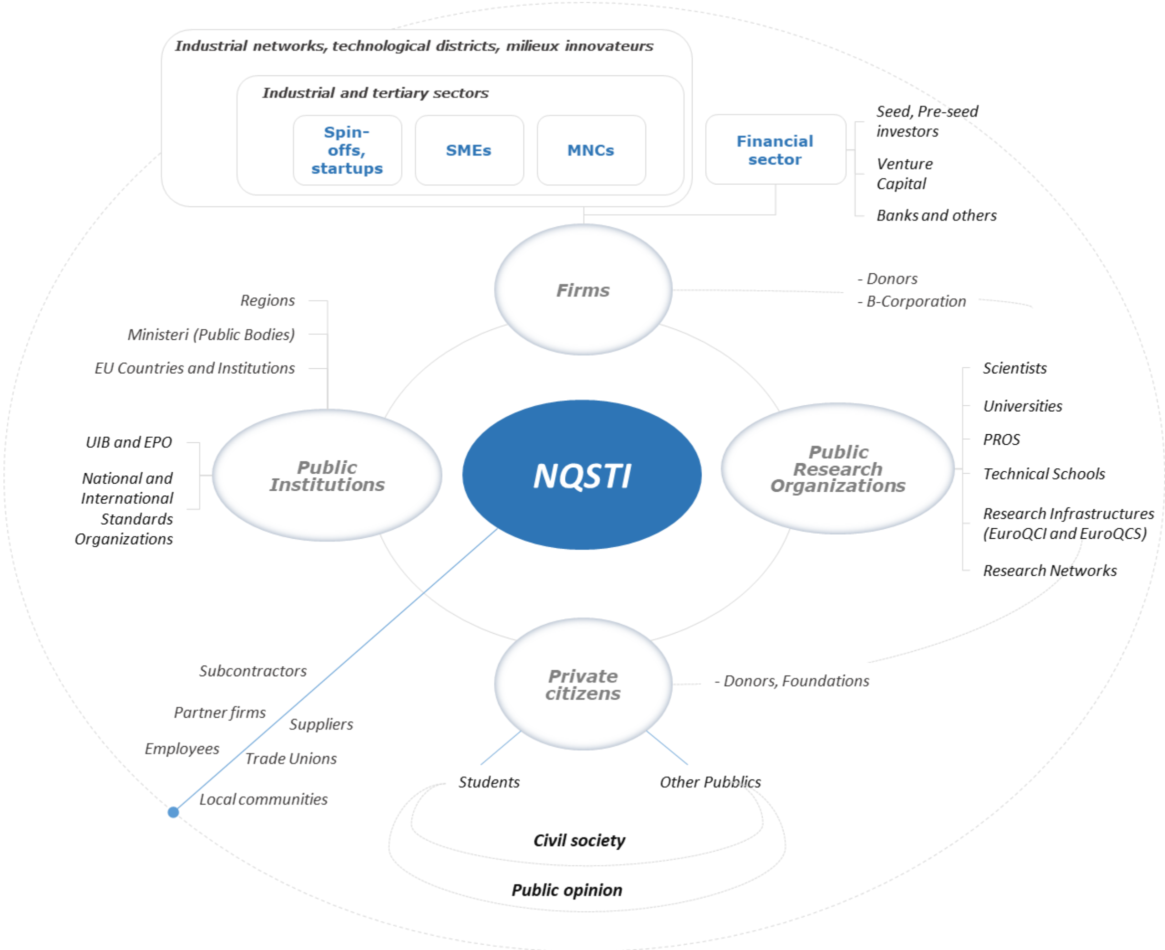
"The ***National Quantum Science and Technology Institute*** **(*NQSTI*)** represents a strategic national initiative aimed at consolidating and advancing Italy's capabilities in quantum technologies. Through coordinated action and the support of **PNRR** funding, *NQSTI* has **modernized research infrastructures**, fostered collaboration among universities, research centers, and industry, **and trained a new generation of scientists**. Its **open and integrated model** has successfully unified national competences, enhanced technological platforms, and stimulated innovation and technology transfer. The recent establishment of **Quantum Technology Fabs** is particularly relevant since it ensures long-term sustainability by providing **shared facilities for the design, prototyping, and certification of quantum devices and systems**.
This document reflects ***NQSTI*'s strategic vision and outlines the national landscape of quantum technologies**, highlighting their essential role in strengthening Italy's scientific excellence, industrial competitiveness, and contribution to a vibrant quantum ecosystem".

The knowledge transfer system for QST

NQSTI is designed to effectively coordinate the efforts to bring science and development within all main stakeholders, *in primis* Research Organizations, Universities, and Industry, reconciling the different purposes and time horizons (*figure 2*). This coordination will make it possible to overcome the current structural weakness that limits the ability to transform Italian *blue-sky* research into innovation. The aim is to create products and services with high added value, generating great opportunities for the social and economic well-being of the community (health, safety, energy, environment). It is equally necessary to combine the effort in research and innovation with a suitable upgrade of the education and training system. The goal to be achieved is the creation of a **learning ecosystem** capable of transferring the basic concepts of quantum science at all levels, from school to professional environments. It is necessary that the key concepts of quantum mechanics become an integral part of the training curriculum for all innovation actors, starting with engineers and computer scientists, as well as, naturally, chemists and physicists. This not only serves to train workers ready for the quantum revolution but also to create an advanced, informed society with open knowledge and attitudes towards quantum technology.

The long-term vision of *NQSTI* is the establishment of a national institute capable of structuring human resources, technical infrastructures, public and private investments to promote scientific research, technological development, and, in the medium term, industrial adoption of QST. In other words, a new ecosystem of innovation in which today's ability to study and manipulate single quantum objects (atoms, photons, molecules, nano-devices) results in tomorrow's industrial applications (see *box 1*).

Figure 2. The NQSTI Stakeholders



Box 1. The National Research Plan for QST

The *National Research Plan 2021-2027* (*MUR*, 2020) sets a series of overarching objectives. Within the scope of the Extended Partnership and taking into account the other efforts financed within *M4C2* and by EC, the successful completion of our program will realize those objectives:

- Make Italy a key player of QST, both as a supplier of qualifying technologies, as a developer of integrated platforms and algorithms, and as an industrial end-user.
- Make Italy technologically independent by creating vertical production chains of quantum devices.
- Demonstrate the possibilities of QST for the increase in the efficiency of devices and systems and for improving the sustainability of industrial processes and the energy efficiency of consumer products.
- Set up at the national level a ***QT supply chain*** for:

i) integrated electro-optical, photonic and scalable hybrids;

ii) devices based on semiconductors, superconductors, molecular nanomagnets, photonic, atomic and hybrid systems;

iii) miniaturized quantum sensors based on neutral atoms, superconductors and opto-electro-mechanical devices;

iv) quantum imaging devices;

v) quantum interfaces capable of combining different platforms;

vi) test, validation and certification of QST systems.

All this is obtained by completing existing infrastructures, complementary in different areas (superconductivity, cryogenics, etc.).

- Create a *National Institute for Quantum Technologies* that allows to preserve and enhance the great national human capital and the key technologies for industrial development. *NQSTI* will have a federative role in the national community, and provide coordination and support between research and industrial development as well as between the different QST, within a network, and in synergy with the European strategy.
- Create new interdisciplinary paths of Higher Education (master's degree and doctorate) in this advanced and rapidly evolving scientific sector to prepare highly specialized staff and in possession of transversal skills involving industrial realities in training and academic research.

SPOKE 8 “Technology Transfer”

Among the various mechanisms to encourage the transfer of academic knowledge, the commercialization of research results (IPRs, licensing, spinoffs) is the tool that has generated the greatest number of insights in the last thirty years, both within the scientific literature and within institutional reports (*OECD* 2011, 2013, 2019). Although patenting and licensing activities represent effective ways to contribute to the development of the economy and society, several other ways exist through which scientific knowledge flows between public research bodies and non-academic organizations (see *box 2*).

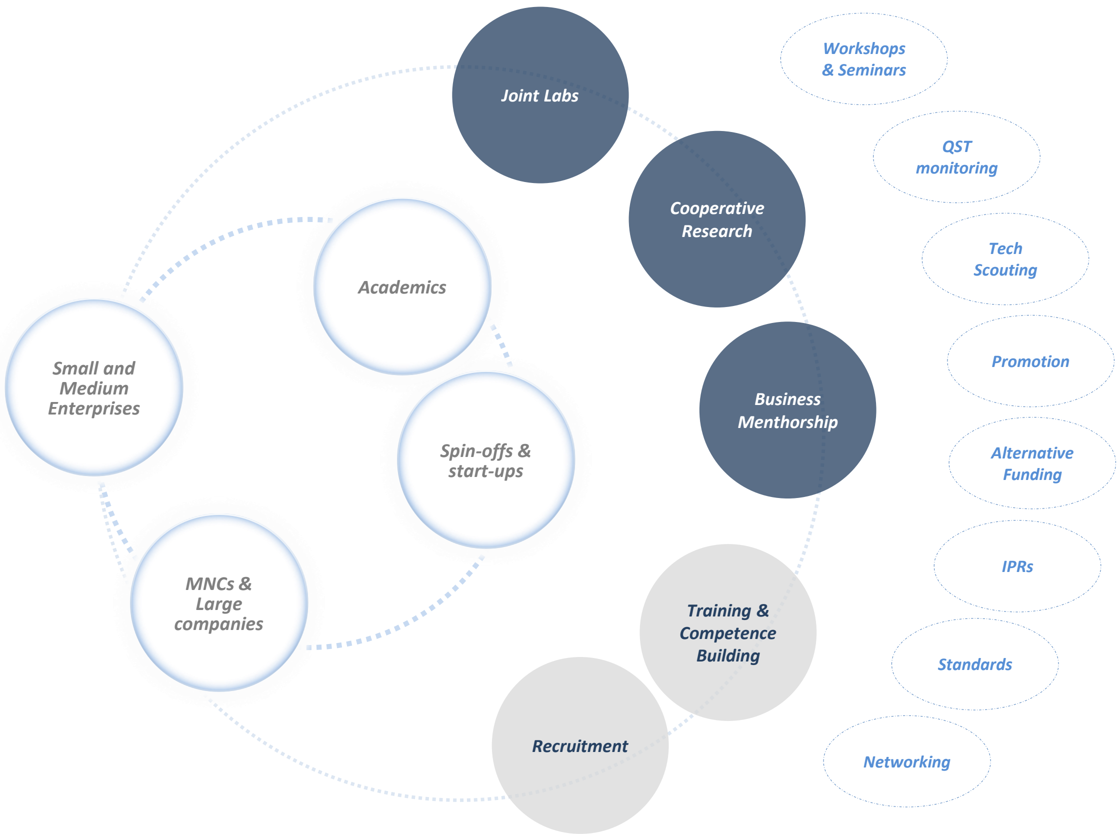
Box 2. The Knowledge transfer (KT) for the EU

Knowledge transfer (KT) is a concept used broadly to describe the **flow of (scientific) knowledge between research organizations (including universities and PROs) and business**, with the objective of creating socio-economic impact through promoting better use of the (public) research base. This concept replaced the formerly used “Technology Transfer” (TT) to reflect the wider knowledge base than just technology being transferred. Nowadays, the term “knowledge exchange” is used instead to reflect the fact that **the**

flow of knowledge is neither one-dimensional in the direction "research organization to industry', nor only between the players on this scale (multidimensional), *European Commission* (2014).
The *European Commission* (2020) underlines how Knowledge Transfer **is a complex process that involves many non-scientific and non-technological factors**, as well as many different stakeholders. Good or high-quality research results are not enough for successful technology transfer; **general awareness and willingness,** both at the level of organizations and individuals, as well as skills and capacity related to specific aspects, such as access to risk finance and intellectual property (IP) management, are also necessary components.

NQSTI intends to push for the adoption of the most diverse mechanisms of knowledge transfer, both formal and informal, with an interdisciplinary and holistic approach: cooperative research, joint laboratories, personnel exchanges, participation and organization of roadshows and fairs (see *figure 3*). The several channels of technology transfer, in fact, play a different role according to the specific context in which they develop and according to the objectives declared by the organizations participating in the process (see *box 3*). Furthermore, informal mechanisms are often important catalysts for more formal instruments of exchange (Debackere and Veugelers, 2005). [1]

Figure 3. The NQSTI "Knowledge Transfer" activities



[1] For more Information on NQSTI Spoke 8 "Technology Transfer" activities: https://nqsti.it/technology-transfer

Gaia Raffaella Greco, PhD

Spoke 8 "Technology Transfer" Coordinator

Researcher

Istituto di Calcolo e Reti ad Alte Prestazioni del Consiglio Nazionale delle Ricerche

"As actors in the *National Quantum Science and Technology Institute*'s technology transfer activities, we first have to **analyze and understand the national QST system**. Knowledge on the international and Italian industrial quantum structure is scarce and scattered across multiple sources (academic literature, consulting and institutional reports*, EU-Cordis* repositories, IPRs, and VC's datasets).
Incomplete Information could lead to incorrect or worthless decisions at the national level and in companies' long-term choices. **Strategic monitoring is** always **ongoing**".

Box 3. The main goals of NQSTI Knowledge Transfer

Main Goals of *NQSTI* "Knowledge Transfer" are:

- *to translate* ***basic research*** *into* ***applied knowledge****;*
- *to know and to* ***collaborate*** *with* ***science-based companies****;*
- *to* ***develop*** *"****academic engagement****" in knowledge transfer;*
- *to boost the* ***"absorptive capacity" of companies****;*
- *to* ***create trust*** *and promote* ***team spirit*** *within the NQSTI network;*
- *to* ***reduce*** *socio-cultural, organizational and technical* ***barriers*** *between academia and companies;*
- *to take advantage of all* ***formal*** *and* ***informal*** *collaboration tools;*
- *to encourage the creation of* ***new companies*** *in the sector;*
- *to train a* ***new class of scientists and entrepreneurs*** *in the sector;*
- *to* ***attract investments*** *and talents, also through internalization processes;*
- *to* ***inform*** *main stakeholders about Quantum Technologies, scientific developments, initiatives, and use cases implemented at the national and international level;*
- *to obtain the maximum* ***economic and social benefit to society*** *from research activities on the technological frontier.*

SPOKE 9 "Education and Outreach"

Carrying out the ambitious and highly innovative program of *NQSTI* requires highly qualified and specialized personnel who are able to operate within scientific and industrial organizations both at the national and international level in an extremely advanced and rapidly evolving scientific sector. From the point of view of human resources training, these characteristics pose non-trivial challenges, also considering that interdisciplinary skills are required, transversal with respect to the usual disciplines into which the university system is divided.
These needs originate from the academic/research world and are driven more and more from the industrial demand, where the interest in QT has rapidly increased in the last decade, initially stimulated by large multinational companies, and progressively also from small/medium enterprises and spinoffs, focused on specific devices and/or applications.

The level of Italian university education is generally very high and internationally appreciated. In the QT sector, at the time of the writing of the proposal, a few specific degree courses dedicated to QT were present, coming mostly from physical science. Recognizing the relevance of human resources training from the perspective of a longer-term horizon of the *PNRR* duration, *NQSTI* has decided to invest in the development of quantum-technology-oriented education and training via the activities and resources of *Spoke 9*. In this effort, special care has been devoted to guaranteeing wide access to the QST field, taking into account factors such as gender equality and diversity.
The activities carried out by *Spoke 9* encompass all the levels from high school to higher education, but it also includes the essential training at the professional level both of high-school teachers and of industry employees, which is required to increase the amount of highly qualified personnel towards quantum technology (see *box 4*).

Elisabetta Paladino, PhD
Spoke 9 "Education and Outreach" Coordinator
Full Professor of Theoretical physics of matter, models, mathematical methods and applications
Università degli Studi di Catania

"An extremely **advanced and rapidly evolving scientific sector** poses non-trivial challenges. We need an **interdisciplinary training system** that goes beyond actual academic departments. The industrial ecosystem, as well as the ambitious and highly innovative program of *NQSTI*, requires **highly qualified and specialized personnel**".

The effectiveness of these actions is tightly connected to the general awareness of the extraordinary revolution that QTs are bringing closer and closer to everyday life, as witnessed by the decision of the *United Nations General Assembly* to declare 2025 the *International Year of Quantum Science and Technology*. Because of the broadness of the research, knowledge transfer, education and outreach activities carried out at the national level and within international collaborations, *NQSTI* is one of the *Distinguished Partners* of the *IYQ*[2].
Another aim of *Spoke 9* is to raise awareness on QST of civil society, particularly with companies and professional organizations that do not yet know the potential of quantum technology but might become relevant stakeholders in the future. A vast number of outreach initiatives at all levels have been undertaken and are in progress in the course of 2025[3].
To implement this work program *NQSTI* has exploited the expertise on education and outreach of the consortium partners, firmly based on the output of the *Quantum Flagship Initiative* under the *QTEdu Coordination and Support Action* and on the

[2] More Information is on: *https://quantum2025.org/*.
[3] Detailed Information is on: https://nqsti.it/index.php/activities/outreach.

recommendation of the Italian *Programma Nazionale per la Ricerca 2021-2027* (*MUR, 2020*).

Box 4. The main goals of NQSTI Education and Outreach

Main goals of *NQSTI* "Education and Outreach" are:

- ***Identification of QST educational strategies*** *and available infrastructures and services;*
- *Establishment of* ***training courses for high school teachers*** *on QST topics;*
- *Establishment of* ***scholarships for specialized QST-training in industry*** *or joining academia/industry labs;*
- *Activation of* ***specialization internships*** *within existing Masters;*
- ***Activation*** *of new I and II level* ***Masters*** *in dedicated academic/****industrial laboratories****;*
- *Organization of* ***outreach events for civil society*** *and of info days dedicated to industries.*

The *NQSTI* Report: purpose and objectives

NQSTI objective for all the academic institutions involved is to strengthen cooperation with the private sector in two complementary directions: inducing the research community to respond to the needs of industry and encouraging the latter to contribute to a re-launch of the technologies available to QST researchers.
Within the process of research valorization, one of the actions envisaged was the drawing up of a dataset of possible users of the knowledge produced inside the academic institutions. Furthermore, *NQSTI* aims at informing the academic, the industrial and the institutional stakeholders on major technical advances, state of development, use cases implemented, real-market applications, and standards definition at national and international levels.

The Italian industrial sector analysis was driven by the need to understand the main dimensions of the *Quantum Science and Technology National System*, to comprehend the principal variables of the internal market (geography, size, collaborations, and industries involved), and to fully channel fundamental Technology Transfer, Education, and Communication initiatives (see *figure 4*).

Figure 4. The first NQSTI TTOs' evidence

"The priority is to understand the context in which we are moving"

Needs

- ***Need of national coordination*** *- For Knowledge Transfer Activities in the Quantum Science and Technology field of research (benchmark to which to refer)*
- ***What do industrial partners do in this field?*** *- Who are true industrial partners? What research do they conduct? What do they need? How to build long-term relationships with them? What are their education needs?*
- ***Need to create a relationships and knowledge network***
- ***Need of professional figures as bridges between scientific and industrial research activities***

Actions

- ***Scientific outreach and sensibilization activities***
- ***Proof of concept (POC) to advance TRLs (Technology readiness Levels); challenges to sustain Research 2 Business***
- ***Incubation and consulting services to RTDA and PhDs to form new entrepreneurial science-based firms***
- ***Companies dataset in Quantum Science and Technology Industries (data collection and analysis)***
- ***Coordination activities with the other Spokes (Methods and timing); internal Communication Strategy***
- ***Technology Transfer seminars and education program***
- ***Events participation definition (Communication Strategy)***

It emerged early in the first meetings among the *NQSTI* partners that there was a need for a clear understanding of the national Quantum technological context, analyzing the essential characteristics, the value chain, the collaboration capacity, the research cooperation culture, and the propensity of the firms in Italy. Specific questions remain:

- *How many firms in Italy work on QST research projects?*
- *Where are they?*
- *What are the main characteristics?*

- *Who is collaborating with whom?*
- *What are the main topics of investigation?*
- *In which industries do they operate?*
- *How do they build their cooperative networks?*

Science-based firms are defined as organizations where the main source of technology lies in the R&D activities of the companies themselves (Niosi, 2000). The knowledge resulting from research, pure and applied, which is carried out in universities and other public research centers flows, thanks to the collaborative activities carried out to companies. However, only a knowledge base created thanks to internal R&D activities allows the company to benefit from the research that is carried out in other organizations (Cohen and Levinthal, 1989).

The backbone of Italian enterprises is represented by SMEs that in many cases do not have the resources and expertise to take advantage of the Quantum Revolution that is going to be pervasive and will influence several economic sectors. Is this vision fully authentic?

Through the construction of an *original dataset of firms*, the *NQSTI* Report intends to represent a first picture of the Italian QST Knowledge system, shedding light on the leading actors, analyzing primary industrial sectors and applications, investigating the geographical distribution of companies and spinoffs, questioning the strategic missions, and reflecting on emerging trends.
The scope of the document is to describe the current efforts towards the implementation and deployment of quantum technology (QT) in Italy, through the presentation of the main global dynamics and politics. Notably, the report includes four separate Chapters.

The *First Chapter* presents an investigation of the *institutional and consulting literature on quantum technology and markets*, analyzing industrial segments (quantum communication, quantum computing and simulation, and quantum sensing), public and venture capital financing, outlooks, and trends on a global scale. The aim of the Chapter is to represent international dimensions broadly by comparing the most relevant references and offering insights for further in-depth analysis.

The *Second Chapter* introduces European policies related to Quantum Science and Technology, explicitly describing the *Quantum Flagship* initiative and the *Quantum Europe Strategy*. The scope of the Chapter is not to analyze single European national policies, but to contextualize the Italian national system of innovation inside the European general framework.

The *Third Chapter* analyzes the QST system by investigating the original *NQSTI* dataset. It presents a *comprehensive overview of Italian companies entering the quantum* *industrial sectors*. Several key highlights emerged, including the geographical distribution of these companies, the industries to which they belong, and the markets they serve. One particular section focuses on the role of Italian startups, emphasizing their growing importance in this field (a list of these startups is provided in the text).

Finally, the Fourth Chapter aims to represent and analyze each Quantum "vertical" (computing, communication, simulation, and sensing), further highlighting synergies and interdependencies among them, and evidencing the relevant role played by supporting firms and other industries. Along with the analysis of the quantum sectors of application, a *particular focus will be on Italian research and industrial excellence, analyzing specific business case studies*.

Direct interviews were conducted to give voice to the protagonists who live in the Quantum industrial and scientific systems. Indeed, a specific set of questions has been asked to: ***academics*** with specific Technology Transfer backgrounds (*Chapter One*), ***venture capitalists*** operating in Italy (*Chapter Three*), and ***CEOs and research managers*** of QST firms (in *all Chapters*).
Relevant questions pertain to actual and future QST industrial applications, supply chain challenges, the current state of final markets, hypothesized outlooks, and underlying significant difficulties faced in strengthening coordination and excellence.
The report aims to provide an initial representation of the state of the art in national industrial sectors, offering a valid tool for discussion among all stakeholders of the Quantum Science and Technology system to support the development of an Italian research infrastructure and future strategic programs.

CHAPTER 1. THE QUANTUM TECHNOLOGY: OVERVIEW AND TRENDS

1.1 The Quantum Revolution: the main pillars' definitions[4]

Quantum Science and Technology (QST) is based on the consequences of the most profound and revolutionary properties of Quantum Mechanics. QST is a highly innovative R&D sector with a high impact potential. Future development of these technologies promises to establish a new revolution in different fields. This approach has its foundations in the capability to manage and fully exploit the potential of quantum phenomena (superposition principle, entanglement, etc.), in which particles can assume different states at the same time or the same state in different places. Compared to other more traditional technologies, QST has the unique ability to enable solutions to problems today typically cataloged as impossible, irresolvable, or very expensive from an energy point of view, or to reach measurement sensitivity beyond what is achievable with traditional techniques.

The transformation envisaged is disruptive, considering the ability of QST to have a direct and far-reaching impact on all fields of science, from information technology to biology, from telecommunications to engineering, medicine, and the environment. All this is expected to lead to an exponential growth in simulation power, to communicate information in a totally secure way and, again, to create devices capable of carrying out measurements with yet unattainable precision. These solutions are made possible by exploiting specifically designed platforms that use novel systems based on atoms, molecules, photons, and innovative solid-state materials.

The advent of quantum technology promises to transform our world by harnessing the enigmatic laws of physics at the atomic and sub-atomic scales to advance domains such as computing, communications, sensing, and imaging. Many of the extreme requirements of quantum technology are shared with high-energy physics, including ultra-high vacuums, precise timing, the need for superconducting materials, and more (CERN, 2022).

According to *McKinsey* (2023; 2024; 2025), quantum technology has three subfields: computing, communications, and sensing. On the other hand, the *European Quantum Flagship* (2022) refers to four areas of research and innovation that represent the sector's primary application areas: communication, computing, simulation, and sensing and metrology.[5]

In *McKinsey*'s report (2023), metrology is included in the sensing pillar, but it is not explicitly defined. In addition, quantum simulation is considered as a specific field in

[4] Paragraph 1.1, "The Quantum Revolution: the main Pillars' definitions", was written by Gaia Raffaella Greco and Raffaele Cecere.

[5] *Roland Berger* (2024), as it will be better described later in the text, divides the quantum market into four segments: quantum computers, quantum sensing, quantum communication & cryptography, and supporting technologies (ST).

which quantum technology offers an advantage. In *table 1,* we explain the definitions of the main pillars.

Table 1. The main Pillar definitions

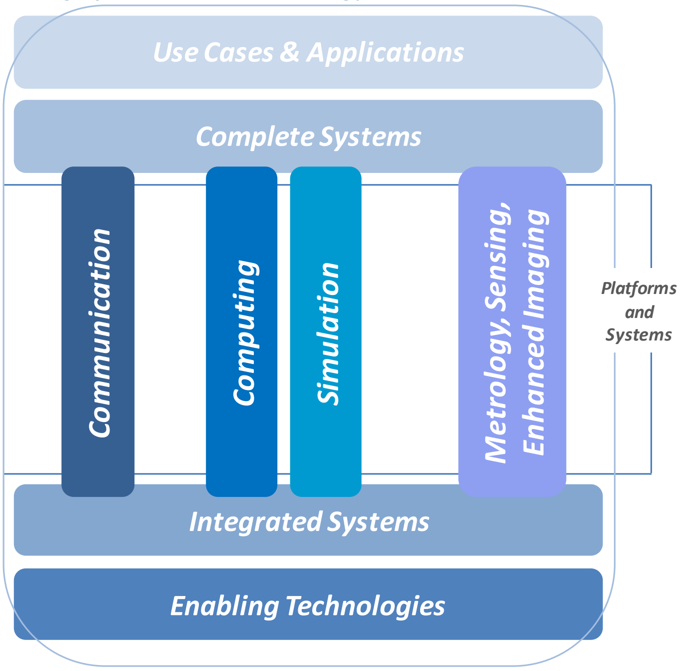
	McKinsey (2023)	QuIC (2022)	CEN-CENELEC (2023a)
Computing	Quantum computing is a new technology for computation, which leverages the laws of quantum mechanics to provide exponential performance improvement for some applications and to potentially enable completely new territories of computing. Some of the early quantum hardware products are special-purpose quantum computers, also called quantum simulators.	Quantum computing is a computational paradigm that exploits quantum effects such as superposition, interference, and entanglement to solve problems by applying a quantum algorithm. There are different variants of this paradigm. The most common is digital gate-based quantum computing, in which quantum algorithms are represented as quantum circuits–i.e., a sequence of quantum gates applied to qubits.	Quantum computing is related to several applications. Software applications depend on different types of hardware: Cryogenic solid state based, Room temperature solid state based, Trapped ions, Neutral a toms, Photonic quantum, computing.
Communication	Quantum Communication is the secure transfer of quantum information across space. It could ensure security of communications, enabled by quantum cryptography, even in the face of unlimited (quantum) computing power.	The area of quantum communication aims at designing the tools and protocols to exchange quantum information among distant users.	Quantum communication enhances classical communication or enables new possibilities through the transmission/distribution of quantum states. To transmit quantum states, it is not only necessary to have the ability to create and manipulate quantum states, but also to provide quantum channels to distribute these states. Therefore, the distinguishing requirement of quantum communication from other quantum technology areas is the ability to create, maintain and use quantum channels. At the same time, all types of quantum communication require specific quantum information processing protocols.
Sensing and Metrology	Quantum sensing and metrology is the new generation of sensors built from quantum systems. It could provide measurements of various quantities (eg, gravity, time, electromagnetism) that are orders of magnitude more sensitive than classical sensors.	Quantum sensing and quantum metrology are based on exploiting the quantum properties of nature, quantum phenomena, quantum states, their universality and intrinsic reproducibility, the quantisation of associated physical quantities, or their high sensitivity to environmental changes.	Quantum metrology and quantum sensing are fields that leverage quantum properties and phenomena to enhance the precision and accuracy of measurements in diverse physical systems, including condensed matter, single photons, NV centers, cold atoms, ions, and single electrons. These quantum-enhanced devices are designed to overcome limitations associated with conventional classical measurement strategies, such as noise from vacuum fluctuations and position measurement limitations. By leveraging entanglement and nonclassical correlations, QMSI devices enable more precise and reliable parameter evaluation across a wide range of systems. The applications of QMSI devices are diverse and span a range of industries, including physics, chemistry, biology, medicine, materials science, information technology, computation, and quantum communication. From fundamental research to practical applications, QMSI plays a crucial role in advancing measurement capabilities and has the potential to revolutionize various scientific and technological fields.

Simulation	Compared to classical computations, QC is expected to enable precise simulation of molecules (eg, electronic structure or molecular dynamics).	Quantum simulators are highly controllable quantum devices that allow you to obtain information about the properties of complex quantum systems or solve specific computational problems that are inaccessible to classical computers. These are expected to find applications in diverse fields such as quantum chemistry, nuclear physics, materials science, fluid mechanics, logistics, routing, and, more generally, optimization.	The simulation includes many different technology platforms that are also used for sensing, timing, and metrology. Consequently, it is anticipated that there will be a great deal of synergy between standardization activities in many cases. For instance, quantum computing based on ion traps is a nascent field, yet ion traps have been utilized for timing applications for quite some time. The technology is more developed and perhaps primed for initial standardization activities to commence than initially anticipated.

Source: McKinsey, 2023; QuIC, 2022; CEN-CENELEC, 2023a.

These pillars shape an imaginary 'Greek Temple' of Quantum Technology (*figure 5*), based on enabling technologies and a quantum subsystem. The pillars support complete systems and the development of case studies and real-world solutions (*CEN-CENELEC*, 2023a).

Figure 5. The Structuring of Quantum Technology



Source: Adaptation on van Deventer et al., 2022.

These application domains are based on a common foundation of fundamental science, with prominent research institutes and companies assisting their objectives by providing novel concepts, instruments, techniques, and procedures. In particular, these are supported by cross-cutting areas covering engineering and control, software and theory, education and training, and general innovation and international cooperation activities.

The pillars only represent a shortcut to facilitate the knowledge of the fields of study and applications of quantum technology, as they often communicate with each other in their development and diffusion (see *box 5: Structuring Quantum Technology*).

Box 5: The structuring of Quantum Technology

Quantum Technologies are commonly structured in domains. The *European Quantum Flagship roadmap*, for instance, features four domains or 'pillars' covering the whole range of QT (…). This classification brings the disadvantage that there are strong commonalities between those pillars, as for example some enabling quantum technologies that are equally applicable to all domains (…). A common way to categorize the range of QT is to think in terms of pillars, namely quantum communication, quantum computing & simulation and quantum metrology, sensing & enhanced imaging. This is, however, an oversimplification due to many matrix-like connections (…). Indeed, this is common for all QT underlying hardware or "enabling technology" that facilitates the design and prospective manufacturing in the QT pillars/domains. Accordingly, the tools, as for instance software, used for controlling quantum states are typically universal. Combining elements from enabling technologies and tools facilitates the assembly of subsystems, which can be combined to create QT platforms, systems and higher-level composite systems or infrastructures. These various technological levels then give rise to societally relevant applications to be grouped in general use cases.
We propose to consider these horizontal layers common to several or all fields of QT, representing different levels of technological complexity and proximity to applications and use cases, jointly with the traditional pillars. Naturally, the latter are still highly relevant, but their connections to each individual horizontal layer, representing a "matrix structure", need to be included.
Source: extract from van Deventer et al., 2022

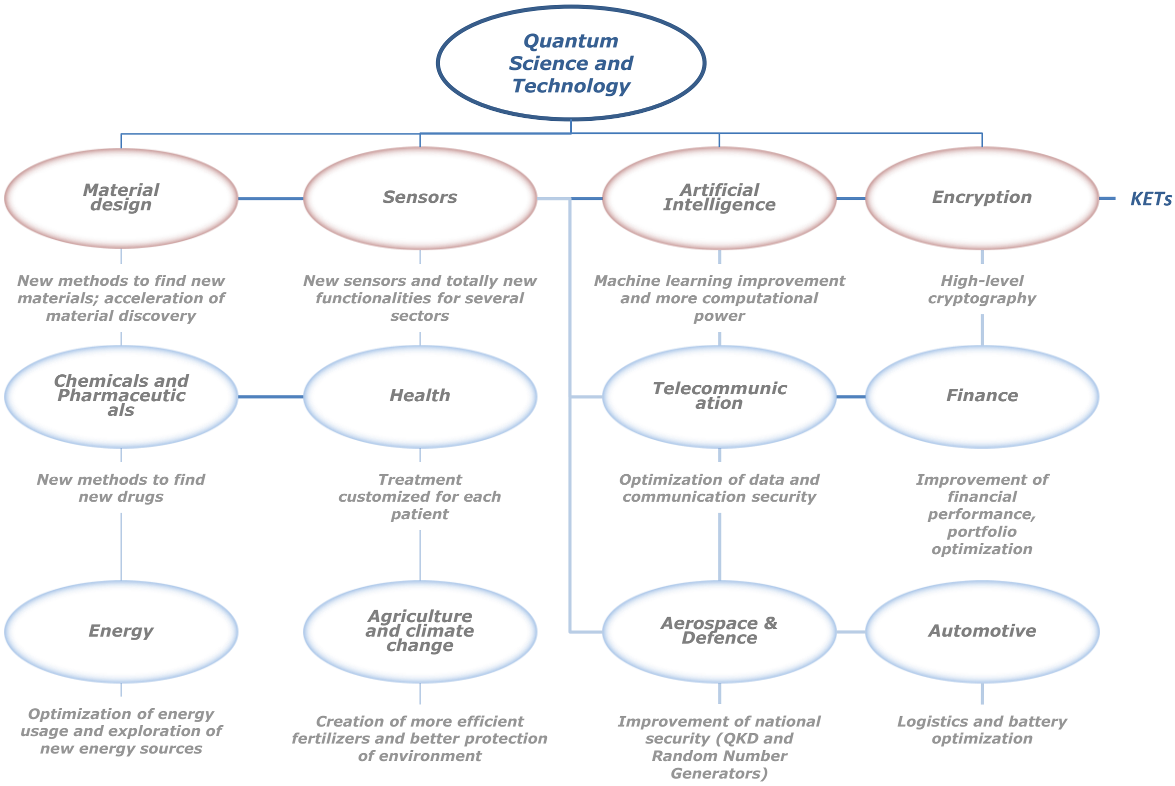
The *Quantum Flagship Initiative* in the "Strategic Research and Industry Agenda" (2022) develops specific recommendations to facilitate the development of quantum technologies based on the connection between the pillars and the choice of innovative open-type systems.
In particular, it emerges from the report the need to:

- Consolidate both quantum communication and quantum computing activities in order to increase the capabilities of both pillars synergistically;
- Establish close links between quantum simulation and quantum computing, as well as quantum metrology and sensing, in particular through industry-targeted roadmaps;
- Promote the demonstration of use cases relevant to end users by demonstrating them;
- Enhance cost-effective prototype development by extending Europractice solutions to commercial partners in the context of accepted research;
- Establish precise needs and expectations from industrial partners;
- Increase the general awareness of quantum simulation in European industry;
- Support the advancement of open standards to enhance the connectivity of projects and facilitate technology transfer;
- Support the *strategic enabling technologies*, such as cryogenics, microwaves, lasers, and classic superconducting circuits, which are crucial for computing and communication.

As underlined, the various pillars are strongly interconnected, and concepts, tools, and technologies developed within one pillar may find applications in other pillars. For

instance, the advancement of quantum communications can aid in developing quantum sensor networks or protocols for distributed quantum computing. Similarly, techniques for efficient quantum information processing could be used in the construction of quantum repeaters for long-distance quantum communication.
Quantum effects and established concepts from quantum science has become new technological applications and have helped develop new products and services. Stronger relationships with the industrial partner, while boosting scientific excellence, could facilitate the way towards market applications, helping to find new, productive, and commercial solutions. Several developed scientific and technological concepts are yet ready to enter the industrial value chain, offering relevant chances to develop new business organizations and new professional figures (*Quantera*, 2022).
As underlined earlier in the text, the Quantum Revolution could impact almost all the scientific fields and, in the long run, several technological areas and industries. Many diverse consulting and government reports underline uses or emphasize specific industrial sectors. When discussing *Key Enabling Technologies* (KET) it is not easy to synthesize all the areas of QST interests. The following figure represents the main ones, highlighting the reasons for the emergence of radical innovations.

Figure 6. The primary applications of quantum technology



As *Chapter 4* will better evidence, every QST vertical has a specific level of maturity and the several technologies that give shape to the pillars go through their own phase of development. Strategically, for the companies, the entrance moment in the technological arena could vary, depending on the industry to which the organizations belong (see *Chapter 4*).

A Puglia *Regional Agency for Technology and Innovation* (ARTI) study analyzes the leading companies involved in QST and how the technologies are applied. Notably, an overview of the applications shows that:

- **Quantum imaging** systems are applied in industrial inspection and diagnostics, while quantum magnetic sensors are useful in environmental monitoring and Earth observation;
- **Hybrid classical-quantum computing** systems can accelerate algorithms for simulations of complex systems and artificial intelligence, with cross-sector applications (machine learning, predictive maintenance, autonomous driving);
- **Communication** security can benefit from quantum cryptography and, in the future, quantum internet, which will affect various industrial sectors.

If predictions are fulfilled, advanced countries will split between those with direct access to QST and those without, with serious problems for strategic infrastructures and national security. It is now widely understood how the control of technologies based on substantial scientific advances and incorporating innovations can determine, soon, the prosperity of countries or entire regions of the planet. A high level of expertise in these technologies will become the fundamental element for economic development and our societies' digital self-determination in the next decade.

The development of QST will inherently involve those realities capable of bringing these technologies to an industrial level (micro- and nano-electronics, photonics, software, etc.) and those able to enhance and to exploit them. This overall coordinated effort will be necessary to maximize the benefit of this radically new technology. Moreover, such activities through QST would acquire a notable advantage of competitiveness in highly technological fields such as the pharmaceutical, chemical, aeronautical industries, and unbridgeable in others, such as research and applications on new materials, cyber-security and energy resources (see *table 2*).

Table 2. The Quantum Technology and its impact on the main industrial sectors

Quantum Sensing	The detection of magnetic anomalies applies to advanced mechanics (diagnostic systems), aerospace (Earth observation), the health industry (medical imaging and diagnostics), and energy and environmental systems (monitoring). The application of high-resolution quantum imaging technologies may be of interest in industrial inspection (advanced mechanics, automotive, and aerospace), medical imaging, and 3D microscopy (health industry). Lidar/radar applications and gravitational field detection are readily applicable in Earth observation and navigation (Aerospace) and environmental monitoring (energy and environmental systems).
Quantum Computing	High-performance computing applications primarily target sectors such as aerospace (fluid dynamics and material analysis) and advanced services (cloud computing, big data, and quantum algorithms). Moreover, logistics planning for advanced services is an application area for solving complex optimization problems. Simulation using quantum computers finds suitable applications in advanced mechanics, electronics, automation, automotive, aerospace, and energy and environmental systems. Finally, advanced applications of artificial intelligence linked

<table>
<tr><td></td><td colspan="3">to quantum technologies are applied across various sectors through machine learning, predictive maintenance, autonomous driving, and data analysis.</td></tr>
<tr><td>Quantum Communication</td><td colspan="3">Cybersecurity has broad applications across various sectors (Automotive, Aerospace, Health Industry, Advanced Services, and Energy and Environmental Systems). In contrast, quantum internet offers advanced connectivity in various fields where its competitive advantage is required.</td></tr>
<tr><td>Aerospace
Regarding the aerospace sector, the main companies involved are Airbus, Boeing, NASA, U.S. Air Force, Raytheon, and Lockheed Martin, with the following areas of application:
- High-sensitivity sensors and precise timing
- LIDAR (Laser Imaging Detection and Ranging)
- Neuromorphic computing
- Secure communications
- Advanced fluid dynamics
- Finite element simulations
- Aerodynamics and flight mechanics
- Free satellite Navigation</td><td>Automotive
Rolls-Royce, Volkswagen, and Andretti Autosport are the main companies involved, and the key areas of application are:
- Computational fluid dynamics
- Image recognition
- Workflow scheduling
- Real-time race analysis
- Performance optimization
- Machine learning + Quantum
- Issues with painting multiple cars
- Battery materials</td><td>Chemical/Pharmaceutical
For the chemical/pharmaceutical sector, the main companies involved are Janssen, BP, Merck, and Abbvie. The areas where quantum technologies are most engaged in problem-solving include:
- Quantum chemistry
- Molecular modeling
- Quantum-inspired research
- Drug discovery
- Accelerating research on targets and drugs
- Peptide engineering</td><td>Finance
Finally, the leading companies in the financial sector utilizing quantum technologies are Wells Fargo, MasterCard, and Bank of America to address issues related to:
- Ultra-fast trading platforms
- Fraud detection
- Portfolio optimization
- Data security
- Communication security
- Multi-currency payment optimization</td></tr>
<tr><td colspan="4">ARTI. (2024). Technology Focus Report. Retrieved from: https://www.arti.puglia.it/wp-content/uploads/ARTI_TFR-Tecnologie-Quantistiche.pdf. Consulted in October 2024.</td></tr>
</table>

The development of theoretical quantum research to initial practical application requires the intervention of governments, who assume an increasingly critical role in quantum technology, as well as national laboratories and quantum research facilities in Europe, North America, China, and other parts of the globe. Also of extreme importance are the new quantum research centers, which act as hubs for the growth of ecosystems in quantum technology, thanks to partnerships between public bodies, researchers, and industry.

Not being able to dispose of consistent technological capabilities in these sectors could lead, over time, to severe difficulties in terms of supply for the country's needs. In the long term, this will lead to a consequent dependence on other economies in some sectors, negatively impacting the stability of the productive system and commercial exchanges. As it will be better evidenced later in the text, all the major developed countries have implemented ambitious national programs that face the challenge of quantum technology in a global way, with investments estimated at several billion Euros per year on a global scale.

Vittorio Giovannetti, PhD

Professor of Theoretical Physics (Full professor)
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Planckian S.R.L.
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"The only way of discovering the limits of the possible is to venture a little way past them into the impossible. [A.C. Clark]"

Research field:
Quantum Communication, Sensing, and Computing.

Technological application(s):
Quantum Communication can potentially enable ultra-secure data transmission using quantum encryption, such as *Quantum Key Distribution* (QKD), which ensures that eavesdropping is detectable. Quantum Sensing could in principle improve measurement precision in fields like medical imaging, navigation, and geophysics by exploiting quantum states like entanglement and superposition for higher sensitivity. Quantum Internet promises to revolutionize global connectivity by enabling instant, secure communication across quantum networks, offering breakthroughs in data privacy and computational speed. Quantum algorithms, like quantum annealing, can optimize logistics, supply chains, and financial portfolios by solving large-scale, combinatorial problems faster than traditional methods.

Main area-sectors-markets interested:
Informatics, Communication technology.

Main Research Centers or firms-companies investing in the sector:
IBM, *Amazon*, and many others.

Main challenges to face in the future (mid to long-term):
Scalability remains a significant challenge, as *increasing the number of qubits while maintaining stability and coherence* is essential for the practical use of quantum computers and networks. Error Correction is difficult due to the fragility of quantum states, requiring complex error-correction codes and techniques to minimize decoherence and noise. *Integration with Classical Systems poses also a challenge*, as *developing hybrid systems* that can efficiently connect quantum technologies with existing classical infrastructure is crucial for widespread adoption.

Mikkel Ejrnaes, PhD

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"The Quantum Revolution has only scratched the surface"

Research field: Detection of quantum states of light
Because quantum measurements can strongly change a quantum state it is a fundamental tool for quantum science and technology. This is particularly true for detection of quantum states of light where the ability to detect a single photon and possibly directly the Fock state is highly desired.

Technological applications:
Detection of single photons is a cornerstone technology which enables many different quantum technologies in the fields of quantum communication, quantum sensing and quantum metrology.
Main area-sectors-markets interested:
In my opinion, *several sectors are interested in detection of quantum states of light*, e.g infrastructures (like quantum networks), high-end applications (like quantum sensing for medical exams) and cornerstone applications (like characterization of components for quantum technologies).
Main Research Centers or firms-companies investing in the sector:
On a global level, the main research centers investing in this field of research are *MIT* (US) and *SIMIT* (China).
Main challenges to face in the future (mid to long-term):
Improve performance and reduce technological barriers (ease of use, cost and encumbrance) of quantum detectors.

Annamaria Cucinotta, PhD

Electromagnetic Fields (Full professor)
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Università di Parma
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"The Quantum Revolution must enter in the Engineering Departments"

Research field:
Optical fibers, specialty optical fibers, hollow core fibers for the generation of entangled photons, active rare earth- doped optical fibers
Technological application(s):
Optical Communication, computing.
Main area-sectors-markets interested:
Photonics, quantum photonics
Main Research Centers or firms-companies investing in the sector:
University of Modena, "*HOCQUS - Hollow-core fibers for Optical Communication QUantum Sources*" PNRR - Missione 4 "Istruzione e Ricerca" - Componente 2 - Investimento 1.1 "Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)" – Bando PRIN 2022 - Settore ERC PE7, from 2023 to 2025
Main challenges to face in the future (mid to long-term):
To teach photonics quantum technologies to engineering students, to establish quantum industry in Italy, *to explore the application of photonic quantum technologies in different field*.

Lorenza Ferrario, PhD

Head of Facility
Micro and Nano Fabrication (MNF) facility
Sensors and Devices Centre
Fondazione Bruno Kessler
***E-mail:** ferrario@fbk.eu*

"Quantum Technologies: bridging technological gaps with quantum jumps!"

Research field: semiconductor technology for sensors fabrication

The development of innovative quantum devices requires up-to-date laboratories, where researchers can implement and validate research results. To this aim, QT projects are supported in *FBK* thanks to the *Micro and Nano Fabrication facility of FBK*, in particular the clean room laboratories and the relative processes dedicated to silicon technologies to produce radiation and light sensors, photonic integrated circuits and *MEMS*. Implementation of new technological platforms (*SiC* and other wide bandgap materials) and realization of the relative infrastructures (laboratories, equipment, personnel).

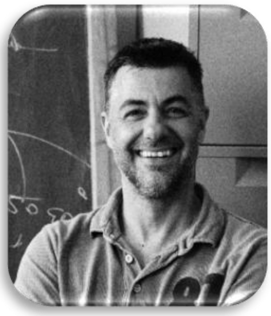
Main area-sectors-markets interested:

Quantum Communication, Quantum Computing, Quantum Sensing.

Main challenges to face in the future (mid to long-term):

Further *reduction of "critical dimension" capability* and *implementing hybrid integration solutions*, necessary for systems combining Si, SiC, III-V and other semiconductors.

Vanni Lughi, PhD



Materials Science and Technology (Associate Professor)
Dipartimento di Ingegneria e Architettura
Università degli Studi di Trieste
E-mail: vanni.lughi@dia.units.it

"Materials are at the cornerstone of the development of all game-changing technologies"

Research field (main): Nanotechnology and nanomaterials for sustainability and energy applications

We developed a toolbox for producing a variety of complex nanoparticles and use them as building blocks for creating new nanostructured materials with engineered functional properties.

Technological application:

While we focus mostly on materials for sustainability and energy, quantum nanostructures are at the cornerstone of the development of quantum computing.

Main area-sectors-markets interested:

Optoelectronic devices: LED, photovoltaic solar cells, displays. Nanocomposite functional and structural materials. Quantum computing.

Main Research Centers or firms-companies investing in the sector:

All major research centers and large companies of the sectors mentioned above, globally.

Main challenges to face in the future (mid to long-term):

Industrial scale-up of nanomaterials manufacturing. *Industrial scale-up of nanoparticle production*. *Toxicity assessment* of nanostructures and nano-based materials. *Green manufacturing* processes for nanostructures and nanomaterials. *Stability of new nanostructured materials*.

Roberto Gunnella, PhD

Experimental Physics of Matter and applications (Associate Professor)
School of Science and Technology- Physics Section
Università degli studi di Camerino
Email: roberto.gunnella@unicam.it

"There is still limited financing in research infrastructures and human resources education"

Research field:
Physics of fields and matters at the interfaces and at low dimensional materials. Electronic and structural properties by means of advanced scattering and spectroscopy. Scanning microscopy. Fabrication and characterization of devices.
Technological application(s):
Field effect, surface enhanced processes .
Main area-sectors-markets interested (who eventually):
Ultra-sensors technologies,
Quantum computing,
Energy storage and conversion industry.
Main Research Centers or firms-companies investing in the sector:
Public entities (large scale facilities, foundries). Small companies and spinoff's but with limited resources.
Main challenges to face in the future (mid to long-term):
Limited access to large scale foundries and facilities funded by public entities. *Limited investments from public and industry for research infrastructures* in the Universities for research and *human resources formation*.

Antonio Cassinese, PhD

Matter Physics (Full Professor)
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"Materials for quantum will drive us towards a true coming of age"

Research field:
Quantum sensing, Maser, High Q Microwave-Cavities.
Technological application(s):
Single Photon Counting, Maser, quantum detectors.
Main area-sectors-markets interested:
Metrology and Advanced Sensors.
Main Research Centers or firms-companies investing in the sector:
North-Western University (Australia), *Yale University* (US), *SeeQC*, *QuantWare*, *Photec*.
Main challenges to face in the future (mid to long-term):
The next challenge is to realize improved microwave quantum sensors for particle field applications.

Milena D'Angelo, PhD

Professor of Experimental Physics of Matter (Coordinator of the 2nd level Master in QS&T; Leader of the Quantum Optical Technologies 2.0 Lab)
Dipartimento Inter-ateneo di Fisica
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E-mail: milena.dangelo@uniba.it

"The Quantum Revolution is being extraordinarily powerful in combining passion for fundamental physics with enthusiasm for transforming scientific discoveries into technologies for society"

Research field:
Quantum imaging.
Technological application:
Fast and high resolution 3D and hyperspectral imaging devices for studying dynamic processes in real time.
Main area-sectors-markets interested:
Bio and biomed, space, security. Further potential markets: automotive, industrial inspection, environmental monitoring.
Main Research Centers or firms-companies investing in the sector:
Leonardo, Thales France, Thales Alenia Space Italia, INFN, INRIM, CNR, ENEA, ASI, many universities and research centers worldwide. A startup company is under constitution.
Main challenges to face in the future:
Starting a spinoff company, addressing the market needs, increasing the TRL of the diverse developed technologies (covered by 8 patents).

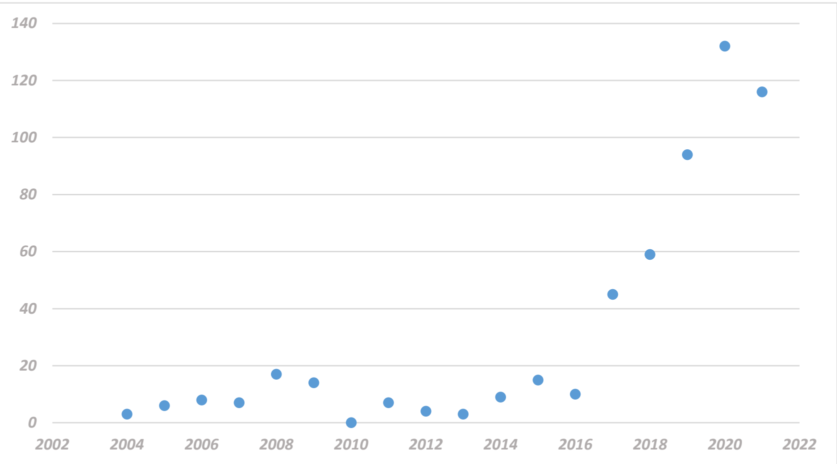
In *box 6*, three studies on Intellectual Property Rights at the European level are presented: two realized by the *European Patent Office* on Quantum Computing and Quantum Simulation, and a *QUIC* (European *Quantum Industry Consortium*) analysis on Quantum Technology in general. The studies would underline the still-limited role played by Europe in specific sectors.

Box 6. The Quantum World Patent Landscape

The ***European Patent Office*** (*EPO*) published two insight reports related to patent dynamics on Quantum Computing and Quantum Simulation in 2023 (*EPO*, 2023a; 2023b). The primary evidence that emerged from the analyses is:

- the number of inventions in the field of second-generation Quantum Computing and Simulation has multiplied over the last decade;
- the trends both show a higher growth rate than the other technological fields in general;
- the trends testify to high economic expectations for the technologies in question and multinational commercialization strategy;
- the most active applicants are companies, mainly located in United States, followed by Canada, Europe, China, and Japan. Some US Universities also played an important role (see *figure 7*).

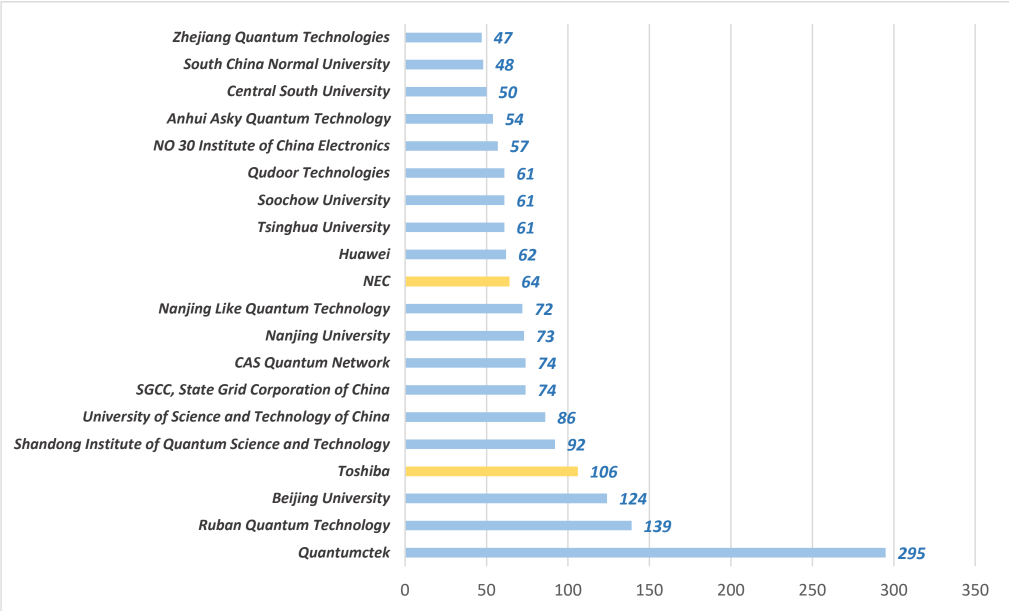
Figure 7. The number of international patent families in Quantum simulation



Source: EPO, 2023a.

The European *Quantum Industry Consortium* (*QUIC*, 2024) investigates the global Quantum patent landscape in Computing, Communication (*QKD* and *Internet*), and Sensing, highlighting similar trends: a fast rate of growth in each sector, with the United States leading as the applicant in Quantum Computing and China as the leader in Quantum Communication. The *QUIC* experts underline that Europe has no significant specific focus, with the three quantum segments having the same dimension. The *figure below* shows the principal global applicants in the field "Quantum Communication". As it is particularly evident from the analysis of the figure, the first global assignees are Chinese organizations, with just two Japanese firms in the top ranking. No other country, then, is represented in the classification.

Figure 8. The main assignees in quantum communication, ranked by the number of alive patent families



Source: EPO, 2023b.

1.2 The Global Public Investments: China's leadership position

Among the main public investors in QST Research, China has a budget that surpasses heavily the ones of the other countries (see *figure 9*). Particularly, both in *McKinsey* (2024) and *Roland Berger* (2021) reports, China ranks first among national investors, showing a budget three times bigger than the one of the second position. Germany occupies the second global position, and the UK occupies third place (2021, 2024).

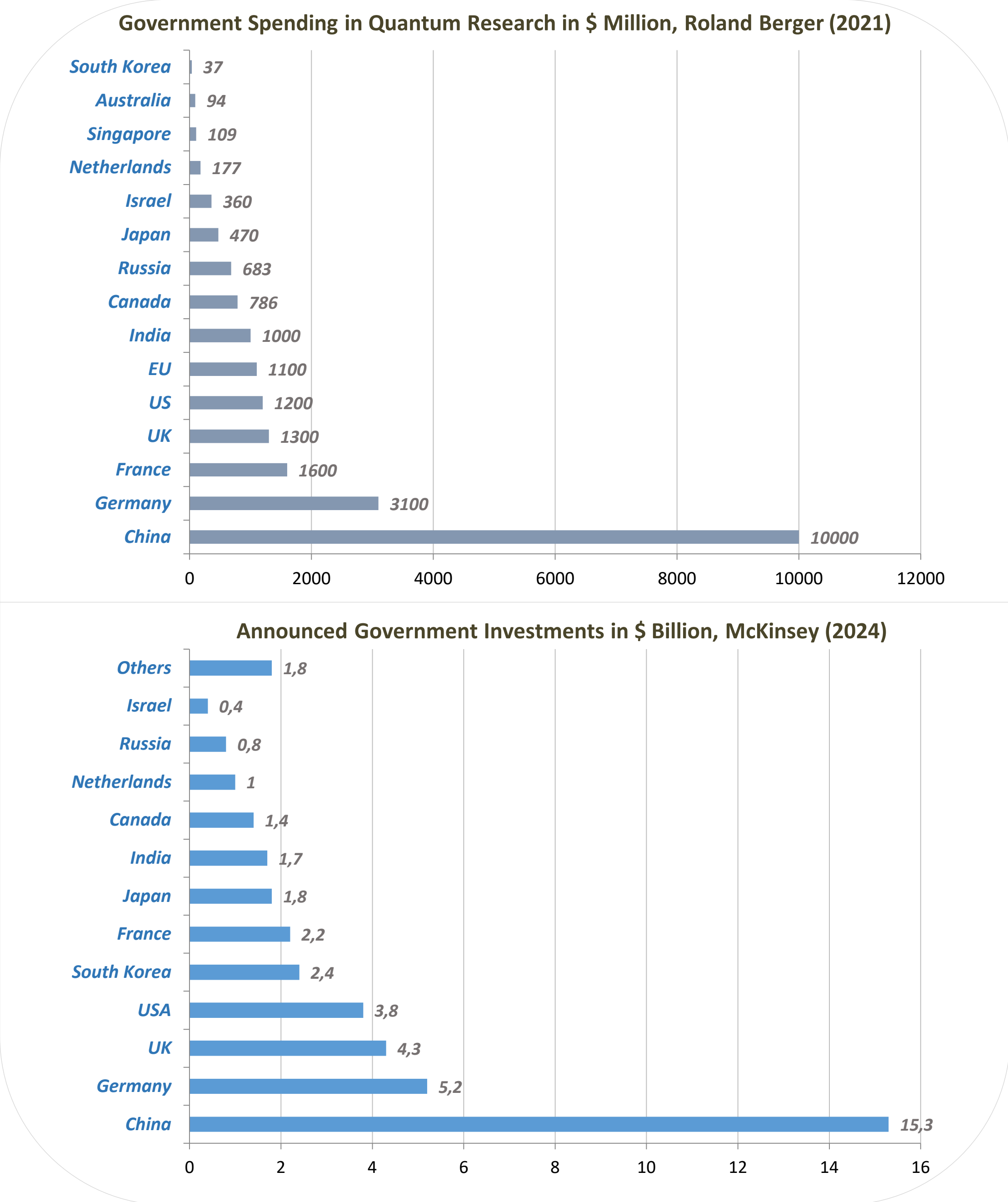
Several countries have decided to invest heavily in these last few years. We can observe France, but also the important leap made by South Korea, from the 15th position in 2021 to the 5th in 2024.

Roland Berger (2024) underlines how the spending gap between China and the other countries underlines a need for the US and Europe to double down on investments if they are to compete in the race for quantum supremacy.

Governments of the UK and South Korea want to establish themselves as leaders. Quantum technologies are at the center of the strategic plans revealed by both countries.

Through its *National Quantum Strategy*, the UK government has identified quantum technologies as a key factor in the country's future economic, social, and environmental prosperity. Further, South Korea has announced a substantial investment of more than 3 trillion Won ($2.3 billion) to establish the nation as a global leader in quantum technology (Kim, 2023).

Figure 9. The global public investments in 2021 and 2024

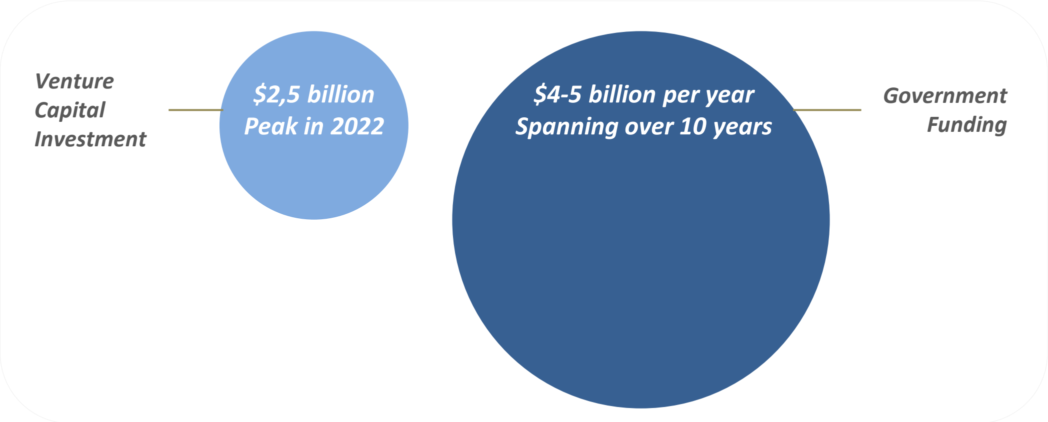


Italy still does not appear to be among the prominent investors. Nonetheless, Italy has an excellent tradition in Quantum Physics research, thanks to many leading researchers and an internationally competitive network of laboratories. European institutional publications and consulting reports underline that it would remain a chronic delay in the country's system in terms of technological and industrial development *vis-à-vis* other industrialized nations. In particular, the connection between the fundamental and the industrial research sectors would need to be significantly improved. However, such a delay would still be recoverable if an ambitious plan on QST was implemented. It is therefore necessary, focusing on the excellence of research in these sectors and on the strong skills of the connected industries, to initiate industrial and research policies capable of improving the link between academic organizations and firms, thus allowing Italy to remain among the leading industrial powers and among European leaders in this technology. Such academic and industrial effort also has a financial dimension, as several other countries are accelerating on QST investments, and the financial gap could reveal itself as strategically unbearable.

1.3 The QST private financing: the differences on the global scale

Roland Berger (2024) underlines how investments in quantum technology have shifted, following the growth of the total quantum market. Public funds still represent the most significant percentage, but private investors are entering the business, as technological readiness is rapidly developing (and perceived as such). More than 2 billion US dollars have been spent each year since 2021, tripling the total amount since 2020 (*figure 10*).

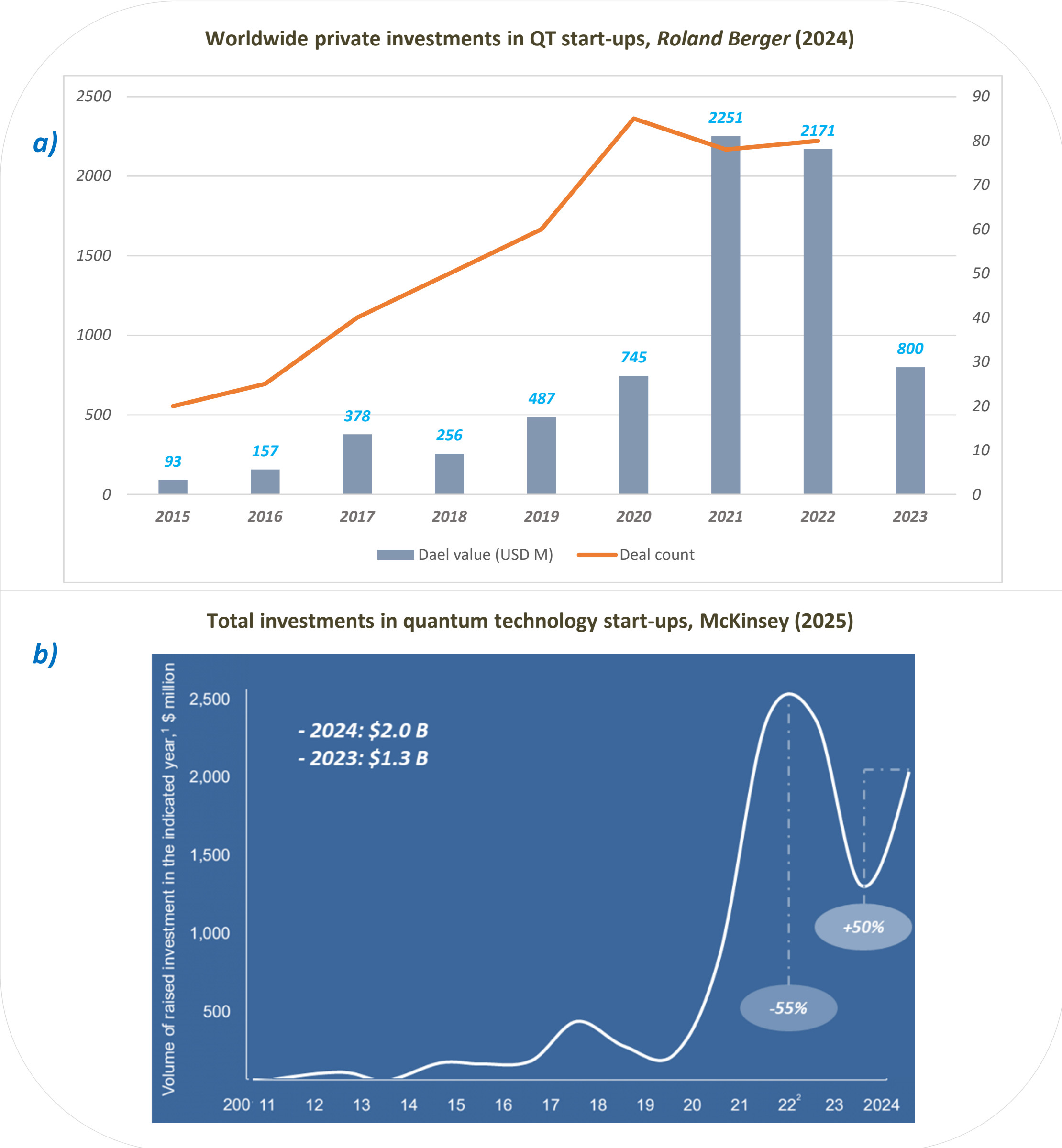
Figure 10. The Venture Capital Investment vs Government Funding



Source: IQM et al., 2024.

According to *IQM et al.* (2024), government funding provides an important backbone, especially when private investments decline. Indeed, at a time when private investment declined in 2023, governments around the world strongly believed in the development of quantum technology and the importance of its applications in defense, privacy, and security. Worldwide, national governments have pledged $40-50 billion in funding. The dynamic combines historic spending and forward-looking commitments with strong political commitment. Despite the peak VC investment of $2.5 billion in 2022, the value of government investment spread over ten years is about double ($4-5 billion).

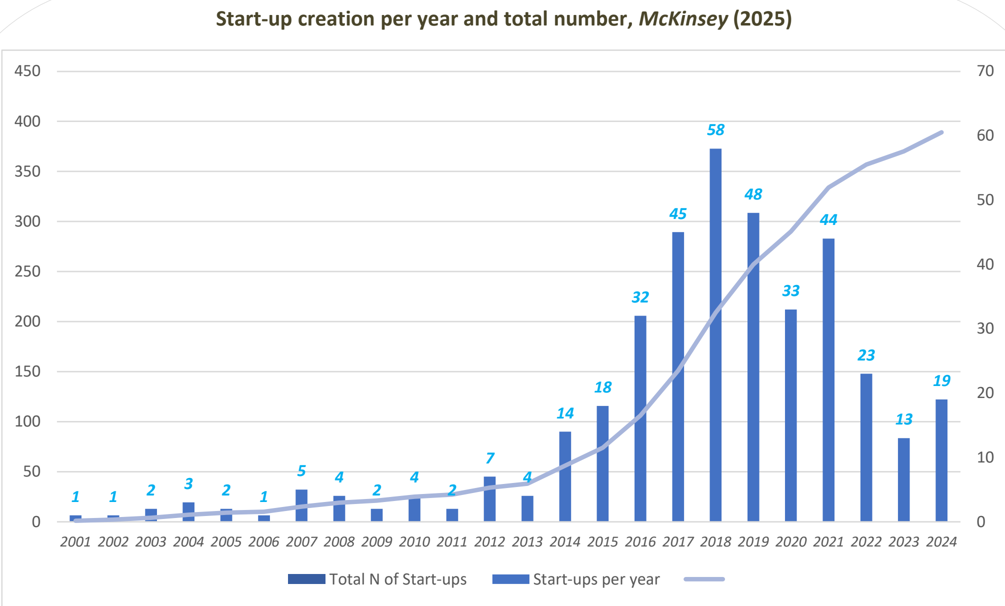
Figure 11. The total investments in startup creation

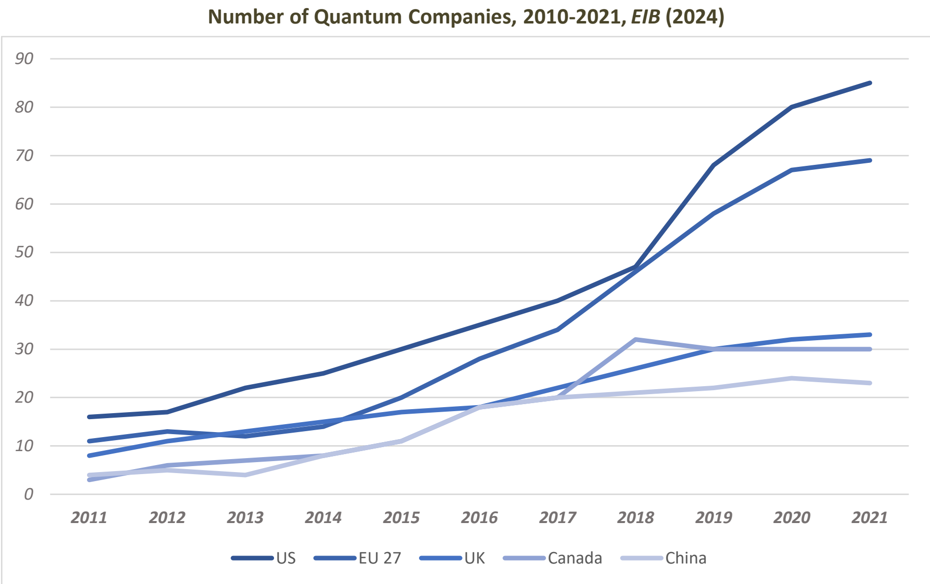


Source: Roland Berger, 2024; McKinsey, 2025.

According to *McKinsey* (2023), overall annual Quantum Technology (QT) startup (about 350 involved in the Quantum Technology ecosystem) investments reached $2.35 billion, and about 68 percent of them occurred in the years 2021 and 2022 (see *figures 11 and 12*). Moreover, during that period, *SandboxAQ*, *Rigetti Computing, D-Wave,* and *Origin Quantum* closed some of the biggest deals, i.e. $500 million in *Special Purpose Acquisition companies*: $345 million, $300 million, and $149 million, respectively. In *figure 11a*, it is possible to analyze the trend in worlwide private investments in QT startups from 2015 through 2023 for total deal value and deal count (*Roland Berger*, 2024). *McKinsey* (2025), in *figure 11b*, investigates a broader time segment, representing the total investments in startups from 2011 to 2024.

Figure 12. The number of Quantum startups, 2010-2021/24



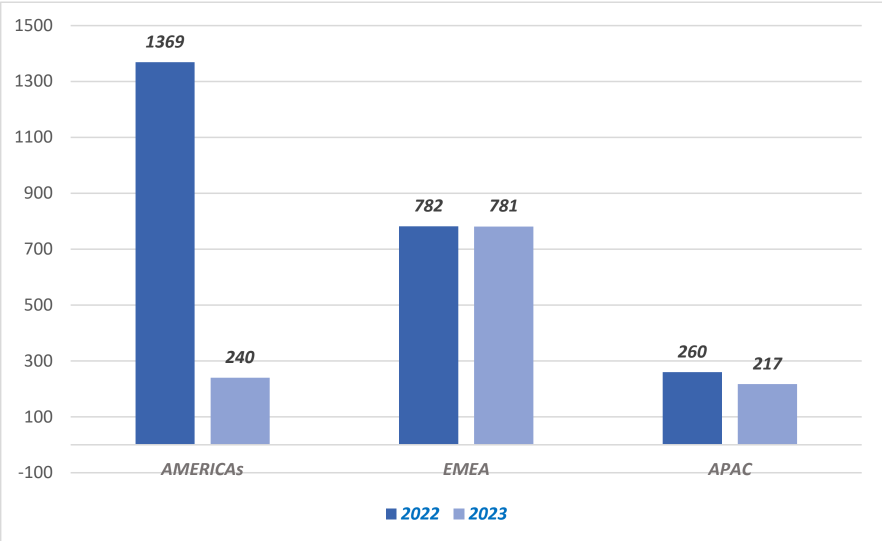


It is to highlight that there are geographical differences in private investments in quantum technology. In 2023, the United States experienced an 80% decrease in venture funding in quantum technology (*IQM et al.*, 2024; see *figure 13*).[6]

[6] *Reuters*. (2024). US Startup Funding Continues to Drop Despite AI Frenzy. https://www.reuters.com/technology/us-startup-funding-continues-drop-despite-ai-frenzy-2024-01-11/

This decline can be attributed to the numerous investments made in 2022, including large rounds fueled by *SPACs* (*Special Purpose Acquisition Companies*) and a few select, large *Series B* and later funding rounds. On the other hand, the APAC (Asia-Pacific) and EMEA (Europe, the Middle East, and Africa) regions showed more resilience, with a 17% decline in APAC and a constant percentage in EMEA compared to the previous year.[7] The global positioning will be further analyzed in the next chapter, which discusses the main characteristics and specific financial difficulties of European startups.

Figure 13. The Total Private Investment in QT (2022 and 2023)



Source: IQM et al., 2024.

The *top 10 venture capital and private equity investments in QT startups* are mostly involved in **hardware manufacturing,** followed by those involved in **software**. Only one (*Quantinuum*) is vertically integrated, i.e., engaged in both the production of hardware and software. The technologies' applications encompass quantum computing, and some of them are also linked to **quantum sensing** and **quantum communication** (*figure 14*).

It is worth noting that venture capital investment (in general) is declining, with the past decade seeing significant growth in this sector. For example, in the US alone, over $250 billion of new capital was invested in 2021, more than five times higher than in 2011. The decline in venture capital investment in the quantum technology sector is consistent with the overall decline in the venture capital market, with a 50% decrease in 2023 compared to 2022.[8]

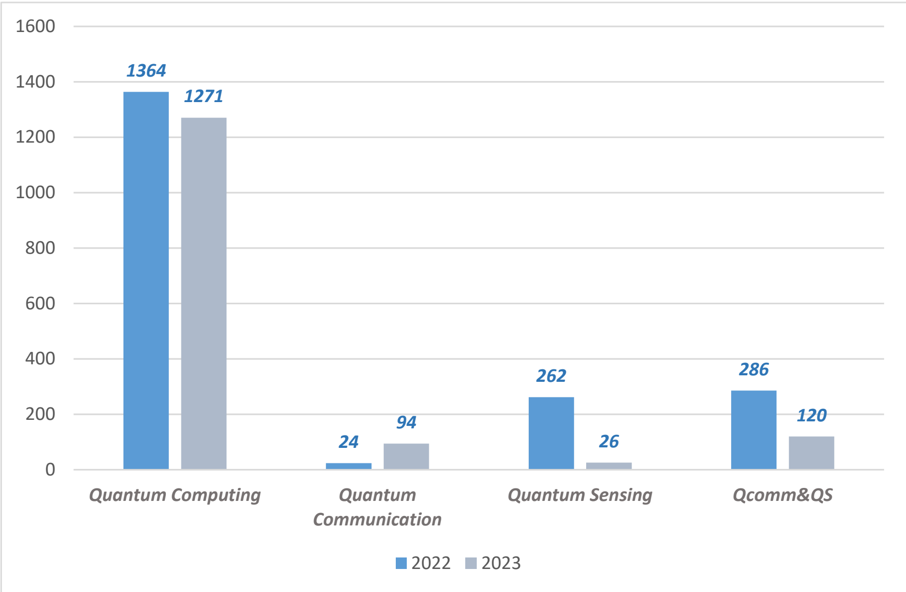
Despite the decline in venture capital investment during the summer of 2023, several companies secured significant funding to support their growth. *Photonic Inc.*, a Canada-

[7] Euractiv. (2024). Europe's Quantum Tech Sees Rosy Outlook for 2024. https://www.euractiv.com/section/industrial-strategy/news/europes-quantum-tech-sees-rosy-outlook-for-2024-report-says/

[8] Crunchbase News. (2023). Global Funding Data Analysis: AI EOY 2023. https://news.crunchbase.com/venture/global-funding-data-analysis-ai-eoy-2023/

based company, raised $100 million in a funding round led by *BCI* (*British Columbia Investment*), *Microsoft*, and other investors as part of their partnership.[9]
PASQAL, a French quantum processing company, completed a *Series B* funding round of 100 million euros[10]. This investment, led by *Temasek* and supported by a group of new and existing investors, will aid *PASQAL* in its expansion phase. *Q-CTRL*, a quantum software company, welcomed *Morpheus Ventures* as a new investor, raising $54 million in its *Series B* funding round. In the UK, *Quantum Motion*, a quantum computing company, secured over £42 million in equity funding, with *Robert Bosch Venture Capital* and *Porsche SE* taking the lead.[11] These funding rounds demonstrate continued support and investment in the quantum technology industry.

Figure 14. The capital invested in QST startups per sector in ML USD (2022-23)



Source: McKinsey, 2023.

Despite the growing number of investments, the theme of **'quantum winter'** has been attributed to this decrease (*McKinsey*, 2023; *Yole Intelligence*, 2024; *IQM et al.*, 2024), but consultants assert that it is exclusively a cooling period, as we will have to wait a few years to consider the real positive trend of the investments in quantitative technologies. Experts' insights confirm that despite reduced investment rates, the quantum industry continues progressing, albeit more slowly. They therefore refer to the need to moderate expectations by focusing on long-term research and development, understanding that

[9] *Photonic Inc.* (2023). Photonic Raises $100M for Quantum Technology. https://photonic.com/news/photonic-raises-100m-for-quantum-technology/
[10] Reuters. (2023). French Quantum Computer Startup PASQAL Raises 100 Million Euros. https://www.reuters.com/technology/french-quantum-computer-startup-pasqal-raises-100-million-euros-2023-01-24/
[11] Q-CTRL. (2023). Q-CTRL Adds Morpheus Ventures to Record-Setting Series B Funding Round. https://q-ctrl.com/blog/q-ctrl-adds-morpheus-ventures-to-record-setting-series-b-funding-round-with-total-of-54-million-usd-raised

practical applications of computing and quantitative technologies could find applications in a few years. Reasons for quantum winter are summarized in *boxes 8*, *9*, and *10.*

Box 7. The Quantum Winter

The term "quantum winter" is used to describe a period of stagnation or significant decline in enthusiasm, investment, and research in quantum technology.
According to *McKinsey* (2023), potential hypotheses on the causes of the slowdown are:

- *Lack of talent*: most experienced specialists (generally academics with a research focus in QT) already work in a startup;

- *Few working use cases*: application startup creation is limited because working use cases are very limited or not sufficiently developed for commercial implementation (eg, in QS);

- *Investor trends*: investors prefer investing in companies that are already in late-stage startups and scale-ups, reducing the possibility of obtaining funding for fledgling companies.

Other causes can be identified. In particular, possible causes include unrealistic expectations, technical difficulties, high costs, and competition from other technologies. Specifically, exaggerated expectations about the timing and results of quantum technologies can lead to disappointment when progress is not as rapid as expected. Complexity can slow progress by discouraging investors and researchers. Also, if tangible results take a long time to materialize, the costs associated with research and development can be a negative sign. In addition, other technologies that are cheaper and more immediately available could pose a threat.
The quantum winter could be a significant problem for development, as it could lead to a reduction in public investment, with inevitable consequences such as a delay in innovation and the loss of talent that could begin to cultivate other research interests and invest in other areas (*McKinsey*, 2023).
Some solutions lie in educating investors and stakeholders about the real potential and timeframe for real development, encouraging long-term investment, and fostering collaboration across multiple science and technology sectors to accelerate processes.

Box 8. The Quantum Winter?

"*Not so sure, each year continues to see newcomers emerging, but everyone hopes to see a commercial use case soon*", consultant, *Yole Intelligence* (2024).
The quantum ecosystem is maturing and strengthening step-by-step through research project collaborations, patent portfolio, creation of startups, and semiconductor vendors-equipment makers entering the game, but partnerships are still very important, since only a few can pursue different R&D approaches for qubits in parallel.
Global public and private investment in quantum technologies is high, with $30 billion (public) plus an estimated $4 billion (private) to date. Most investments (about 75%) go to quantum computing hardware, as massive capital investments are necessary for its development. The rest is mainly for systems and applications software. Also, companies are today shifting from private financing to IPOs (Initial Public Offering), M&As (Merger and Acquisition), and spinoffs. However, IPO creation is not successful, as short-term revenues are not expected for quantum technologies.
In the future, to be successful, quantum computers will need to work on SWaP-C (size, weight, power, and cost). Although quantum technologies are long-term, the investment time is today. This is also because all technologies developed for quantum (photonics, cryogenics, RF, advanced packaging, control electronics, etc.) will also find new opportunities outside quantum computing.

Source: Yole Intelligence, 2024

Box 9. No Quantum Winter, Just A Bit Colder

Venture investments in quantum technology reached a high of over $2 billion in 2022, indicating strong investor confidence in this emergent market. However, by 2023, this investment decreased by approximately 50%, prompting discussions of a "quantum winter." In reality, industry experts refute the notion of a quantum winter, suggesting that the decline aligns with overall macro venture capital trends and does not reflect diminishing faith in quantum's potential. If anything, the downturn in private investments has started to be increasingly picked up by government backed funding commitments and contracts, bridging the gap in investor apprehension. Insights from experts confirm that despite reduced investment rates, the quantum industry continues to progress although at a slower pace. A need for tempered expectations is called upon with a focus on long-term research and development, understanding that the practical applications of quantum computing could be still years away. Quantum technology remains a niche sector, accounting for less than 1% of total VC funding. So, while the quantum technology industry is adjusting after a period of heightened investment, it is not entering stagnation, and industry insiders maintain a cautiously optimistic outlook for its future trajectory.

Source: IQM et al., 2024

1.4 The Quantum technology: the size and the forecast

The development of quantum technology is expected to have a substantial effect both socially and economically worldwide. *Yole Développement* (2021; 2024) forecasts that by 2030, the total market for quantum technology (computing, cryptography, sensing) will reach US$2.9 billion.

The market research company estimated a 18% and 30% *Compound Annual Growth Rate* (CAGR) for the periods "2020-2025" and "2020-2030", respectively. The three main market segments, quantum computing, quantum sensing-timing, and cryptography, grew between 2020 and 2030 to reach US$1,147 million, US$598 million, and US$1,163 million, respectively.

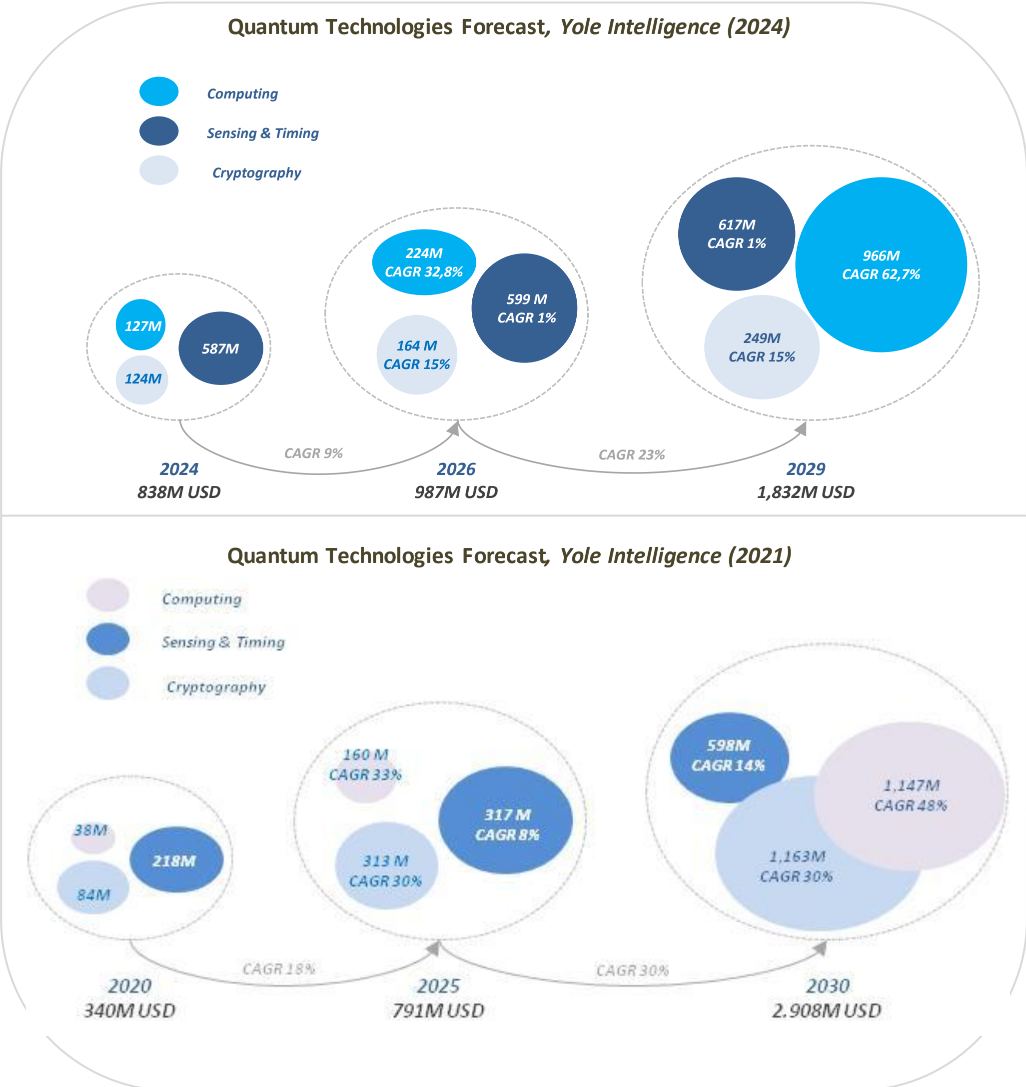
As evidenced in *figure 15*, the consulting firm consistently changed the percentage of the forecast for the CAGR, even though the QST dimension overall is expected to reach a market of 838 USD million in 2024 (in line with the first evaluation). *Yole Développement* (2024) envisages a growth rate of 9% between 2024 and 2026 and reduces CAGR between 2025 and 2030 (from 30% to 23%). It forecasts a reduced investment amount, from 2,9 to 1,8 million dollars globally.

It is also interesting to underline the change in the single pillar dynamics from 2021 to 2024. Quantum Computing shows almost the same forecast until 2026, with a CAGR of around 33% (from 2024). Predictions to 2029 grew consistently, passing from 48 to around 63% in the second evaluation (*Yole Développement*, 2024).

Forecasts on Quantum Sensing and Quantum Cryptography have changed consistently. "Sensing and timing" which represented the largest segment inside the quantum market at the beginning of the evaluation (2021, 2024), are expected to grow at a slower rate in the second report, passing from 8-14% to 1%-1%. Consequently, the consulting firm believes that the sensors' sector has already reached its peak and will grow moderately. "Cryptography" in the second analysis still shows a consistent rate of development (15%), while in the first market analysis *Yole Développement* previewed a double amount (30%).

As the dimension of the circles highlights, in the *Yole* forecasts, “Computing” will represent 53% of all QST investments (instead of the 40%) in 2029. “Sensing and timing” will then keep their relevance, representing almost 33% of the market (the first prediction was around 21%). Finally, “Cryptography” will represent only around 14% in 2029, a sensitive change from the first report that showed the total market size of around 40%.

Figure 15. The Quantum Technology Forecasts Comparison (2021, 2024)



Roland Berger (2024) highlights how quantum technologies have experienced significant market growth over the past decade, thanks to the theoretically and practically proven technological benefits of quantum mechanics applications, which are significantly more potent in secure communications, sensors, computing, and simulation. The consulting company predicts a market size by 2021 of around 1 billion US dollars. This value is expected to increase tenfold by 2025 and hit 50 billion in 2030. Outlooks are brighter in comparison to the *Yole*'s report. Internal pillar trends look similar in quantum sensing and quantum cryptography. *Roland Berger* (2024) underlines that each quantum segment represents around 25% of the total market; however, it is expected to shrink to around 10% by 2040, with quantum sensing showing a stable share of 3% (see *figure 16*).

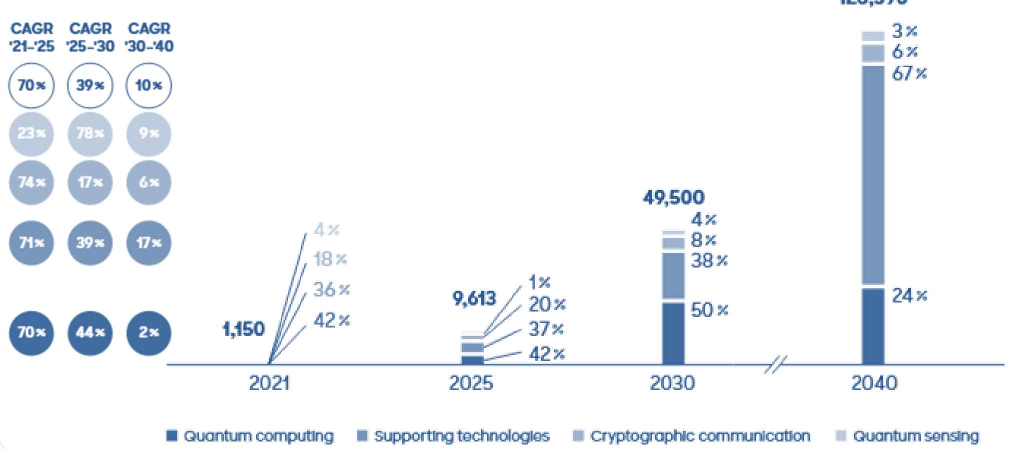
Figure 16. The Quantum Technology Market Scenarios

Quantum Technology Market Scenarios, *McKinsey (2024; 2025)*

	Quantum computing (24; 25)	*Quantum Communication (24; 25)*	*Quantum sensing (2024)*	*Quantum sensing (2025)*
2035	*28-72 B $*	*11-15 B $*	*0,5-2,7 B $*	*7 – 10 B $*
2040	*45-131 B $*	*24-36 B $*	*1-6 B $*	*18 – 31 B $*

Based on existing development road maps and assumed adoption curve

QT Market Outlook (USD m), *Roland Berger (2024)*



Still, the consulting company highlights how quantum computing is currently the most important market driver, accounting for more than 40% of the total dimension, and reaching around 50% by 2030. In the Market Analysis, *Roland Berger* (2024) underlines the pivotal role the *supporting technologies* play, as vital enablers of quantum computing. As commercialization and automation continue to develop, technologies such as optics, lasers, photonics, cryogenics, packaging, electronic components, and software systems will particularly increase in importance, potentially doubling their size by 2040. The trend could have a significant impact on the quantum sectors and represent a strategic entry point for firms not directly engaged in quantum technology, which could take a substantial role inside the *quantum value chain* (see *figure 17*).

McKinsey (2024) published "Quantum Technology Monitor", based on existing development roadmaps and an assumed adoption curve. Quantum Computing, particularly, will represent the largest segment in 2035, showing a similar rate of growth to quantum communication. Quantum sensing has a tiny dimension compared to the other pillars, both by 2035 and by 2040. The last *McKinsey* report (2025) maintains a coherent forecast for Computing and Communication, while predictions for Quantum Sensing consistently augment.

Figure 17. The Quantum Technology Global Players

Source: Yole Intelligence, 2024.

As emerged in the comparison of reports, quantum computing is poised to revolutionize our technological landscape, signifying a swift change in paradigms. The market is already showing signs of transitioning towards accelerated commercial expansion, as evidenced by the progress of companies such as *IonQ*, *Rigetti Computing*[12], and *Pasqal*[13].

Deloitte (2024) evidences how quantum computing is not only an emerging technology but also represents a ground-breaking shift poised to redefine the fabric of computing, ushering in a new era of incredible problem-solving capabilities. Governments, organizations, and researchers are investing in building quantum computers, bracing for the positive and negative transformative impacts it could unleash – while harnessing its principles to conquer intricate challenges that elude conventional technology.

From a geographical point of view, many companies have their headquarters in the USA (*SandboxAQ*, *IonQ*, *Rigetti Computing*, *Infleqtion*, *Atom Computing*), in the UK (*Arqit*[14], *Quantinuum*), Canada (*D-Wave Systems*[15], *Xanadu*), China (*Origin Quantum*), Finland (*IQM*), Switzerland (*Terra Quantum*), and Israel (*Classiq*).

PsiQuantum recently closed a $1 billion *Series E* at a $7 billion valuation, the largest round ever for a quantum startup. The round attracted both private and public capital,

[12] *Rigetti*'s business case study is described later in the first Chapter.
[13] A brief *Pasqal* case study is described in *Chapter 2*.
[14] A brief *Arquit* case study is described in *Chapter 2*.
[15] *D-Wave Systems'* business case study is described later in the first Chapter.

from *BlackRock* and *Nvidia* to the governments of Australia and Illinois. The goal of the Australian professor, Jeremy O'Brien, is to build a useful quantum machine by 2027, using light in silicon chips, a photonic computer[16].

The Italian *Quantum Computing and Communication Observatory* analyzes the global Quantum Computing supply chain, investigating companies, startups, and spinoffs from the hardware and its enabling components, to the development platforms and middleware environments, up to the software and algorithms. The report identifies 250 global players, 70% of which represents new entrepreneurial firms at different levels of market maturity. The total financing for these segments would amount to 4.6 billion dollars, with 1.2 billion invested from 2022. [17] Main sectors involved in QST financing would be the financial, chemical-pharmaceutical, automotive, and energy sectors.[18]

QED-C (2025) in the *State of the Global Quantum Industry* report highlights how QST comprises both *pure-play* companies and established technological organizations, including universities, laboratories, SMEs, MNCs, and other actors that dedicate a portion of their research activities and resources to Quantum Technology. At the global level, pure-play companies would exceed 500, while partial players would number more than 5,000 organizations.

Rigetti Computing[19]

Rigetti Computing was founded in Berkley (California, USA) in 2013 by Chad Rigetti, a former *IBM* employee, on the mission to build a quantum computer that could outperform classical machines.[20]*Rigetti Computing* is a full-stack quantum computing company specializing in superconducting qubit technology and hybrid quantum-classical systems. The company offers quantum computing-as-a-service ('QCaaS'), a cloud-based access to its quantum systems for enterprises, allowing for stable recurring revenues from a subscription service. *Rigetti* also provides on-premises quantum systems for organizations that require localized infrastructure, like national labs and academic institutions. The company's offering systems are, in fact, diversified through proprietary hardware and co-development projects with government agencies and industry leaders.[21]

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[16] *Atomico* Insights, "$1B of New Capital to Build the World's First Useful Quantum Computer", 18 September, 2025. https://atomico.com/insights/1b-of-new-capital-to-build-the-worlds-first-useful-quantum-computer

[17] Cited in *AI4Business*, Redazione, "Tecnologie quantistiche in Italia: oltre 140 milioni di euro dal PNRR", November 23rd 2023.
https://www.ai4business.it/quantum-computing/tecnologie-quantistiche-in-italia-oltre-140-milioni-di-euro-dal-pnrr/

[18] More Information on Alex Challans, "Quantum Computing Market Map and Data 2022", May 9th, 2022, The *Quantum Insider*.
https://thequantuminsider.com/2022/05/09/quantum-computing-market-map-and-data-2022/

[19] Raffaele Cecere and Gaia Raffaella Greco wrote the introduction to the business-case study "Rigetti Computing".

[20] Tom Simonite, "The Tiny Startup Racing Google to Build a Quantum Computing Chip", February 8th, 2016, *MIT Technology Review*.
https://www.technologyreview.com/2016/02/08/162384/the-tiny-startup-racing-google-to-build-a-quantum-computing-chip/

[21] GuruFocus, "Rigetti Computing: An Egregiously Overvalued Quantum Computing Stock", *Forbes*, October 1st, 2025.
https://www.forbes.com/sites/gurufocus/2025/01/10/rigetti-computing-an-egregiously-overvalued-quantum-computing-stock/

The company offers a range of services related to quantum computing. *PyQuil* is a Python library for the development and execution of quantum programs, while *Quilc* is an optimizing compiler for gate-based quantum programs. *Novera* is Rigetti's quantum processor and comprises a 9-qubit chip. The realization of this project has involved the formation of several key partnerships for *Rigetti*, including *Blue Fors* for cryogenics-related components, *Quantum Machines* and *Zurich Instruments* for control hardware, *Horizon Quantum Computing*, *Classiq Technologies*, River Lane, *Strange Works* and *Q-CTRL* for software platforms, and *ParTec Modular Supercomputing* and *Treq* for creating integrations based on quantum computations.
Rigetti is engaged in a collaborative effort with *Amazon* on *Amazon Braket*, a fully managed quantum computing service designed to facilitate accelerated scientific research and software development for quantum computing[22]. Furthermore, the partnership with *Microsoft* has led to the development of the *Azure Quantum cloud platform* (*Rigetti Computing*, 2024a). *Box 10* reports an interview with Stefano Poletto (Director of the Quantum engineering department) and Rebecca Malamud (Senior Marketing & Communications Manager).

Box 10. The interview with Stefano Poletto (Director of the Quantum engineering department) and Rebecca Malamud (Senior Marketing & Communications Manager)

Does Rigetti collaborate with European companies and research institutes? What may be future collaborations?
Rigetti collaborates closely with government, academia and industry to advance quantum computing commercialization and R&D. Many of our longtime collaborations are based in the UK and funded through *UK Research & Innovation* (UKRI). Most recently, *Rigetti* was awarded a *Small Business Research Initiative* (SBRI) grant delivered by *Innovate UK* and funded by the *National Quantum Computing Centre* (*NQCC*) to develop and deliver a quantum computer to the *NQCC*. *Rigetti* also collaborates with leading European financial institutions including *Moody's and Standard* chartered to develop quantum computing applications for finance.
Rigetti is focused on developing high performing quantum computers to solve real-world problems, and fostering new collaborations and expanding existing ones is an integral part of our success. There are many strong quantum computing ecosystems across Europe, and we are regularly evaluating new collaboration opportunities. Additionally, *Rigetti* is eager to support the construction and development of testbeds throughout Europe with *Rigetti* hardware.
Who are your direct competitors?
Quantum computing is an emerging technology. We are still in the early stages of understanding what it takes to build a fault tolerant quantum computer that can achieve quantum advantage. There are different approaches to building quantum computers based on different types of qubit technologies. *Rigetti* builds superconducting quantum computers. Our qubits are based on superconducting electronic circuits. We believe that superconducting quantum computers have a clear path to scale as our processes are manufacturable and adopt many of the fabrication techniques already developed from the semiconductor industry. Other companies building superconducting quantum computers include *IBM* and *Google*. Among other qubit modalities that garner investment and commercial interest are ion trap, photonic, and neutral atoms.
What, in your opinion, can be an outlook for the quantum computing supply chain? What are the challenges to be faced?

[22] AWS. (n.d.). Rigetti Quantum Computers on AWS. Accessed July 2024. https://aws.amazon.com/it/braket/quantum-computers/rigetti/.

There is increasing attention on the supply chain for manufacturing quantum computers from both governments and private entities, as it is a critical technology to many national strategies, and there is significant revenue generation expected as the technology matures. For superconducting quantum computers in particular, many of the supply chain challenges are related to fabrication of the chips containing quantum integrated circuits, as well as manufacturing of the supporting cryogenic hardware. In 2016, we created the first captive foundry for superconducting quantum device fabrication - *Rigetti's Fab-1* - which helped mitigate risks to critical aspects of our internal supply chain. One of these technologies are low-noise quantum amplifiers - such as *TWPAs* (*Traveling Wave Parametric Amplifiers*) - that help read out the signal coming from the qubit. We design and manufacture our own *TWPAs*, and support increasing diversity in the quantum hardware marketplace for such key supporting technologies. More broadly, some of the *supply chain challenges* to the quantum computing industry are:

- *availability of high-purity substrates and superconducting metals/alloys;*
- *standardization of quantum device manufacturing tools and guidelines;*
- *availability of cryogenic systems (including helium-3, an export-controlled element);*
- *standardization of RF and cryogenic components, including specifications for use in quantum computing systems.*

What are the main areas of application for quantum technologies? What are the target markets?

Quantum computers harness the unique processing capabilities of quantum mechanics to exponentially reduce the time and energy needed for high-impact computing. This computational power unlocks the potential to address complex problems across industries that were previously unsolvable by classical computers alone. *Applications* include:

Pharmaceutical: Design and optimize new druglike molecules for known targets, Aid drug discovery;
Finance: Optimize returns and manage risk for investment portfolios;
Machine Learning: Train better AI with less computational overhead;
Logistics: Reduce time and fuel costs by optimizing vehicle routing.

Can you provide examples of real use cases?

Rigetti is pursuing several real-world applications of quantum computing:

- Developing quantum-enhanced machine learning methods to improve recession prediction with *Moody's Analytics*;
- Enhance quantum machine learning methods for anti-money laundering detection with *HSBC, University of Edinburgh, and the UK's National Quantum Computing Centre*;
- Develop quantum machine learning techniques for financial data streams with *Standard Chartered, Imperial College London, and AWS*.

What is Rigetti's turnover?

$12M USD in revenue for January 1 - December 31, 2023

Who are your current customers and what are your potential customers?

Rigetti's customers include:

- National labs and quantum computing centers (ex. *UK's National Quantum Computing Centre, Fermilab, Oak Ridge National Laboratory, Air Force Research Lab*);
- Quantum hardware and software companies (ex. *Horizon Quantum Computing*);
- Public cloud providers (ex. *AWS, Microsoft Azure*);
- Government agencies (ex. US Department of Energy and Department of Defense).

Our *potential customers* are those who are seeking any of our product offerings or services to advance their quantum computing efforts:

- Integrated, high qubit-count (24-qubit, 84-qubit) quantum computing systems;
- Our 9-qubit Novera™ QPU;
- *Rigetti* quantum foundry services;
- Quantum Computing as a Service (QCaaS);
- Quantum application and research services.

D-Wave Systems[23]

D-Wave Systems[24] is a Canadian company that specializes in the development, manufacturing, and marketing of quantum computing systems. *D-Wave* was born in 1999 by Haig Farris, Geordie Rose, Bob Wiens, and Alexandre Zagoskin. Since its establishment, the company has been at the vanguard of research and innovation in quantum computing. Currently, the firm offers a range of products and services, including quantum systems, cloud services, application development tools, and professional services, which collectively facilitate the end-to-end quantum journey and provide practical applications for customers.

D-Wave employs over 180 individuals with expertise in processor development, chip fabrication, cloud infrastructure, and physics. Approximately 20% of its workforce holds doctoral degrees in their respective fields. Moreover, the company registered over 200 patents in the United States. Its research on the evolution of quantum computing has resulted in the publication of over 100 scientific articles in leading journals.

D-Wave has raised substantial funding over its history, including a major step in going public via a SPAC (Special Purpose Acquisition Companies) merger in 2022, valued at approximately $1.6 billion. In addition, *D-Wave's* latest financial report shows that the company had about $29.3 million in cash as of Sept. 30, 2024, and settled an outstanding balance of $13.7 million in a loan granted to *PSPIB* (*Public Sector Pension Investment Board)*.[25]

The company has a substantial customer base, including *Volkswagen*, *Pattison Food Group*, *DENSO*, *Toyota*, *BBVA*, *NEC*, *Interpublic Group*, *Lockheed Martin*, *Menten AI*, and *SavantiX*. In collaboration with such relevant players in various industries worldwide, the company has developed a multitude of quantum applications with the objective of enhancing production processes, logistics, mobility, resource planning, and customer portfolio optimization[26].

One of the services provided by the company is *Leap*, a quantum cloud that offers immediate, real-time access to *Advantage*, the company's quantum computing service. The cloud is accessible via *Python*, which is accompanied by a software development kit (SDK), a series of demonstrations, *Jupyter* notebooks containing live code, and a community that is available to assist with the rapid initiation of quantum application development. As previously stated, *Advantage* is the quantum computer manufactured by D-Wave for business applications.[27] The processor has over 5,000 qubits and 15-way qubit connectivity, enabling it to solve complex business problems.

D-Wave's pioneering role, practical focus, and commitment to expanding quantum computing's capabilities make it a crucial player in the industry. Its emphasis on both *annealing and gate-based models* reflects the diversity of approaches in the quantum ecosystem, highlighting different methodologies for solving computational problems. *D-Wave's* extensive commercial applications and partnerships also underscore its influence in driving adoption across industries.

Menten AI: quantum protein design

D-Wave has collaborated with the company *Menten AI* on the design of peptide therapies on a quantum computer. Peptides are medium-sized molecules composed of amino acids and are at the basis of many

[23] The business-case study “D-Wave Systems” has been written by Raffaele Cecere and Gaia Raffaella Greco.

[24] *D-Wave Systems*. (n.d.). About D-Wave Systems. Accessed July 2024. https://www.dwavesys.com

[25] *D-Wave Systems*. D-Wave Quantum to Report Third Quarter 2024 Financial Results on November 14th, 2024. https://www.dwavesys.com/company/newsroom/press-release/d-wave-quantum-to-report-third-quarter-2024-financial-results-on-november-14-2024/

[26] *D-Wave Systems*. (n.d.). D-Wave Quantum Computing eBook. Accessed July 2024. https://www.dwavesys.com/media/qlgj4hla/dwave_qc_ebook_v18c_0.pdf

[27] *D-Wave Systems*. (n.d.). D-Wave Announces General Availability of First Quantum Computer Built for Business. Accessed July 2024. https://www.dwavesys.com/company/newsroom/press-release/d-wave-announces-general-availability-of-first-quantum-computer-built-for-business/.

drugs investigations. However, their computational design is slowed due to complex energy dynamics and the relevant search space. The utilization of quantum annealer and hybrid methodologies offers an alternative toolkit for the design of peptide therapies, potentially providing a practical solution for the creation of revolutionary new drugs (Mulligan *et al.*, 2019). The significance of the company's role in undertaking such projects in the field of peptide design for the development of new drugs is evidenced by the testimonies of their partners. As Hans Melo, CEO and Co-Founder of *Menten AI*, asserts: "*Using hybrid quantum applications, we're able to solve astronomical protein design problems. We've seen extremely encouraging results, with hybrid quantum procedures often finding better solutions than competing classical solvers for de novo protein design. This means we can create better proteins and ultimately enable new drug discoveries*". Conversely, as Dr. Vikram Mulligan, a research scientist at the *Flatiron Institute* and co-founder of *Menten AI*, states: *"Using D-Wave's hybrid quantum-classical technology helps us to solve much larger problems in a fast and efficient manner and allows us to not only design these molecules today but also reimagine tomorrow's therapeutics".*

Volkswagen: traffic flow optimization

The collaboration between *D-Wave* and the automotive manufacturer *Volkswagen* has yielded several applications, specifically in the field of urban traffic management. The system calculates and guides drivers along optimized routes based on real-time traffic data. The inaugural pilot project was initiated in Lisbon in 2019. A traffic management system developed in-house by *Volkswagen* was installed on nine buses transporting attendees to the Altice Arena, where the 2019 Web Summit conference was being held. This was a route that was typically busy, approximately 10 km from the city centre, with multiple opportunities to reach the destination. *Volkswagen's* solution involved the development of an Android-based app that could communicate with a *Quantum Web Service* (QWS) cloud platform, which was in turn connected to a *D-Wave* quantum computer. The computer processes information to identify the most efficient routes through city traffic, considering both time and distance. As a preliminary step, three bus routes were identified, encompassing a total of 23 stops. These routes were designed to connect conference participants with the Altice Arena, their accommodations, and the city's central attractions. Over the course of the four-day conference, the Quantum Shuttle buses (referred to as the "fleet") completed 162 trips. Each of the 162 trips, distributed across the three predetermined runs, yielded different outputs and a total of 1,275 optimization tasks. This demonstrated that none of the three bus routes followed a fixed trajectory; rather, they adapted to prevailing road conditions, resulting in relatively consistent travel times, regardless of the hours when city traffic is typically at its peak.

Volkswagen: improving assembly line processes

In its pursuit of quantum technologies, *Volkswagen* has formed a partnership with *D-Wave* to develop a system based on quantum computing with the objective of enhancing efficiency during the pre-painting phase of cars along the assembly line. The assumption that cars receive either a pre-paint of white or black prior to receiving their final color paint is the basis for the use of quantum technology to minimize the time required to switch between sets of vehicles to be painted black and white throughout the entire sequence. The quantum algorithm has enabled the optimization of the flow of paint work based on the queue of projects established, for instance, by incorporating another small set of vehicles to be painted black into the queue of a large production run without necessitating constant color changes between white and black. As Florian Neukart, *Volkswagen Data Director* of the Munich Lab, also notes, a quantum computer is capable of processing such calculations at higher speeds, thereby optimizing large-scale production.

Recruit Communications: opportunities for Digital Marketing

Recruit Communications offers a comprehensive array of online services, including job search, travel, dining, hotel reservations, and other related services. Analytical tools play a pivotal role in the enhancement of their promotional efforts, in accordance with the firm's guiding principle: the delivery of the optimal message to the optimal individual at the optimal time. The field of sales and marketing has been revolutionized by the advent of quantum annealing. In 2017, they announced a pioneering collaboration with D-Wave with the objective of enhancing marketing, advertising, and communication technologies and strategies. The initial project undertaken by Recruit involved the optimization of television advertising placements with the objective of enhancing brand awareness[28].

Subsequent applications of the company involved improving the accuracy of machine learning methods that influence marketing technology, such as recommendation systems. The collaboration between *Recruit Communication* and *D-Wave* resulted in the development of an algorithm that can generate highly accurate results based on real values and minimal use of features with the weakest meaning. The use of a quantum computer enabled the overcoming of issues related to the high computational cost that a classical computer incurs in identifying data through techniques such as *L1 Regularized Logistic Regression* (L1LR) and *Feature Selection by Random Forest* (RFFS).

A further application involved determining the optimal order for search result placement on a hotel booking website and creating an algorithm to maximize sales. In contrast to classical computers, which prioritize the accessibility of popular options, quantum computers are capable of processing a greater volume of information by considering both popularity and the optimal mix for each customer, taking into account their individual buying habits.

SavantiX: application in logistics

SavantiX is a company of engineers and data scientists, already known for their contributions to the fields of quantum computing, artificial intelligence, and machine learning. They have been contracted to offer an improved solution to cargo handling operations at the *Port of Los Angeles*. The inefficiency of the operations was largely attributable to the random stacking of containers, which resulted in lengthy waits by trucks before cargo was delivered via the use of gantry cranes with rubber tires. The collaboration between *D-Wave* and *SavantiX* has yielded a framework, *HyperOptimized Nodal Efficiency Engine* (*HONE*), which employs quantum annealing technology. This technology enabled the development of a model that facilitates the more efficient use of cranes in unloading processes, thereby reducing truck waiting times. The application demonstrates the potential of quantum computing in the logistics industry.

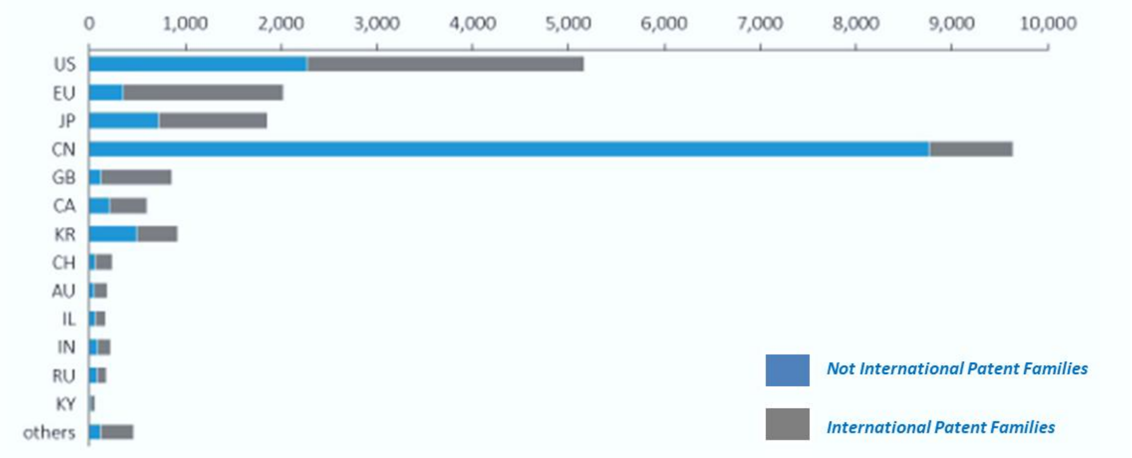
[28] *D-Wave Systems*. (n.d.). D-Wave Quantum Computing eBook. Accessed July 2024. https://www.dwavesys.com/media/qlgj4hla/dwave_qc_ebook_v18c_0.pdf

CHAPTER 2. THE QUANTUM SCIENCE AND TECHNOLOGY POLICY IN THE EU

2.1 The road to the *Quantum Europe Strategy*

In 2024, the *European Commission* published the “Draghi Report” on the future of European competitiveness. In *Part B*, “In-depth analysis and recommendations”, in the digital technologies section, an overview is offered on strengths and weaknesses that characterize the continental situation for quantum technology. It is underlined that Europe has key strengths in public investments, human resources, education, and academic research. The report evaluates public spending, underlying how Europe would be second only to China globally, as more than 7 billion Euros have been allocated to quantum research. Furthermore, European countries would show the largest concentration of quantum-ready experts (231 per million inhabitants), claiming excellence in scientific research, a strong academic base, and a robust research infrastructure. This data would also be confirmed by the position of Europe in the global patenting ranking on QST (see *figure 18*).

Figure 18. The share of patents in quantum computing by segment and country (number of patent families with the earliest publication date from 2000 to 2023 by top applicant country)



Source: European Commission, 2024 (from European Patent Office Data Desk).

As evidenced in the figure above, analysing international patent families between 2000 and 2023, Europe would rank second globally, with 16% of the total amount, behind the US (32%), Japan, and China which followed with 13% and 10%, respectively.
Also, regarding computational infrastructures, Europe leads with 48.8 million HPC cores (compared to 40.1 million in the USA, 22.6 million in China, and 11.4 million in Japan);

of these, 4.4 million are in Italy, which ranks fourth in the world.[29] The key asset of the European quantum industry is its capacity to develop and nurture talent. While in absolute terms, large economies such as China and India are ahead, the *per capita* density of quantum talent is higher in Europe. The United Kingdom is at the top of the table with over 1800 quantum-related talents per million people, followed by the United States (around 1000) and the European Union in third (around 700).

The report "*Quantum Technologies Public Policies in Europe"* (2023) highlights how Europe ranks first globally in terms of the number of graduates in quantum subjects. Following the statistics realized in 2020, Europe (27 countries) with 135.511 laureates has overtaken India (82.110), China (57.693), and the United States (45.087). In this ranking, Italy is seventh globally; in Europe, it is surpassed only by Germany (27,133) and the United Kingdom (25,805).[30]

A flourishing quantum industry needs employees from varied scientific backgrounds, including quantum physics, chemistry, and statistics. The industry is already experiencing talent shortages that will worsen as it grows. Academic breakthroughs are the first step towards unlocking value from quantum technologies.

European Policy Centre (2023) underlines the main differences between Europe and the United States in the dimension of quantum organizations. In the United States, big tech companies as *IBM*, *Google*, *Intel*, and *Amazon* are also trying to express themselves as leaders in QST. A vivid startup base would instead populate European markets. Specifically, the report stresses the most significant number in new science-based firms' establishment in 2021, with companies leading the way in Europe, such as *IQM* and *Bluefors* (Finland), *Pasqal* and *Alice&Bob* (France), *Plancq* (Germany), *Delft Circuits,* and *QBlox* (the Netherlands), and *Multiverse* (Spain). These National Champions of Innovation would need significant capital for industrial development and scale-up.

The *European Commission* (2024) strongly warns of the need to develop private investment markets for deep technologies, as the private funding in quantum technologies is very limited. There is no European company in the global ranking on private investments in startups, as five are from the US and four belong to China.

The *European Union* attracts only 5% of global private funding compared to 50% of the funding allocated by the United States.

Notably, the *European Policy Centre* (2023) stresses that Quantum Technologies represent a new test case for Europe in securing strategic autonomy and reaping economic, technological, and military benefits. While Big Tech giants dominate the United States' technological industries, European markets are characterized by a vibrant ecosystem of research organizations and startups. The "valley of death" must be overcome to become a European quantum-competitive industry.

Following the expert of the *European Policy Centre*, Europe would be in the phase of reevaluating its strategic military and technological missions, reconsidering appropriate

[29] Massimo Carrà, "Il futuro del computing varrà 500 miliardi nel 2030. Ecco le 7 startup italiane più promettenti", *Forbes*, May 20th, 2024.
https://forbes.it/2024/05/20/ia-quantum-computing-varra-500-miliardi-entro-2030/

[30] *Startup Business*, "*Obloo Ventures, investing in deeptech to meet global challenges",* May 13th, 2024.
https://www.startupbusiness.it/en/obloo-ventures-investing-in-deeptech-to-meet-global-challenges/129673/

policy instruments. A new focus would emerge on relevant public-private partnerships, and greater funding for specific sectors from batteries to semiconductors (see *box 11*).

Box 11. The recommendations for the EU's quantum industrial policy mix

KNOW - Embrace tech forecasting at the EU level

Recommendation 1: Map and conduct periodical assessments of Europe's quantum ecosystem's position in international value chains and its access to critical components and materials.

Recommendation 2: Develop analytical tools to monitor the international flows of other key elements of the industrial base, such as investments, skills, related technologies, and final products and uses.

COOPERATE – Combine European efforts in an EU Quantum Industrial Alliance

Recommendation 3: Enhance cooperation between Europe's different national quantum communities and programmes, with a view to ultimately establishing a public-private EU Quantum Industrial Alliance (EQuIA).

Recommendation 4: Use the Alliance to drive the development of Europe's industrial ecosystem through roadmaps on factors of industrial growth, operational cooperation such as joint procurement and the federation of infrastructure, and input to EU policy settings.

INVEST – Mobilise European public-private capital for industrial scale-up

Recommendation 5: Create a smart investment environment focusing on supporting the growth stage and speedy industrial scale-up of European startups, actively monitoring, protecting and supporting their technology programmes, financial health, and ownership, including by pairing private/foreign investment with public equity.

Recommendation 6: While continuing to provide a broad base of public R&D support across technologies, EU 'fund of funds'-investment tools are needed to leverage private capital into 'series B' and 'series C' financing of maturing startups. In parallel, the announced EU Sovereignty Fund should be used to create dedicated EU Co-investment Facilities that provide equity directly to scale-ups in critical technology areas, such as quantum, with fast turnaround and low bureaucratic overhead.

Recommendation 7: Use the *European Chips Act* to launch industrial 'first mile'-pilots and establish a financing and project roadmap leading to a future European quantum chips foundry.

PROTECT – Deploy Europe's defensive toolbox, prudently

Recommendation 8: Proceed carefully with restrictive export and import policies given the low maturity of quantum technologies and the global needs of Europe's burgeoning startup ecosystem.

Recommendation 9: Build strategic technological leverage towards the US to guarantee a low-barrier transatlantic space, and develop collaboration schemes with like-minded partners (UK, Switzerland, Canada, Japan, South Korea).

Recommendation 10: In response to both international pressures and technological change, reform Europe's export control framework and promote more active uptake of knowledge security policies.

Source: Extract from *European Policy Centre* (2023)

The *European Chips Act*[31] is the foremost example, aiming to give Europe leverage over key segments of the semiconductor value chain. It consists of three pillars:

- *bolster innovation 'from lab to fab'*;
- *attract investment and enhance domestic production capacities*;
- *set up a monitoring and response mechanism in case of supply disruptions*.

In the quantum sector, the strategic measure aspires to the creation of pilot lines for the testing and experimentation of quantum chips and a design library.

Criticisms to the measure highlight the need for international cooperation, as national specialization, dependencies, and resource-intensive science-based industries could limit the initiative's success. Specific industrial policy would require informed choices,

[31] *European Chips Act* (2023), "Strategy and Policy Priorities". Accessed December 2024. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

based on a deep knowledge on the industrial dimensions and the global value chains.

2.2 A quantum leap in finance?

The *European Investment Bank* (*EIB*, 2024) publishes its report "A Quantum Leap in Finance", investigating the total dimension of QST markets and analyzing the state of the art of public and private funding in European countries in comparison with main trends on a global level. *EIB* (2024) worries that Quantum Technologies represent strategic sectors, and European countries must guarantee digital sovereignty in this particularly complex geopolitical situation.

While a large percentage of companies are located in Europe (almost 25%), only 5% of global funding is spent on European startups (see *box 12*). If the funding bottlenecks persist, Europe will struggle to establish a world-leading quantum industry.

Box 12. Why is private investment lagging in Europe?

1) The transfer of scientific excellence into commercial success requires business experience. Some European companies may have excellent scientific outcomes but overlook the areas in which investors focus on (product development, client acquisition or retention). A common theme that emerged from our interviews was that European *founders of quantum startups often do not communicate well with potential investors due to limited financial and business knowledge*.

The strong European academic foundation has translated into a rapidly growing universe of young quantum technology businesses, but scaling them up is challenging because of ***slow commercialisation or limited evidence of commercial viability***. In recent years, many new quantum computing hardware and software players have emerged. However, many of these young companies struggle to raise the funding they need to survive and grow. They *often lack a proven track record, solid and established business models, or customer relations* because they were too slow to focus on commercialisation. This is ***particularly problematic for university spinoffs***, for reasons that go beyond the business acumen of the founders. While some universities and research institutes offer robust support, others, including ***some renowned institutes, tend to slow spinoffs down with long and complex procedures and negotiations***. They need to become more effective in transforming academic breakthroughs into successful companies with the speed to match the progress in the quantum industry.

2) Corporations in Europe are slow to take up quantum technology projects because they perceive the development risk as too high or the potential payoff too far beyond the horizon of quarterly and annual reporting. There is an acute need to increase awareness of the potential benefits of quantum applications among potential end users so that quantum technology startups can secure the customers they need to attract investment. *Reliable commercial partners are essential for the long-term success of young quantum companies in Europe.*

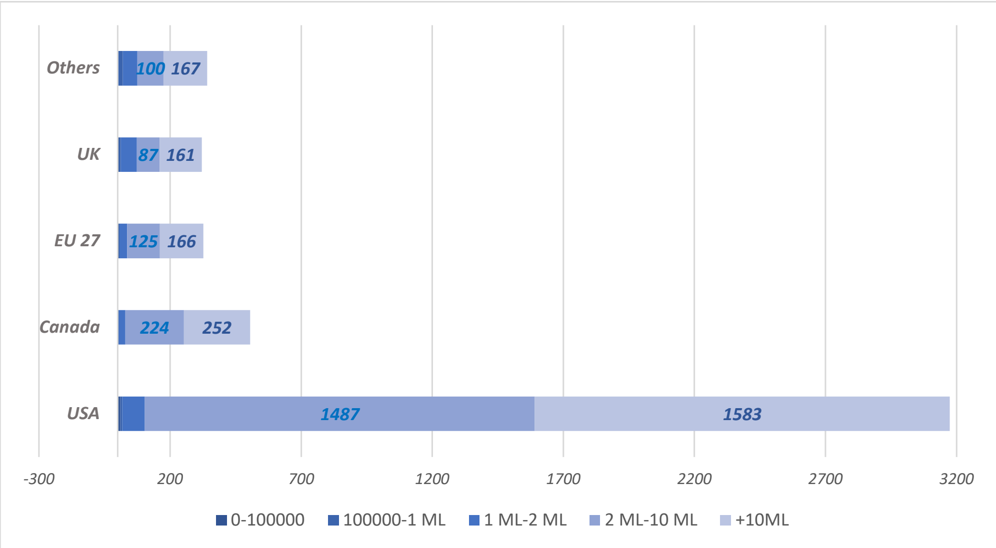
For entrepreneurs, especially those coming from academic backgrounds, it may be difficult to predict who their final customers and beneficiaries will be, or what the final product and/or service will look like. *The lack of collaboration with end users outside the quantum value chain is a significant obstacle to commercial development*.

The European quantum industry derives its strength from patient public capital but needs stronger private capital flow to thrive. Patient, non-dilutive public capital underpins *Europe's stellar academic base* and large pool of early-stage quantum technology ventures. Such support helps bridge the highest-risk stage of development — the so-called valley of death between fundamental research and early-stage commercialisation. ***Strong public support*** is not uncommon for nascent industries such as quantum technologies, but it ***is disproportionately large in Europe***. Public financing still has an ***important role to***

play, for example in the development of supporting infrastructure (pilot lines, testing facilities, and quantum cloud computing or communication networks).
Private investors need to step in, as they are best suited to supporting companies in the long run.

3) Europe faces a multi-year financing gap due to a limited pool of private investors that understand the specific market and technology risks of quantum technologies. Private funding for quantum technology is on the rise globally, yet the European Union is lagging behind by a significant margin. Despite the vibrant European quantum startup landscape, the region has consistently underperformed in securing growth funding. Growth is expected to remain strong as quantum technology commercialisation gains traction.
The low funding volumes for European quantum technology companies are linked to ***the lack of specialised investors able to provide support throughout the entire company life cycle***.
European deep-tech investors are scarce and those that exist tend not to invest large sums. A lack of understanding makes it difficult for generalist investors to assess the disruptive potential, technology risk or viability of quantum technology business ideas. Furthermore, there is a misalignment between the timescales of quantum development and the return horizons of average investment funds. The massive return potential of quantum technology is too far in the future to counterbalance the high levels of uncertainty today.

Figure 19. The size deal in Quantum Technology, 2018-2021



Source: EIB (2024, PitchBook).

The lack of private funding for European quantum companies is evident in ***both the lower number and the lower overall value of funding rounds*** (see *figure 19*). The deal sizes for European quantum startups in all business life cycle stages and fundraising rounds (*seed*, *early*, and *growth stage*) are smaller than those for comparable companies in the United States and Canada. The cumulative effects of underinvestment are beginning to show. ***There are relatively few mature European quantum technology companies in the highest-value segments.***
Source: extract from EIB (2024).

European Policy Centre (2023) stresses the importance of *European Union* financial measures to push startups towards technological maturity and early industrialisation. The *European Innovation Council* (EIC) Accelerator offers equity investments of up to 15 million euros or more for strategic technologies. Furthermore, the *European Investment Fund* has launched a €300 million pilot, *Escalar*, to direct venture capital towards

Europe's scale-up challenge.[32] Furthermore, by the end of May 2025, the *European Commission* had published "The EU Startup and Scaleup Strategy: Choose Europe to start and scale" with the goals of closing the innovation divide between the EU and its global competitors and boosting competitiveness [33]. In particular, the strategic plan proposes a comprehensive list of actions to make the EU the best place in the world to launch and grow technology-driven innovative companies. It outlines legislative, policy, and financial support measures at both the EU and Member State levels to address the needs of innovative companies throughout their development.

2.3 The national European initiatives[34]

The *Italian Observatory on Quantum Computing and Communication* underlines how public financing strategies are too fragmented, as only 11% of funds come from Union Initiatives, while the largest percentage of research activities is supported directly by national governments. The *European Commission* (2025) highlights that European Member States have spent more than € 11 Billion over the past five years; however, the insufficient coordination among programs has led to duplication of efforts, inefficient use of resources, and growing competition for talent.

Every European country's challenge is to establish and pursue technological leadership, avoiding the strategic mistakes made at a national level for other inventions developed on the continent. The absence of a truly coordinated European effort could, anyway, undermine the continental initiative, with the risk of reducing the ability to build critical mass and scale, slowing down the commercialization pipeline, and limiting the development of a competitive industrial capacity.[35]

The centrality of government interventions is particularly geared toward two main general policy strategies, namely ***organizing a network for research*** and ***planning or facilitating research application and commercialization***.

According to Kung and Fancy (2021), national approaches to quantum technology research and development can be broadly classified into three groups:

- *Countries with a coordinated national strategy (including those with strategies in development);*
- *Countries without a coordinated national strategy but with significant government funding or programs;*
- *Countries that are involved primarily through participation in international partnerships*.

[32] *Welcome Europe* (n.a), "ESCALAR: 1.2 billion EU new investment strategy for SMEs", accessed December 2024. https://www.welcomeurope.com/en/escalar-1-2-billion-eu-new-investment-strategy-for-smes/

[33] https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/jobs-and-economy/eu-startup-and-scaleup-strategy_en

[34] Paragraph 2.3, "QST: the national European initiatives, was written by Raffaele Cecere and Gaia Raffaella Greco.

[35] *AI4Business*, "Tecnologie quantistiche: stanziati 17,7 miliardi di dollari di fondi pubblici nel mondo dal 2025 al 2035", November 26th, 2024. *https://www.ai4business.it/quantum-computing/tecnologie-quantistiche-stanziati-177-miliardi-di-dollari-di-fondi-pubblici-nel-mondo-dal-2025-al-2035/*

Countries with a strong predisposition for technological innovation have been in the first category for several years already, such as the United States, the United Kingdom, Israel, China, Canada, Germany, France, among others.
Countries such as Italy, Denmark, Spain, Portugal, Finland, Australia, Sweden, Ireland, and New Zealand, belonged instead to the second group in 2021.
Finally, Croatia, Estonia, Greece, Poland, Belgium, and Norway were examples of countries without significant initiatives in 2021, showing participation in international partnerships. Interestingly, nations such as Austria, Denmark, Finland, France, Germany, Israel, Italy, and the Netherlands also participated to international quantum partnership programs. Such synergies among countries are useful ways to accelerate technology developments.
In other countries, such as Sweden, the United Kingdom, and Japan, work is being done to build *quantum computers*. In others, projects are being supported to *identify possible applications* of the technologies for future commercialization. In this area, sectors such as finance, logistics, energy, artificial intelligence, machine learning, chemicals, pharmaceuticals, and materials are the ones getting the most support (Bova *et al.*, 2021).
Apart from government-level coordination (see *box 13*), a common national policy is the *creation of centers of excellence engaged in quantum research* and development. Main examples are the quantum technology centers in Australia (*QUBIC*[36] *and EQUS*[37]), Canada (CQRC[38]), UK (the *Sussex Centre for Quantum Technologies*[39]), Finland (*QTF*[40]), Germany (*Centre of Excellence in Photonics*[41]) or United Arab Emirates (QRC, *Quantum Research Center*).

Box 13. The countries and their QST Initiatives

Governments play several roles beyond funding calls. Indeed, in some countries, such as Japan, the government has provided direct and targeted funding for projects of national strategic importance, such as a 100-qubit quantum computer. In South Korea, the government selected some companies to create a nationwide QKD pilot network. Even in countries such as France, Wales, Austria, and Finland, investments have been made and direct financing has been provided for companies working in the field of quantum technologies.
In some countries, such as Israel, the *Ministry of Defense* is one of the main stakeholders. In others, such as South Korea, the various stakeholders are committed to strengthening the strategic advantage the country already maintains with information and communication technologies. In particular, the *Israeli Innovation Authority and the Defense Ministry* spent approximately $62 million to develop Israel's first quantum computer (*Times of Israel*, 2022). As for South Korea, the government planned to launch a 20-qubit quantum computer cloud service accessible to the private sector by the end of 2024 (*The Quantum Insider*, 2024).
Numerous investments also involve quantum sensing technologies, such as the Canada's *Quantum Sensors Challenge Program* of the *National Research Council*, which aims to develop applications for health, environment and defense (*National Research Council Canada*, 2024).

[36] https://www.qubic.au/
[37] https://equs.org/
[38] https://candqrc.ca/
[39] https://www.sussex.ac.uk/research/centres/sussex-centre-for-quantum-technologies/
[40] https://qtf.fi/
[41] https://www.leistungszentrum-photonik.de/en.html

Also of specific relevance is the Quantum Technology Hub Sensors and Timing of the UK's NQTP (*UK National Quantum Technologies Programme*, 2024).
Many short-term investments related to countries' strategies, such as in China and South Korea, concern the development of quantum communication technologies, quantum cryptography, quantum satellites, and Quantum Key Distribution (QKD). Investments in this area also concern Europe, such as developping a quantum network at an infrastructural level for the entire continent. Furthermore, as an example, the *North Atlantic Treaty Organization* (*NATO*) is working to develop a link based on Quantum Key Distribution technology between Malta and Italy (*NATO*, 2019).
Further investments are on using of materials more suitable for quantum use cases, such as semiconductors, topological materials, silicon, and diamond, which, due to their impurities, are exceptionally reliable for quantum applications. Examples represent the NSF in the United States (*National Science Foundation*, 2024) and the Center for Quantum Materials and Technology in Eindhoven (TU/e, 2024).

Governments wield significant influence, as they can convene investors, startups, and other pivotal stakeholders. Collaboratively, they can formulate policies and incentives essential for nurturing the quantum ecosystem's ongoing growth.
The investigation of the last *Quantera's* report, together with other institutional documents (2023; *Qureca*, 2024; Ezratty, 2024; *MUR*, *MIMIT*, 2025), shows current data and new strategies concerning different countries worldwide. The reports underline how countries such as Denmark (Danish Strategy for Quantum Technology, DSQT), Latvia (European Union Recovery and Resilience Mechanism Component 'Digital Transformation', DT), between 2021 and 2024, have built their own national strategy on the evolution of quantum technology. Other countries, such as Ireland, Romania, Slovakia, Spain, and Sweden, are in the process of having their own national strategy. *Table 3* summarizes the policies updates in different nations to 2025.

Table 3: The quantum strategic changes in different countries between 2021 and 2025

Country	2021 (Kung and Fancy)	2023 (Quantera)	Qureca (2024)[42] and others
Denmark	No national strategy, but significant government-led or endorsed initiatives	Danish Strategy for Quantum Technology, DSQT (2023)	Long-term focus on quantum research and innovation to solidify Denmark leadership position. As part of the research strategy, the Danish government intends to spend a billion DKK over the next five years
Italy	No national strategy, but significant government-led or endorsed initiatives	Italian Plan for Recovery and Resilience, PNRR	National Quantum Strategy published in 2025 (*MUR*, *MIMIT*; 2025)
Latvia	No significant initiatives, but participants in international partnerships	European Union Recovery and Resilience Mechanism Component 'Digital Transformation', DT	The Latvian Quantum Initiative (2024) supports global and national efforts in the creation and application of quantum technologies and serves as a framework for the effective

[42] *Qureca* (2024), "Quantum Initiatives Worldwide", updated November 23rd.
https://www.qureca.com/quantum-initiatives-worldwide/

			development of quantum technologies[43]
Ireland	No national strategy, but significant government-led or endorsed initiatives	In progress	Quantum 2030, National Quantum Technologies Strategy for Ireland, was launched in November 2023[44]
Romania	No significant initiatives, but participants in international partnerships	In progress	National Strategy for Quantum Technologies (2024-2029) was launched in August 2024[45]
Spain	No national strategy, but significant government-led or endorsed initiatives	In progress	Spain announced an investment of 60 million € to build a quantum computer through the Quantum Spain project, which will contribute towards the creation of a quantum ecosystem
Sweden	No national strategy, but significant government-led or endorsed initiatives	In progress	The Wallenberg Center for Quantum Technology (WACQT), in partnership with the Swedish Research Council, has initiated a decade-long research program with an investment of SEK 1.6 billion ($160 million) supporting the establishment of a national quantum research centre

Source: Kung & Fency, 2021; Quantera, 2023; Qureca, 2024.

Before discussing the Italian Strategy and the EU Initiatives in Quantum Science and Technology, some of the most relevant European startups, who represent national champions of innovation, will be briefly introduced.

Qnami[46]

Qnami is a Swiss company founded in 2017 in Muttenz, specializing in the development of quantum mechanical-based technologies, with a special focus on quantum sensors. The main founders are Mathieu Munsch, CEO of *Qnami*, and Patrick Maletinsky, a professor at the *University of Basel*. The idea for the company was born during a shared trip after a quantum physics conference, where they saw the disruptive potential of Maletinsky's technology.

In 2019, the company launched the *Qnami ProteusQ*, the first commercial Nitrogen-Vacancy (NV)-based magnetometer for studying magnetic materials at the nanoscale. The technology uses patented diamond

[43] Latvian Quantum Initiative, Research Directions. Accessed December 2024. https://www.quantumlatvia.lu.lv/en/research/research-directions/

[44] Government of Ireland (15th November 2023), A National Quantum Technologies Strategy for Ireland". https://www.gov.ie/en/publication/126b4-quantum-2030-a-national-quantum-technologies-strategy-for-ireland/

[45]Ministry of Research, Innovation and Digitalization (2023), "National Strategy in the field of Quantum Technologies 2024-2029". https://www.mcid.gov.ro/programe-nationale/strategia-nationala-in-domeniul-tehnologiilor-cuantice-2024-2029-2/

[4646] The business case study "Qnami" was written by Raffaele Cecere and Gaia Raffaella Greco.

probes, *Quantilever*, offering innovative applications in materials, spintronics, and semiconductor research.[47].

The instrument provides high-precision images that allow direct observation of the finer properties of samples and the effect of microscopic changes in the design or manufacturing process. Key applications include materials characterization, current imaging in integrated circuits, spintronics, non-volatile memories, 2D materials, biological systems, and quantum devices.

Qnami's quantum sensors were essential to observe how quantum light emitters, capable of generating single photons with circular polarization and nonclassical statistics, could enable non-reciprocal single-photon devices and deterministic spin-photon interfaces for quantum networks (Li *et al.*, 2023).

Qnami completed a CHF 4 million Series A funding round in 2021, supported by investors such as *Runa Capital*, *SIT Capital*, *Quantonation*, *Verve Ventures*, and others. The funds were aimed at expanding product capabilities and entering new markets, such as cryogenic design and spintronic device development.[48]

Qnami represents a practical example of how quantum sensors can be translated into commercial tools, contributing to emerging fields such as spintronics and quantum computing. Its ability to transform academic research into industrial applications underscores the critical role of quantum innovation in enhancing materials science and next-generation technologies.

Arqit[49]

Arqit, based in London, UK, specializes in quantum cryptography-based cybersecurity. Founded in 2017, the company is dedicated to developing advanced security solutions to protect data from current and future threats, including attacks from quantum computers. Its key technology is the *Symmetric Key Agreement* (SKA) *Platform*™, formerly known as *QuantumCloud*™, which provides strong and scalable encryption through symmetric key agreement on a global basis, without the need for satellites[50].

Arqit develops quantum-safe encryption solutions for various industries, including finance, defense, telecommunications, and IoT. Key services include:

- *SKA Platform™*: a symmetric key agreement platform designed to simplify and strengthen cryptography. This platform enables organizations to move from a complex PKI infrastructure to a secure and scalable cloud-based solution (SKA Quantum Encrypt).
- *NetworkSecure™* Adapter: the software application protects VPN communications from traditional and quantum attacks, such as "store now, decrypt later" attacks. This solution easily integrates with existing network infrastructure and provides on-demand quantum-safe shared symmetric keys.
- *TradeSecure™*: the tool for securing digital trading instruments against quantum threats, improves the security of financial transactions, reducing operational risk.

One of the most relevant case studies for *Arqit* was the implementation of the *NetworkSecure™ Adaptor*. This solution demonstrated its effectiveness in securing VPN communications for a global financial organization. The company was able to:

[47] *Qnami*. (n.d.). *About Qnami*. Accessed July 2024.
https://qnami.ch/about-us/company/

[48] *Venturelab*. (2021). Qnami raises CHF 4 million to advance its patented quantum microscope technology. https://www.venturelab.swiss/Qnami-raises-CHF-4-million-to-advance-its-patented-quantum-microscope-technology.

[49] The business case study “Arqit” was written by Raffaele Cecere and Gaia Raffaella Greco.

[50] *Arqit*. (n.d.). Who We Are. Consulted July 2024.
https://arqit.uk/who-we-are

- *Increase security*: hardening network communications against man-in-the-middle and SNDL (Store Now, Decrypt Later) attacks, which pose a significant threat with the advent of quantum computers.
- *Ease of deployment*: adoption was effortless due to integration with existing infrastructure, avoiding costly and complex hardware upgrades.
- *Compliance*: the solution helped the organization comply with National Security Memorandum NSM-10 security recommendations and NSA requirements for symmetric key management.

Arqit has raised significant funding through various channels, including a $400 million SPAC merger in 2021, which allowed it to list on the *Nasdaq* under the ticker *ARQQ*. Despite this, the company has faced financial challenges, with revenue generation lagging expectations and operational losses being reported in recent years.[51]

As of late 2024, *Arqit* has faced mixed progress. It announced a $13.6 million capital raise to strengthen its financial position. While the company has gained significant recognition, including awards for cybersecurity innovation, its FY 2024 revenue dropped to $293,000 from $640,000 the previous year.

Arqit has achieved new multi-year contracts, especially within government and telecom sectors, which are expected to boost recurring revenues. The company has also scaled back its focus on satellite technologies to streamline operations and address ongoing investigations by the U.S. *SEC* (*Security and Exchange Commission*).[52]

Arqit continues to innovate in quantum security, collaborating with various industries to ensure that their data is protected against current and future threats while maintaining a strong commitment to creating robust and scalable encryption solutions.

Quandela[53]

Founded in 2017 with a specialization in quantum photonics, *Quandela* is a French startup based in Messy (Paris). The company grew out of the research conducted at the *Center for Nanoscience and Nanotechnology* at *Paris-Saclay University*. The principal founders are Nicolò Somaschi, Valérian Giesz, and Pascale Senellart. The startup is pioneering the development of a quantum computer based on single photons, using innovative approaches for generating and manipulating quantum states. The company offers different services: a platform dedicated to quantum photonic computing (*MosaiQ*), a quantum photonics development toolkit for a wide range of end users (*Perceval*), and an autonomous quantum light source (*Prometheus*). The use cases are diverse and cover the following application areas: cybersecurity, logistics, aerospace, pharmaceuticals, chemical energy, and finance[54].

The company has experienced significant growth through major milestones and funding. In 2023, it raised 50 million in a funding round to accelerate the development of its quantum hardware and expand its

[51] *TheQuantumInsider*. (2021). Quantum SPAC in Space: Arqit Limited to Raise $400 Million Through SPAC Deal. https://thequantuminsider.com/2021/05/12/quantum-spac-in-space-arqit-limited-to-raise-400-million-through-spac-deal/

[52] *Arqit*. (2024). Arqit Quantum Inc. Announces Financial and Operational Results for the Fiscal Year 2024. https://ir.arqit.uk/news-events/press-releases/detail/98/arqit-quantum-inc-announces-financial-and-operational

[53] The business case study "Quandela" was written by Raffaele Cecere and Gaia Raffaella Greco.

[54] *Quandela*. (n.d.). Quandela Applications. Consulted July 2024. https://www.quandela.com/applications/

software capabilities[55]. *Quandela* also delivered a quantum computer to *OVHcloud*, making it the first private company in Europe to integrate an operational quantum system into its infrastructure[56].
One of the quantum computing use cases involves the generation of intrinsically random numbers on a small two-qubit device. The company used the Entropy protocol on the *MosaiQ* full-stack quantum computer. Other similar applications have involved text analysis and understanding.
In logistics, *Quandela's* challenge with *Thales* is to solve problems related to constructing the shortest path graph in air traffic. Still, with the increasing use of unmanned drones, air traffic management has become more complex. The technology used by *Quandela* is based on the unconstrained QUadratic Binary Optimization (QUBO) approach on the photonic quantum computer to find the shortest path between a starting point and an end point. Other applications of the technology based on a photonic quantum computer include encoding matrices intended as graphs, using algorithms that use a particular encoding to determine whether two graphs are isomorphic, or finding dense subgraphs of fixed size in a given graph. These problems have applications in many fields, such as air traffic management, social networks, and chemistry. The technique in question is boson sampling, a method technically suitable for photonic quantum computers, which can be used to estimate the permanence of a matrix. The permanent reveals the properties of the input matrix and the state of the photonic chip, which we use to solve important problems on graphs, improving on classical techniques.
Aerospace applications include partnerships with *ONERA* and *MBDA* in a project funded by the Île-de-France region. The challenge was to solve systems of differential equations on a quantum computer. Specifically, the scope of the collaboration is to simulate combustion reactions in thermal engines to optimize fuel consumption, using algorithms to be implemented on the *MosaiQ* photonic quantum computer. Another use case for *Quandela* in chemistry involves testing new drugs by simulating the properties of large molecules. *Alysophil* and *MBDA* developed a hybrid classical-quantum algorithm to group polymers with specific properties for large-scale simulations.
Quandela's applications have also extended to the energy sector with a partnership with EDF. The companies developed a quantum algorithm that models the mechanical structure of power plants, with the prospect of improving maintenance planning for safer facilities. A variational quantum algorithm was used to solve a set of partial derivative equations[57].

Alpine Quantum Technologies[58]

With the headquarters located in Innsbruck (Austria), AQT (*Alpine Quantum Technologies*) core activities lie in the development and commercialization of ion-trap quantum computers. AQT's technology uses electric fields to trap single charged atoms inside vacuum chambers, with each ion representing a quantum bit (qubit). These qubits are manipulated and measured using precisely timed laser pulses[59]. The company was founded in 2018 by Thomas Monz, Rainer Blatt, and Peter Zoller, all renowned experts in quantum

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[55] *Quandela*. (2023). Quandela secures €50 million to support international expansion. https://www.quandela.com/about-us/newsroom/quandela-secures-e50-million-to-support-international-expansion/
[56] *OVHcloud*. (2024). OVHcloud arricchisce con Qiskit il proprio portafoglio leader di mercato di notebook Quantum. https://corporate.ovhcloud.com/it/newsroom/news/qiskit-quantum/
[57] *Quandela*. (n.d.). *Quandela* Applications in Pharmaceuticals. Consulted July 2024. https://www.quandela.com/applications/4-pharmaceuticals/
[58] The business case study "Alpine Quantum Technologies" was written by Raffaele Cecere and Gaia Raffaella Greco.
[59] *Alpine Quantum Technologies*. (n.d.). AQT Overview. Consulted September 2024. https://www.aqt.eu/

physics, with extensive experience in areas such as trapped ions, quantum optics, and quantum noise. The founders are associated with the *University of Innsbruck*, one of the world's leading research institutions in quantum technology.

AQT actually offers a range of quantum computing solutions and modules. One of their key products is the *PINE system*, a scalable ion-trap quantum computer designed for various applications, including quantum chemistry, high-energy physics simulations, and universal quantum computing. The *PINE system* shows capabilities in process optimization and memory lifetime, as well as compatibility with 19-inch racks, making it suitable for integration into existing infrastructures.

Use cases and applications of AQT's technology span several fields:

- *Quantum Chemistry*: *AQT's* quantum computers model complex chemical bonds and reactions beyond the capabilities of classical supercomputers. The technology has significant implications for material science, medicine, and industrial chemistry, potentially leading to new catalysts, improved materials, and personalized medicines.
- *Process Optimization*: *AQT's* quantum computers are used for optimizing processes, leading to more efficient operations and reduced costs. This application leverages the computational power of quantum systems to solve complex optimization problems more effectively than traditional methods.
- *High-Energy Physics Simulations*: quantum simulators developed by *AQT* can model high-energy physics phenomena, providing insights that are difficult to obtain through experimental or classical computational methods.
- *Quantum Error Correction*: *AQT* has achieved advancements in topologically encoded quantum error correction, developping fault-tolerant quantum computers. This technology aims to ensure that quantum computations remain accurate even in the presence of errors.

AQT also provides access to its quantum computers through cloud services, allowing researchers and industry partners to utilize its systems for various applications. It supports multiple quantum Software Development Kits (SDKs), such as *Cirq*, *Qiskit*, and *Pytket*, facilitating the integration and development of quantum algorithms.

By pushing the boundaries of trapped-ion systems, *AQT* provides a key example of cutting-edge innovation driving the quantum computing industry forward.

Bosch Quantum Sensing[60]

Bosch Quantum Sensing, established by Robert Bosch GmbH, is a dedicated business unit focused on commercializing quantum sensor technologies. Founded in 2022, the initiative is part of Bosch's long-term strategy to leverage quantum technologies for innovative sensor applications. The unit operates with startup-like autonomy while benefiting from Bosch's extensive R&D resources and industrial ecosystem.

Its activities are divided into four business segments: Mobility Solutions, Industrial Technology, Consumer Goods and Energy, and Building Technology. Bosch offers innovative IoT solutions for smart homes, Industry 4.0, and connected mobility. Bosch pursues a vision of sustainable, safe and exciting mobility. It uses its expertise in sensor technology, software, and services, as well as its IoT cloud to offer its customers connected and cross-industry solutions using the latest technologies such as artificial intelligence and quantum technologies. In the field of quantum technologies, Bosch has been collaborating with IBM since 2022 to develop solutions in the field of material science[61].

[60] The business case study “Bosch Quantum Sensing” was written by Raffaele Cecere and Gaia Raffaella Greco.

[61] *IBM*. (2022). *Bosch* Partnering with IBM on Strategic Quantum Computing Materials Science Engagement. Consulted July 2024.

Bosch, leveraging its activities in the field of electrical mobility, would like to find new concrete applications in which a quantum computer could offer a competitive advantage, namely in the discovery and design of new materials to provide greater energy efficiency. A quantum computer could calculate the electron properties of batteries and electric motors more accurately than a classical computer. The partnership between Bosch and IBM aims to develop quantum algorithms for applications in the field of electric mobility. In fact, in the field of electromobility, quantum sensors could be used to accurately determine the state of charge of batteries, thanks to the measurement with extreme precision of a magnetic field.
However, the use of quantum sensors is not only in electric mobility, but also in navigation. In this area, in fact, very often global positioning system (GPS)-based detections could be interfered with. One of the properties of quantum sensors is their resistance to external interference, as they measure the Earth's immutable magnetic field.
Moreover, Bosch quantum sensors have the potential to revolutionize medical diagnosis by measuring the heart's magnetic field. Unlike current electrocardiography (ECG) devices that require electrodes directly on the skin, the quantum sensors can be embedded in clothing or mattresses, providing more accurate and continuous measurements. The technology eliminates the risk of slipping electrodes and saves precious time in emergencies. The sensors also enable easy and accurate monitoring at home. With this technology, non-contact early diagnosis of atrial fibrillation, a leading cause of life-threatening strokes, heart failure, and dementia, becomes feasible for the first time. Early detection using quantum sensors could prevent fatal strokes and improve patient outcomes. This innovation has the potential to significantly impact medical care and help save lives in the future.[62]
Bosch Quantum Sensing is a prime example of how quantum technology is transitioning from research to real-world applications. Its focus on scalable, industrial-grade solutions underscores the potential of quantum sensors to disrupt fields like healthcare, automotive, and geophysics. Moreover, Bosch's strategic and resource-rich approach demonstrates the role of established corporations in driving quantum innovation.

2.4 The Italian Strategy for Quantum Technology[63]

In 2025, the National Plan for the Development of Quantum Technology was adopted, marking an important step forward in strengthening the country's competitiveness and security. The new Italian Strategy for Quantum Technology aims to enhance research, promote industrial innovation, and strengthen technological capabilities.
The *Working Group* is composed of both experts from the scientific community as of representatives from the *Ministry of University and Research* (*MUR*), the *Department for Digital Transformation* (*DTD*) of the *Presidency of the Council of Ministers*, the *National Cybersecurity Agency* (*ACN*), the *Ministry of Enterprises and Made in Italy* (*MIMIT*), the *Ministry of Defense*, and the *Ministry of Foreign Affairs and International Cooperation* (*MAECI*) in order to duly represent the interests of different public and private stakeholders.

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https://newsroom.ibm.com/2022-11-09-Bosch-Partnering-with-IBM-on-Strategic-Quantum-Computing-Materials-Science-Engagement
[62] *Bosch*. (2023). Quantum technologies: Bosch aims to use sensors to take a leading position.
https://www.bosch-presse.de/pressportal/de/en/quantum-technologies-bosch-aims-to-use-sensors-to-take-a-leading-position-258816.html
[63] The entire paragraph is an extract of the original document *"Italian Strategy for Quantum Technologies"*, 2025, QIS_FINAL_EN.

In addition to the funding of basic research, the creation of public-private collaborative networks is considered crucial to promote applied research and technology transfer, while the enhancement of national laboratories where companies and research institutions can work together will enable the development of new industrial solutions.

Figure 20. The summary of future action lines of the Italian Strategy for Quantum Technology

Scientific development directions	
Basic quantum science	OSc-1: Maintaining and strengthening Italy's role in basic research in the European and global scenario
Quantum computation	OSc-2: Achieving a stage of proven quantum advantage over classical computation
Quantum simulation	OSc-3A: Development of dedicated hardware for quantum simulation
	OSc-3B: Implementation of efficient quantum algorithms for complex optimization problems.
Quantum communication	OSc-4A: Realization of secure and integrated quantum communication networks.
	Osc-4B: Extending secure quantum communications over long distances
	Osc-4C: Enabling quantum networks for direct exchange of quantum resources (quantum internet)
	Osc-4D: Consolidating the security of quantum communication solutions
Quantum sensing and metrology	OSc-5A: Capacity building for testing and certification of quantum technologies and sensors under the community strategy
	OSc-5B: Support for research infrastructures developing quantum sensors, with prototyping and experimentation, to accelerate technology transfer and industrial implementation
	OSc-5C: Addressing research and development of strategic quantum sensors for domestic industry.
Enabling technologies	OSc-6A: Ensure full control of selected technology platforms, significantly reducing dependence on non-EU materials and technologies
	OSc-6B: Development, integration and characterization of components for quantum device fabrication
Standardization	OSc-7: Coordination and
Benchmarking	OSc-8A: Coordination and Collaboration.
	OSc-8B: Tools and Infrastructure
Strategic recommendations	
Research	OSt-1A: Strengthening the research and innovation ecosystem.
	OSt-1B: Coordination of research funding.
	OSt-1C: Research attractiveness and internationalization.
Technological transfer	OSt-2A: Collaborative Ecosystem for Quantum Innovation.
	OSt-2B: Financial Instruments and Incentives for Growth.
	OSt-2C: Skills development and strategic partnerships.
Higher education and vocational training system	OSt-3A: First and second level higher education
	OSt-3B: Third Level Higher Education
	OSt-3C: Workforce training and upgrading for industries.
Communication and outreach	OSt-4: Widespread awareness, awareness and broad access to QTs.
Industry	OSt-5A: Support for the creation of mechanisms for permanent comparison of actors in the Italian ecosystem on QTs
	OSt-5B: Funding for the creation of a structured and mature public-private ecosystem.
	OSt-5C: Promoting industrialization and entrepreneurship on quantum technologies nationwide
	OSt-5D: Ensuring access to quantum technologies and infrastructure critical to the country system
	OSt-5E: Developing a skilled workforce and creating an attractive market for domestic and foreign talent
	OSt-5F: Defining knowledge dissemination programs and increasing awareness of opportunities and risks in user enterprises
	OSt-5G: Promotion of international cooperation in industrial and applied research policies on quantum technologies

The creation of advanced training programs and industrial doctorates will contribute to the growth of the skilled workforce, an essential aspect of the sector's expansion.
Equally important is support for the internationalization of Italian QT operators and the international promotion of domestic ecosystems (attracting talent and foreign capital) through economic diplomacy.
Italy has the opportunity to position itself as a key player in the QT landscape. Yet this requires a clear strategic vision and an ongoing commitment to support research and innovation, international promotion, and security protection in critical technology sectors, particularly in those segments most vulnerable to illicit or unwanted transfer of strategically valuable skills and knowledge (see *figure 20*).
The path outlined in the official document offers a roadmap to consolidate the Country's role in QTs and ensure a secure and competitive technological future. Investing in these technologies means not only seizing an opportunity for economic and industrial growth, but also strengthening national security and contributing to global scientific progress.
The coming years will be decisive: who will lead the industrial and scientific development of QTs will dominate the fields of secure communication, artificial intelligence, simulation of complex materials, and high-performance computing. With the Strategy, Italy aims to close the gap with more advanced countries, strengthen its autonomy in key sectors, and generate new industrial supply chains and skilled employment. The strategy is based on four priority axes:

- *Scientific and industrial development in the five pillars of QT* (computation, simulation, communication, sensing, basic science);
- *Building an integrated national ecosystem capable of generating value along the entire chain*: research, technology transfer, industry, training;
- *Internationalization and security*: active positioning in EU programs and protection of critical technologies;
- *Governance and measurability*: concrete tools to coordinate, evaluate, and update strategic actions.

Italy enjoys scientific excellence but suffers from fragmentation that weakens its competitive stance. The document outlines an operational pathway to:

- attract and retain top talent;
- reinforce test, certification and prototyping infrastructure;
- develop a nation-wide network of competence centers;
- support the scale-up of Italian deep-tech start-ups;
- activate monitoring tools, KPIs and impact evaluation.

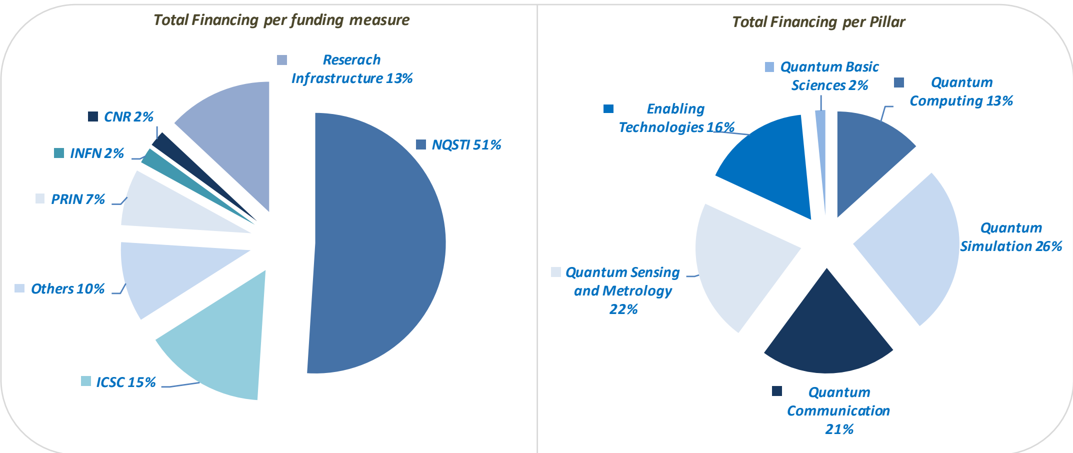
Italy has high development possibilities in the field of quantum technology, thanks to research excellence and the potential of the industrial sector. However, the Country suffers a significant lag in public funding, compared to an international scenario led by countries that have planned large investments over long periods of time. Ecosystem mapping and data from private sector consultations show that funds dedicated to quantum technology under NRRP projects have generated a significant leverage effect, catalysing private investment and stimulating skills development. The funded initiatives have enabled the development of a virtuous synergy between academia and business as well as technology transfer activities, in the context of NRRP spokes. To consolidate and expand these results, however, it would be crucial to continue along this trajectory with targeted measures (see *box 14*).

The analysis conducted by the working group's scientific experts shows that, in order to place itself in the rut of the countries with the highest rate of technological development and increase attractiveness and competitiveness for the benefit of the entire ecosystem, *Italy needs to plan a volume of funding in the sector of about 200 million per year, for a period of five years* (in addition to what has already been invested). This amount would represent 0.01 percent of GDP, a share close to that already planned by France and Germany.

Box 14. The MUR data on Public Investments

MUR, the Italian *Ministry of University and Research*, has recently presented data on national public investments in Quantum Science and Technologies (see *figure 21*). The total amount invested would be around 227,4 million Euros. *NQSTI* represents almost 50% of all public engagement; non-PNRR funds would consequently express a small percentage of the total. Quantum Simulation, Quantum Communication, and Sensing and Metrology show similar amounts of funds invested in total value: 26%, 21%, and 22%. Quantum Computing would represent a smaller fraction (13%). The Italian Ministry also highlights funds devoted to quantum basic science and invested in Enabling Technologies (16%).

Figure 21. The Italian Public Investments – the MUR data[64]



Giving continuity to the funds spent so far in NRRP projects would not allow the development of ambitions commensurate with the potential of the country system, as detailed in the Strategy. It would lead to a loss of competitiveness in a global scenario.

[64] The MUR data were presented at the event “EuroQCI Italy: for the Italian and European Quantum Strategy”. More Information available at:
https://quid-euroqci-italy.eu/it/euroqci-italy-for-the-italian-and-european-quantum-strategy/

2.5 The *Quantum Flagship*: the strategic Research Agenda

Since the *European Quantum Flagship* was launched in 2018, the *European Commission* has allocated more than €1 billion in funding over 10 years. Indeed, the main objective of the *European Quantum Flagship* is to consolidate and expand European scientific leadership and excellence in this research area, in order to revive a European industry in quantum technology (see *box 15*).

Quantum technology is considered the leading technology of the future. The adoption of the official *Flagship* document was supported by more than 3500 experts in the field, including academics and practitioners. The main objectives remain the creation of reference standards for quantum technology, the intensification of education, and the creation of an aware workforce[65].

Box 15. The Quantum Flagship

The *Quantum Flagship* consists of a coherent set of research and innovation projects selected through a thorough peer-review process. Calls for projects are issued based on the Flagship's Strategic Research Agenda. The goal is:

- *to consolidate and expand European scientific leadership and excellence in this research area,*
- *to kick-start a competitive European industry in Quantum Technologies and*
- *to make Europe a dynamic and attractive region for innovative research, business, and investments in this field.*

European institutions offer various funding opportunities for quantum technologies, from early-stage research and applied research (Horizon Europe programme) to infrastructure investments (Digital Europe programme). In addition, individual companies – mainly startups – can receive support from the *European Innovation Council* and the *European Investment Bank*.

Source: https://qt.eu/about-quantum-flagship/, Retrived October 2024.

As in other parts of the world, *Quantum Flagship* projects are creating and developing technologies such as the implementation of quantum computers and simulators in the *European High Performance Computing* (*EuroHPC*) initiatives, or the implementation of a Quantum Key Distribution (QKD) infrastructure in the *European Quantum Communication Infrastructure* (*EuroQCI*) initiatives (see *figure 22*).

The *European Commission* officially announced *EuroQCI* in 2019. The initiative involves all 27 member states in building a secure quantum communication infrastructure that will cover the entire EU, including overseas territories.[66]

Other investments include initiatives related to the workforce to be employed in the growing quantum technology offering, notably *DigiQ* (*Digitally Enhanced Quantum Technology Master*), a quantum education program offering internships and exchange programs, and *QTIndu* (*Quantum Technology Courses for Industry*), a course program

[65] *Quantum Flagship*. (n.d.). About Quantum Flagship. Consulted July 2024. https://qt.eu/about-quantum-flagship/https://qt.eu/about-quantum-flagship/

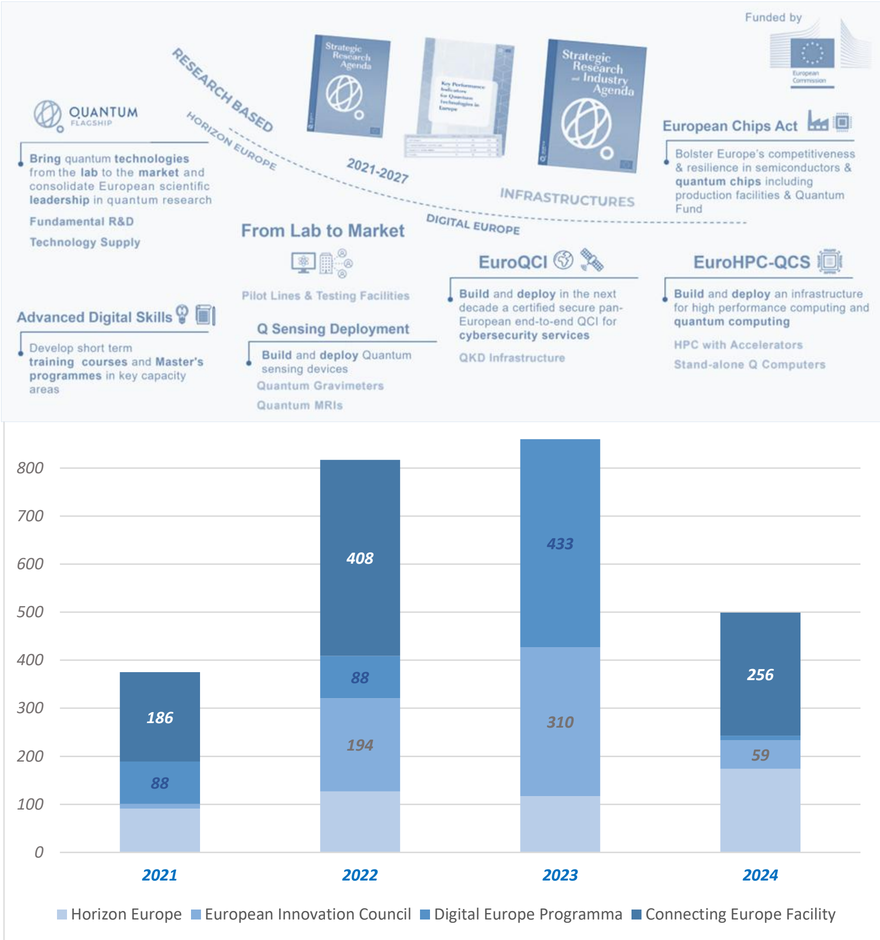
[66] *European Commission*. (2024). European Quantum Communication Infrastructure (EuroQCI). Consulted July 2024. https://digital-strategy.ec.europa.eu/en/policies/european-quantum-communication-infrastructure-euroqci

dedicated to companies operating in sectors where quantum technology can be applied.[67]

To see how quantum technology will affect cybersecurity in the digital domain, the *European Union* set specific priorities for research funding, recommended by a task force based on three main aspects: *quantum resilient cryptography*, *cryptographic agility*, and *best practices for migrating information systems* (Pupillo *et al*., 2023).

In addition to supporting research at the intersection of quantum technology and cybersecurity, the European objectives promote perspectives in line with other parts of the world, such as the United States. One of the initiatives is to promote cryptographic agility policies and coordination at the EU level to facilitate the transition to quantum-resistant cryptography and to promote the standardization of quantum-resistant cryptography. To this end, more emphasis could be placed on the value of the contributions of EU researchers to the EU standardization process. By highlighting the contributions of its researchers, the EU could position itself as a cornerstone of the global standardization process (see *box 16: other pivotal European Initiatives*).

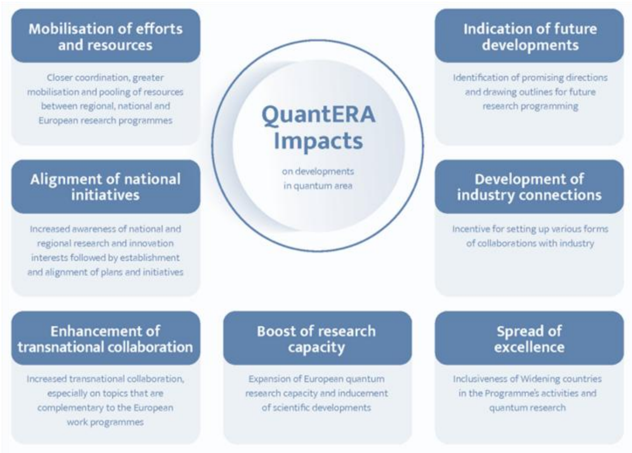
Figure 22. The European Strategic Pillar of EU Quantum Ecosystem and funding dimensions



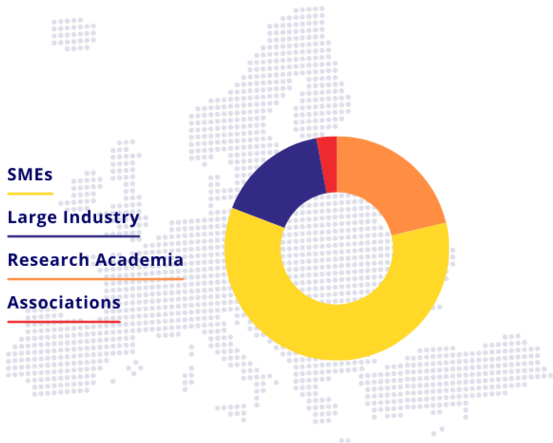
[67] *QURECA*. (2023). Making European Industry Quantum Ready. https://www.qureca.com/qtindu-making-european-industry-quantum-ready/

Source: Quantum Flagship, 2024.[68]

Box 16. The other Pivotal European Initiatives

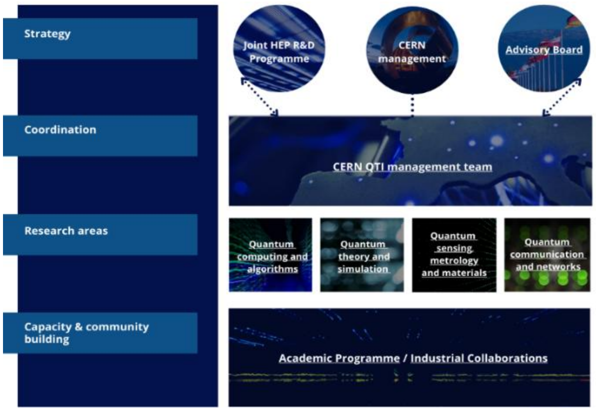


QUANTERA is a leading European network of Research Funding Organisations (RFOs) that supports and subsidises the development of Quantum Technologies (QT). The QuantERA Consortium puts science and technology at its very heart, investing in excellent Research and Innovation.
The main goal of the QuantERA programme is to finance cutting-edge international research projects (see side *figure*). QuantERA answers the growing need for collaborative endeavours and Europe's most effective standard funding scheme. The network aims to launch transnational Calls to develop synergy of European research in Quantum Technologies. So far, Calls in 2017, 2019, 2021, and 2023 have attracted almost 2600 research teams who submitted more than 500 proposals. As a result, QuantERA has funded 101 excellent international projects run by consortia of 541 national teams. The budget dedicated to funding QT projects has already reached EUR 117 M, including cofunding (QuantERA I project in 2016 and QuantERA II project in 2020) from the European Union's Horizon 2020 Research and Innovation Programme.



QuIC[69] (*Quantum Industry Consortium*). The European Quantum Industry Consortium is a not-for-profit industry pan-European association, founded in 2021, dedicated to the growth of the commercial quantum technology sector. QuIC operates as a collaborative hub throughout Europe, bringing together hundreds of SMEs, large corporations, investors, research and technology organizations, and academic institutes, to build a strong, vibrant quantum ecosystem (see *figure* on the left). Together, members of the association address topics of common interest, such as standardization, intellectual property, trade, and workforce development.
Today, QuIC is part of the coordination and support action of the Quantum Flagship, a European project that aims to make Europe a dynamic and attractive region for innovative research, business, and investments in the dynamic quantum field.

[68] *Quantum Flagship*, Funding Opportunities. Consulted November 2024. https://qt.eu/funding-opportunities/
[69] *European Quantum Industry Consortium* (n.d), "QuIC in brief". Accessed July 2024. https://www.euroquic.org/



The CERN *European Center for Nuclear Research*, Geneva, Switzerland) Quantum Technology Initiative (CERN QTI[70]) has defined a roadmap and research program in collaboration with its advisory board, and the high-energy physics and quantum-technology research communities. The initiative aims to establish joint research, educational, and training activities, set up the supporting computing infrastructure, and provide dedicated mechanisms for the exchange of knowledge and innovation.

2.6 The *Quantum Strategy*: the moment for Europe to lead

In July 2025, the *European Commission* published its Communication on the *Quantum Europe Strategy*, highlighting how the global race to harness quantum technology is accelerating, moving beyond the lab and entering real-world applications. European Countries would stand at the inflection point: they boast the world's largest concentration of quantum talent and scientific publications; the EU has the largest quantum startup ecosystems. However, Europe is slow in translating its innovation capabilities into real market applications, lacking sustainable financial support and sufficient market perspectives.

The EU's strategic vision is to transform Europe into a quantum industrial powerhouse and a global market leader, building on sustained scientific leadership. Particularly, the Strategy focuses on five interconnected areas: research and innovation, quantum infrastructures, ecosystem strengthening, space and dual-use technology, and quantum skills (see *figure 23*).

The *Strategic Implementation Framework* includes describing upcoming initiatives in each specific quantum vertical, the main actions:

- launching the *Quantum Europe Research and Innovation Initiative*, a joint EU and Member States' effort to support foundational research and develop applications in key public and industrial sectors;
- establishing a *quantum design facility and six quantum chips pilot lines*, backed by up to €50 million in public funding, to transform scientific prototypes into manufacturable products;
- launching a *pilot facility for the European Quantum Internet*;
- expanding the *network of Quantum Competence Clusters across the EU* and establishing the *European Quantum Skills Academy* in 2026;

[70] *CERN* (n.d), The Quantum Initiative. Consulted July 2024.
https://quantum.cern/

- developing a *Quantum Technology Roadmap in Space* with the European Space Agency and contributing to the *European Armament Technological Roadmap*.

Figure 23. The Europe Quantum Strategy: The Five Targeted Areas[71]

As evidenced in the official Europe Quantum Strategy Press Release[72], the next steps would be:

- to work closely with the Member States and European quantum community including academia, startups, industrial actors, and innovation stakeholders and their representatives to turn Strategy's objectives into reality;

[71] Quantum Europe Strategy
[72] Commission launches strategy to make Europe Quantum leader by 2030

- to form a *High-Level Advisory Board* for bringing together leading European quantum scientists and technology experts to provide independent strategic guidance on the implementation of the *Quantum Europe Strategy*;
- to propose in 2026 a *Quantum Act* to further strengthen the quantum ecosystem and the industrialisation efforts by incentivising Member States and companies, investors and researchers to invest in (pilot) production facilities, under the umbrella of large-scale EU-wide national or regional initiatives.

CHAPTER 3. THE ITALIAN QST SYSTEM OF INNOVATION

3.1 The Italian QST market size and trends in reports

The *McKinsey* Report "Quantum Technology Monitor, 2024" investigates the main dimensions of the Italian national context, underlying how total public investment picked up to 144 million dollars and recognizing almost 70 different partners in the national network (among public and private organizations, see *table 4*)[73]. Particularly, the consulting firm discusses the pivotal role played by the PNRR Projects as *NQSTI* and *ICSC*, as well as the *QUID* project within the *EuroQCI* infrastructure. *McKinsey* (2024) describes the Italian private organizations: 2 companies in quantum computing, 3 firms in quantum communication, and 2 multi-national corporations with an Italian subsidiary, for a total number of 7. [74]

Table 4. The McKinsey Report (2024) on Italy QST Dimensions

Figures	Policies and news	Companies	
~$ 144 Million *Total Public Investment*	*NQSTI Consortium launched in January 2023, is funded under NextGenerationEU and supports quantum technology education, technology transfer, and social outreach*	*Technology*	*N*
No reported Private Investment	*ICSC Spoke 10 focuses on QC applications, HD-SW, and scalability*	***Quantum Computing***	***2***
2% *Of QT-related patents have been granted to researchers based in Italy*	*QUID project within the EuroQCI infrastructure develops 13 QMANs in Italy connected to the IQB, and regions have developed strategies following EU to create ecosystems for startups and spinoffs*	***Quantum Communication***	***3***
~70 *Academic and Industry Partners as part of Italian QT System*	*- February 2024, Italy's first permanent multi-nodes connected to Italian Quantum Backbone, Naples (Funded BY MImit AND Meditech)* *- April 2023, SeeQC developed a joint-lab with Federico II University for first full-stack Quantum Computer"*	***Other (MNCs in Italy)***	***2***

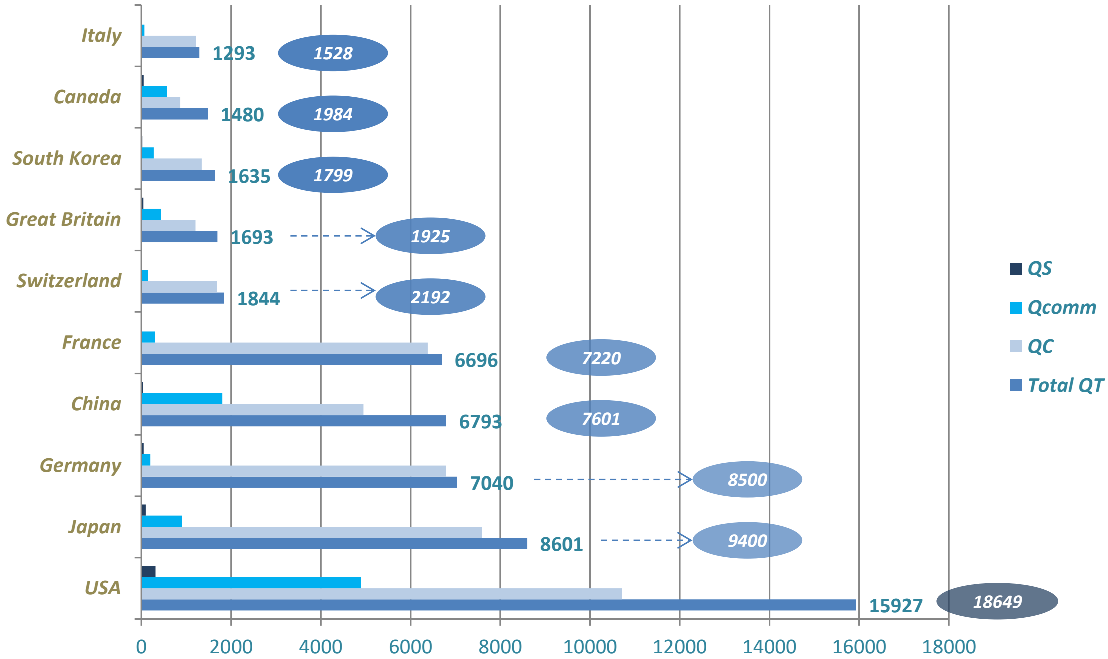
Even though the *McKinsey* Report (2024) finds only 7 companies, the report on patents granted globally evidences a different path of development for Quantum Technology in the country. As evidenced in *figure 24*, the consulting company realizes a classification of patents by Headquarters' location from 2000 to 2024. In 2023, Italy occupies the tenth

[73] The *McKinsey* Report "Quantum Technology Monitor, 2025" does not provide an investigation of the Italian QST system.

[74] The *Quantera Landscape Database* found only 2 Italian companies in a sample of 108 firms populating the European Quantum Technology System (*SeeQC*, and *Engineering*). https://quantera.eu/industry-qt/. Retrieved January 2024.

position in the global landscape with 1293 patents granted: 1215 in Quantum Computing (almost 94%), 64 on Quantum Communication (almost 5%), and 14 on Quantum Sensing (around 1%). As shown in the same figure, Italy's tenth position is confirmed for 2024, with growth aligning with the global trend. Indeed, several companies began research and application projects on quantum technology and decided to protect commercially their inventions. *Evidently, the number of public and private organizations is generally underestimated, as are collaborations among academic and industrial partners*.

Figure 24. The McKinsey Report (2024; 2025) on QT Patents granted by HQ Location, 2000-23 and 2024.



Politecnico of Milano's report, "Lo scenario italiano e internazionale del Quantum Computing" (2023), underlines how the country is taking the first steps toward creating a national ecosystem.

In 2023, Italian private investments in Quantum Computing would be modest, showing a value under 6 million Euros, financed by the companies on internal resources, as the organization's personnel, or external, as consulting, time-machine, or HR education. Quantum Computing at a global level is still a small and emergent market, and investments have picked up to circa 900 million dollars. Technology would still be in a prototypical phase, where government funds would drive innovative ecosystems.

Even though public and private investments are rapidly growing, the innovative quantum system would miss one of the most critical development variables: a support offering system based on startups and academic spinoffs.

Even with the relevant role played globally in the research domains, Italy would have accumulated a 10–15-year delay compared to other countries involved in the quantum

computing arena (both at a global and European levels, where more funds are invested over 5-10-years periods of time)[75].
The Italian Polytechnic experts wish to highlight the following vital signals of attention regarding the quantum revolution: the need for a stronger national coordination process and the development of a national strategy.
The report (*Osservatorio Quantum Computing & Communication*, 2023) does not stress the economic dimensions of the Quantum Computing System in Italy but evaluates the company's investments in the sector. The authors highlight that a few pioneers invested heavily in education programs and consulting, while most organizations only have residual budgets without showing a long-term strategy.
Big international players and consulting giants would be key actors in offering experimentation projects to firms. Specifically, some spinoffs populate the sectors, but *the numbers are still too small compared to those in other European countries, such as the UK, Germany, France, and the Netherlands* (which show almost 10 startups each).
The Observatory "*Quantum Computing & Communication*" (2024), its fourth edition, underlines the relevant role played nationally by PNRR funds, whilst public investments remain limited compared to the other European nations (see *table 5*). The academic excellence of Italian research on QST is not discussed, as testified by essential initiatives such as the first cryogenic quantum computer built in Naples (*University Federico II*) and the Italian photonic platform.

Table 5. Observatory "Quantum Computing & Communication" (2024): Italy Today

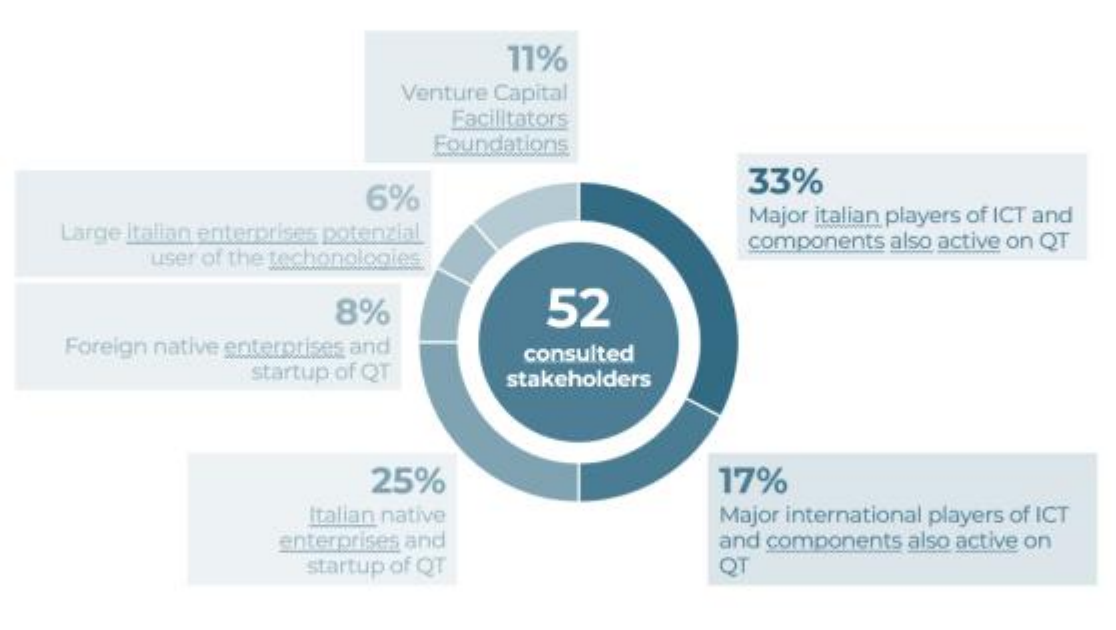
	Italy 2024
Research	7° global positioning for publication numbers in Quantum Computing (>4.200)
Ecosystem Creation and Industrialization	Embryonal ecosystem of 14 startups (9 on Computing, 4 on Communication, 1 Sensing)
Workforce Development	>10 Masters on Quantum Technology, but low capacity to attract and retain talents
Creating Awareness	30% of large companies are active on Quantum Readiness, 12% began Quantum Safe Transition

Still, Italian Polytechnic experts highlight how the *Venture Capital Market needs to be further developed*: Italian startups raised only 12 million Euros in 2023-2024, while France saw a market of almost 255 million. The report shows the birth of an embryonic

[75] Cited in *AI4Business*, "Tecnologie quantistiche in Italia: oltre 140 milioni di euro dal PNRR", November 23rd, 2023. https://www.ai4business.it/quantum-computing/tecnologie-quantistiche-in-italia-oltre-140-milioni-di-euro-dal-pnrr/

ecosystem of startups, identifying 9 firms active in Quantum Computing, 4 in Quantum Communication, and one company in Quantum Sensing.
Finally, the *Italian Strategy on Quantum Technology* (2025) presents the most recent data (see *figure 25*). The institutional document was first diffused as "Work In Progress", and after a period of public consultancy and examination, finally published in September 2025.

Figure 25. The Distribution of the type of organization participating in the MIMIT consultation on QTs



Source: Data processing MIMIT and Osservatorio quantum computing & communication del Politecnico di Milano (2025).

In the document, realized together with *Politecnico of Milano*, among the several QST stakeholders and international players, *31 Italian companies have been interviewed*:

- 14 companies and startups native to the quantum technology sector, and
- 17 large Italian players in the ICT and components sector such as system integrators, consulting firms and telco providers, which are differentiating their value proposition in the field of quantum technology.

Forbes (2024), interviewing *Obloo Ventures*, draws up a list of the most promising Italian startups in QST (see *box 17*).

Box 17. The most promising startups in Quantum Computing for Obloo Ventures

"In Italy, there are many of the conditions necessary to seize this opportunity (…), from highly qualified human capital to the quality of scientific production, up to the technological and infrastructural

endowment, but to express this potential it is necessary to promote and further develop the venture capital ecosystem and technology transfer system", Misal G. Memeo, Obloo Ventures Partner.

1. *Aindo* (2018), founders and role inside the company: Daniele Panfilo, ceo, Sebastiano Saccani, head of research and development, Borut Svara, cto
2. *Sibylla Biotech* (2017). founders and role inside the company: Lidia Pieri, ceo, Giovanni Spagnolli, cto, Emiliano Biasini, counselor, Pietro Faccioli, advisor, Maria Letizia Barreca, advisor, Graziano Lolli, advisor
3. *Mespac* (2022), founders and role inside the company: Andrea Gulisano, ceo, Giuseppe Giorgi, cto, Giulia Cervelli, expert on meteo-marine models, Edoardo Pasta, expert in Data Processing and Artificial Intelligence, Giuliana Mattiazzo, Technology Transfer advisor
4. *Titan4* (2017), founders and role inside the company: Giovanni Quacquarelli, ceo, Francesco Cruciani, cto, Stefano Cruciani, advisor
5. *Focoos AI (*2022), founders and role inside the company: Antonio Tavera, ceo, Fabio Cermelli, cto, Giuseppe Averta, cro, Carlo Masone, cpo, Barbara Caputo, chairman
6. *QuantaBrain* (2023), founders and role inside the company: Elisa Ferrari, ceo, Pietro Carra, cto, H. Teichmann, D. Bacciu, A. Cellerino, A.Retico, advisors
7. *Qbrain* (2022), founders and role inside the company: Paolo Arletti, ceo, Marco Maronese, cto, Lorenzo Moro, head of AI, Enrico Prati, Olivia Nicoletti, advisors

Source: Massimiliano Carrà, "Il futuro del computing varrà 500 miliardi nel 2030", 20-05-2024,
https://forbes.it/2024/05/20/ia-quantum-computing-varra-500-miliardi-entro-2030/

Simone De Liberato, PhD

Chief Technology Officer
Quantum Technologies Venture Capital Firm
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"With its scientific capital and growing deep tech ecosystem, Italy has all the cards to become an important player in the quantum industry. We need to facilitate access to capital and create easy paths to the world of public procurement, inspired by the US SBIR mechanism"

Description of the firm and mission:
Quantum Italia is the only Italian venture capital firm focused on Quantum Technologies.
Our mission is to develop the Italian quantum ecosystem while establishing ourselves as a global Quantum Hub.
We are launching the first European Quantum Studio to complement cutting-edge innovations emerging from quantum research with business expertise.
Our founders, Scientifica VC and Quantonation, offer a unique combination of experience, bridging both the Italian academic and industrial networks, as well as providing deep quantum expertise from research to market entry.
Main area-sectors-markets of investments:
We invest in pre-seed rounds across the entire quantum spectrum, from software to hardware, including quantum-enabling and adjacent technologies in various fields such as photonics and microelectronics.
Dimension of funding and financed firms:
Quantum Italia invests in researchers or early-stage startups with low TRL, offering tickets up to €300K. Our goal is to bring these projects to a stage within two years where they are ready for seed investment, based on a solid proof of concept (POC) and a viable business plan.

Strategy (actual and future):

We are currently expanding our "Quantum Lab Approved" network through partnerships with academic quantum labs. This program allows startups incubated by Quantum Italia to access a wide range of quantum facilities across Italy.

As mentioned, we are establishing the first EU Quantum Studio to help early-stage technologies mature by providing comprehensive support, from funding and access to facilities to essential services like HR, accounting, and marketing - ensuring responsible growth without disrupting the founders' scientific focus.

Lastly, we are launching a program for foreign early-stage startups that are looking to enter the Italian quantum ecosystem by opening a local subsidiary.

Main challenges to face in the future for QST (mid to long-term):

The two main potential challenges would be a reduction in investments at a moment at which practical use cases are still limited and the quantum industry is not yet ready to stand on its own legs, and the impact of present geopolitical tensions, which could hamper crucial flows of capital, talents and information.

Nicola Redi, PhD

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Obloo Ventures
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"Deepscover what matters: the future of quantum startups relies on outstanding infrastructures, system integration and effective business models"

Description of the firm and mission:

We manage early stage venture capital funds, capturing the best deals before any other investor.

Main area-sectors-markets of investments:

Obloo invests in future of computing technologies: quantum and its integration with other technologies represents the answer to energy, computational power, speed and data size challenges in all industries.

Dimension of funding and financed firms:

Today we manage funds for a total of €70M and just launched a new €100M one. We invested in dozens of computational science's companies, spanning from AI enablers to Quantum.

Strategy (actual and future):

Through our partnership with HPC research infrastructures and dedicated access to industry grade ones, we will support portfolio companies from day one to their full steam operations.

Main challenges to face in the future for QST (mid to long-term):

QST will not represent one standard, but a series of technologies to be integrated into existing computational architecture. Each would have a killer application, and a new, quantum-hybrid computational world might be the standard.

Antonio Carbone

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"Venture building plays a critical role in developing new quantum innovations by fostering the collaboration of multidisciplinary teams, providing resources, and accelerating the commercialization of groundbreaking quantum technologies from concept to market"

Description of the firm and mission:
DAY ONE is an innovation studio whose mission is to support the development of radically new products from academic research by driving researchers in an "enterprise-like" product development journey. We team up with researchers to turn disruptive technologies into game changing solutions and startups, through product development, venture building, communication and exploitation and fundraising.
Main area-sectors-markets of investments:
Components, hardware for super-conductive quantum computers
Quantum software for industrial challenges.
Dimension of funding and financed firms:
Micro-seed investments up to 100k for first proof of concept (see next point).
Strategy (actual and future):
Day One is setting up an early-stage VC fund aimed at developing the most promising deep tech proof of concepts in Italy, including the quantum areas above mentioned. The investment size will be twofold: up to €500k (up to the MVP and company formation) and up to €1 million (acceleration). In both cases, along with financial investment, specific expertise in product and business development will be provided. Explore Quantum Market creating innovation is one of the pivot of this strategy.
Main challenges to face in the future for QST (mid to long-term):
Develop platforms that abstract quantum programming to enable easy programming for diverse business problems (pharmaceuticals, finance, etc.) and error correction systems.
Equip with platforms featuring qubits (real or virtual) with low error rates and therefore high reliability, as well as software that can be easily programmed by developers with limited quantum expertise."

Alessandra Scotti, PhD

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"At Liftt, we aspire to drive innovation and growth in the rapidly evolving field of quantum technologies. We aim to impact the entire spectrum of emerging technologies in all major areas: computing, sensing and communication"

Description of the firm and mission:
LIFTT is a VC holding company, which started operating in mid 2020. We now have over 200 shareholders (mostly private investors, Family offices etc) and raised over 100M to invest in our portfolio.

Since incorporation, Stefano Buono, a successful physicist turned businessman (Newcleo), has been our Chairman. We have rather ambitious investment goals: we have currently invested in 54 companies, with more soon to enter our portfolio.
Our investment focus are innovative, disruptive technologies, whatever the field: we have no verticals, though we like to describe ourselves as multivertical, as we have several technological clusters in our portfolio - one of which is Quantum- and we have dedicated team members with specific expertise and network in the field.
We also recently signed a joint venture agreement with the European Investment Bank, which will help us strengthen our position in Europe.
We invest globally, and have an international network of co-investors.

Main area-sectors-markets of investments:

We invest in all sectors, as long as we see a big leap of innovation, mainly in the hardware industrial field. As far as Quantum goes, we are interested in all field: computing, communication & security, sensing and all enabling technologies. At present we have three start ups in our portfolio in the Quantum and quantum enabling technologies, and are negotiating a fourth investment.

Dimension of funding and financed firms:

We have so far raised over 100M to invest, plus we created a joint stock company in which both the EIB and LIFTT will invest €50 million each.
We typically invest from 200k- 2M, from pre-seed to series A.

Strategy (actual and future):

The field of Quantum is constantly developing, and new discoveries and solutions are quick to appear. This is why we are keen to explore both technologies that have a shorter time to market and those that might take longer. We look at the whole spectrum of quantum and quantum enabling technologies.

Main challenges to face in the future for QST (mid to long-term):

We keep a close eye on the evolution in this sector, as we believe it will form the basis of the most significative changes in the near and farther future. While it might take 10-15 years to be able to appreciate the full and true potential of quantum computing, we feel other technologies are much closer to enter, and revolutionize, our daily lives.

Antonella Zullo

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"Quantum computing has the potential to significantly impact Zest Innovation's initiatives, especially in areas like AI, Fintech, IoT, and Cybersecurity. Quantum encryption methods, like quantum key distribution (QKD), are nearly unbreakable with classical computers"

Description of the firm and mission:

At *Zest Innovation*, we focus on supporting the growth of startups and innovative projects. Our mission is to drive innovation by fostering collaboration between companies and startups, particularly in areas like digital transformation and sustainability. We believe in creating synergies that benefit all parties involved, whether it's through startup accelerators or innovative business strategies.
Through partnerships with financial institutions, universities, and corporations, we aim to unlock new opportunities for growth. Our goal is to help both startups seeking investment and established firms looking to innovate and develop long-term strategies. By working together, we can achieve meaningful, lasting impact across industries.

Main area-sectors-markets of investments:

The main areas and sectors for *Zest Innovation*'s investments include:

Artificial Intelligence (AI) & Data: Investments in AI technologies and data-driven solutions that transform industries and create efficiencies.

Cleantech: Focus on clean technology that contributes to sustainability and environmental conservation, including renewable energy and green innovations.

Fintech: Investments in financial technologies, including blockchain, decentralized finance (DeFi), and embedded finance solutions that revolutionize banking and insurance.

Proptech: Targeting technologies that innovate the real estate sector, from project planning and construction to real estate management and valuation.

Internet of Things (IoT) & Connectivity: Investments in IoT solutions that enhance connectivity and enable the integration of devices and systems across sectors.

Cybersecurity: Supporting startups that focus on protecting digital infrastructure, data security, and online transactions.

Health & Wellness: Investments in healthtech startups focused on digital health, wellness platforms, and medical innovations.

Regulatory Technology (RegTech): Supporting solutions that streamline compliance and regulation processes, particularly in financial services and data management.

Dimension of funding and financed firms:

At *Zest Innovation*, we have built a strong track record in venture capital with over 250 portfolio companies in sectors like AI, fintech, cleantech, and IoT. Our strategy focuses on early-stage investments, corporate venturing, and fostering long-term partnerships with startups and corporations. We manage a variety of funding mechanisms, including joint ventures and corporate collaborations, to support the growth and scaling of these startups. We've completed notable exits such as Moneymour, acquired by Klarna, and Cardo AI, reflecting our ability to successfully scale firms and create value. Our funding initiatives provide follow-on investments, strategic advisory, and deal structuring to ensure that our portfolio companies are well-positioned for future growth and success

Strategy (actual and future):

Zest Innovation's current strategy centers on early-stage venture capital investments, corporate venturing, and building an innovation ecosystem. They invest in promising startups, particularly in sectors like AI, fintech, cleantech, and IoT. Zest also collaborates with corporations through joint ventures and corporate accelerators to foster innovation. Additionally, they run acceleration programs to help startups validate their business models and gain market traction. A key focus of their strategy is ESG compliance, ensuring that their investments align with sustainability goals while driving long-term value creation for both startups and corporate partners.

Zest Innovation's future strategy could focus on expanding into emerging technologies like quantum computing, 5G, and edge computing, enhancing their position in sectors such as fintech, AI, and cybersecurity. By increasing their investment in sustainability and green tech, Zest can align with global ESG trends and attract socially responsible investors. Geographically, Zest could expand into high-growth regions like North America and Asia, tapping into diverse innovation ecosystems. Strengthening corporate venturing partnerships with multinational corporations and leveraging AI for data-driven investment strategies could further enhance Zest's ability to identify high-potential startups. Additionally, developing venture builder and corporate incubation programs would allow Zest to co-create innovative startups with corporate partners, while specialized thematic funds in sectors like fintech and AI could focus resources on fast-growing areas, attracting targeted investors.

Main challenges to face in the future for QST (mid to long-term):

Quantum computing has the potential to significantly impact Zest Innovation's initiatives, especially in areas like AI, Fintech, IoT, and Cybersecurity. Here's how quantum computing could influence each area:

Artificial Intelligence (AI) & Data: Quantum computing can exponentially increase the processing power available for AI and machine learning algorithms. This means faster training of AI models and the ability to process larger and more complex datasets. Zest could leverage quantum advancements to invest in startups that focus on next-gen AI systems with superior prediction and automation capabilities.

Fintech: Quantum computing can enhance risk analysis, portfolio optimization, and fraud detection in the financial sector. As Zest invests in fintech, the adoption of quantum technologies could revolutionize banking algorithms, reduce transaction times, and enhance the security of financial systems through quantum encryption.
IoT & Connectivity: With IoT, the vast amount of data generated by connected devices requires immense computing power. Quantum computing can process this data at unprecedented speeds, enabling real-time decision-making and optimization of IoT networks, which would benefit Zest's focus on IoT investments.
Cybersecurity: One of the most immediate applications of quantum computing is in cybersecurity. Quantum encryption methods, like quantum key distribution (QKD), are nearly unbreakable with classical computers. This would significantly enhance the security of Zest's investments in digital and financial sectors by protecting sensitive data and transactions from cyber threats.
Overall, quantum computing aligns well with Zest's focus on innovative technologies and emerging sectors. It can give Zest's portfolio companies a competitive edge by enabling more powerful computations, deeper data insights, and stronger security frameworks. This would likely increase the value proposition for both investors and corporate partners.
By keeping an eye on quantum computing startups, Zest could position itself at the forefront of this transformative technology, furthering its mission to drive innovation across multiple industries.

Jacopo Drudi

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"The Quantum Revolution can relaunch the competitiveness of Italy if we create an ecosystem involving public entities, corporates, universities and investors"

Description of the firm and mission
As a Venture Capital firm, we support extraordinary founders in their journey to build great companies. We help them invent the future by imagining how technology will reshape society, markets, and industries.
Main area-sectors-markets of investments:
Technology is driving radical change across all aspects of our life, and the uncertain times we are going through has accelerated the digital transformation in multiple ways. We believe in the power of technological innovation, and we support game-changing founders to disrupt markets that are still widely undigitalized.
Dimension of funding and financed firms:
> €500m AUM
€1m-€20m per single ticket
Strategy (actual and future):
Technological progress takes place gradually, then suddenly. We don't like to wait for the future to happen, or to jump on the bandwagon. We try to anticipate future needs with facts and data. We are inherently curious with a passion for learning, and we apply a connecting-the-dots attitude to our investment decision-making.
Main challenges to face in the future for QST (mid to long-term):
As of today, the market is not ready for quantum tech / quantum solution; in the coming years, we will have to work together to find the right go-to market and the best use cases.

Anna Amati, Massimo Gentili

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"Technology Transfer is all about people, from the inventor of an idea through to the end-customer once the idea has reached the market. it's all about closing the gap between research and market. it's all about eureka! people"

Description of the firm and mission:
Founded in 2019, *EUREKA! Venture SGR* is the first independent Italian Venture Capital Asset Management Company exclusively focused on deep tech investments thanks to strong competences in scientific research, technology transfer and venture capital industry.
Main area-sectors-markets of investments:
The quantum technologies sector is in a phase of rapid evolution. The Quantum Computation value chain is still in evolution; this opens significant opportunities for new entrepreneurial initiatives that base their value proposition on various segments of the value chain. Eureka, with an investment focus on advanced materials, sees these opportunities as particularly attractive for the development of new architectures for QUBIT, i.e approaches that simplify and make Quantum Processing Units more performant.
Dimension of funding and financed firms:
EUREKA! Venture SGR manages Eureka! Fund I – Technology Transfer": investments are focused on proof of concept, seed and early stage deals in spinoffs and startups steaming out from Italian Universities and Research Centres Eureka! with an initial equity investment between €500K and €1.5M, plus possible follow-ons.
Strategy (actual and future):
Ideas and companies backed by Eureka! Fund has a competitive advantage stems from cutting-edge proprietary technologies and innovations in materials science & engineering with a clear and unique vision on intellectual property rights.
Main challenges to face in the future for QST (mid to long-term):
The main challenges that the quantum computing sector poses are to be found in the development of the software+hardware combination that allows quantum computing with low error rates. Computational error compensation techniques require hardware redundancies that complicate the architecture of the quantum computer and therefore its cost limiting the possibility that it will spread in the market beyond the few large companies that can afford such costs.

Emilia Garito, BSc

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"The future of innovation and the implementation of most scientific discoveries will depend on quantum computing. However, Science and Industry together have to be solution driven instead of technology driven. We all must be prepared to ensure that this computing power is only used for what society really needs and to solve the world's most complex

problems. Let us prioritise the health sector and think about addressing cyber security needs through the development of quantum cryptography"

Description of the firm and mission:
Deep Ocean Capital (DOC) is an independent management company hosting its first Venture Capital fund Deep Blue Ventures (DBV), investing in early stage start up in Deep Technologies.
Main area-sectors-markets of investments:
Deep tech is the next global innovation wave. It will be the most disruptive ever. Deep Tech and mostly Quantum Computing and AI, including quantum machine learning, will change the way we live and work, and more broadly the environment around us.
The main sectors of DBV are Aerospace, Healthcare Technologies, Climate Technologies
Technology Focus: Relevant Key Enabling Technologies (KETs), with a specific focus on Artificial Intelligence, Quantum Computing and related technologies.
Dimension of funding and financed firms:
Fund size target: €70 Million - First closing size: €40,8 Million.
Strategy (actual and future):
DBV is going to focus on seed stage investments (that includes post-seed) where it will play as lead investor, and selected Series-A opportunities across multiple industry sectors where market opportunities are clearly at international scale.
The focus will be consistent with the technology excellence that DBV team and partners plus ecosystem already express. Portfolio will be made up of 16-18 investments. Single investment tickets will stay in the €1-4M range.
Main challenges to face in the future for QST (mid to long-term):
Even if the number of VC investments in deep tech Italian startups is in absolute terms lower compared to other European countries, the value of Italian production based on KETs is rather high in European rankings. For this, the main challenge is to build a large base of early stage investments to establish the values and culture of smart capital formation among local ecosystems stakeholders.

3.2 Quantum in Italy: First evidence from the TTOs and Cordis Datasets

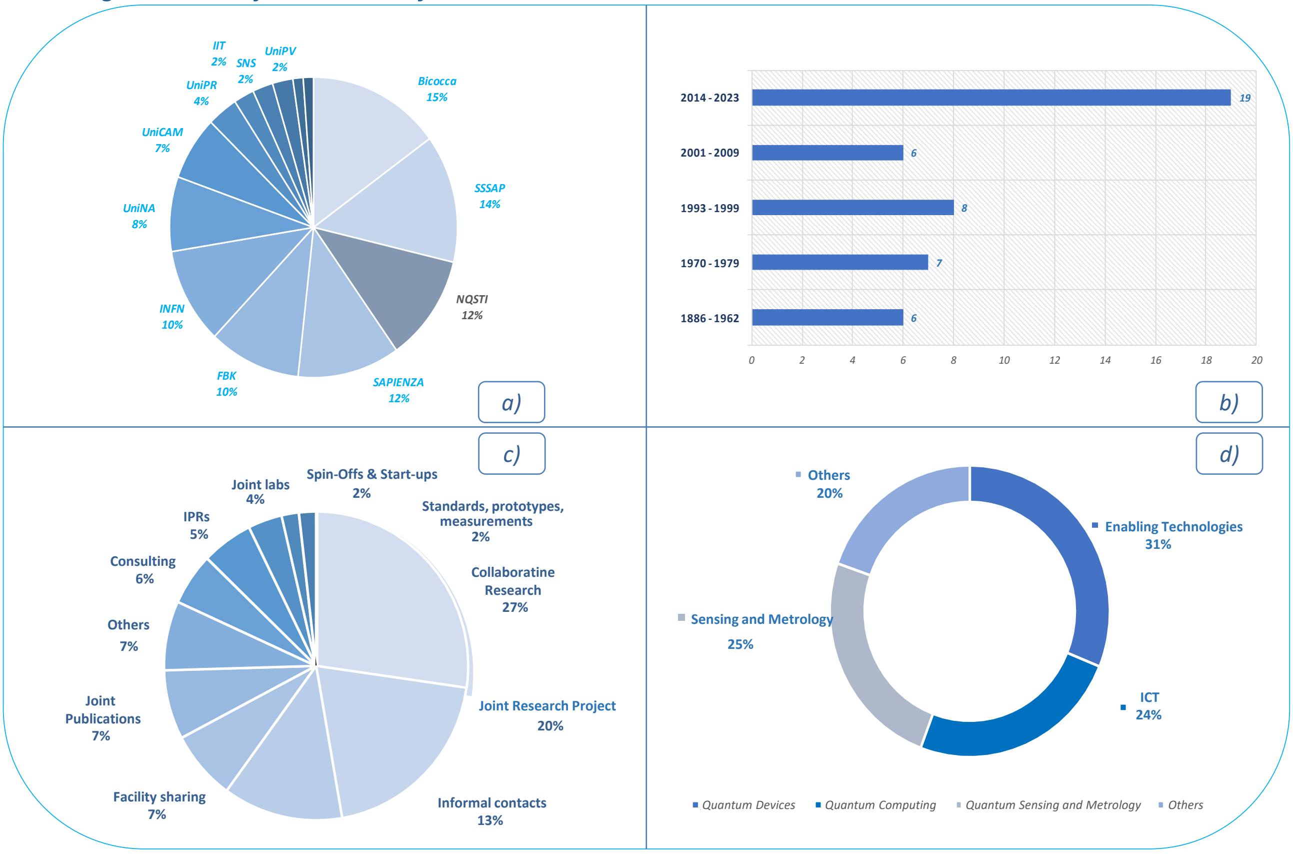
As it is better described in the *Appendix 1 "Methodology"*, the first information on the national dimension of the Italian ecosystem for quantum technology was the result of a survey conducted among academic institutions participating in the Technology Transfer activities within *NQSTI* Spoke 8's network. The number of citations, the total number of firms that composed the dataset, was (very encouraging) 87. Many companies have been cited several times by research organizations. These are the firms with the largest number of active collaborations and their main partners:

- *Airbus (Sapienza, INFN),*
- *CAEN spa (INFN, SSSAP, UniCAM),*
- *IBM Research EU (UniPR, IIT, CNR),*
- *Leonardo (IIT, Sapienza),*
- *SeeQC (UniNA, SNS),*
- *Telespazio (SSSAP, Sapienza),*
- *Thales (Sapienza, FBK),*

- *STMicroelectronics (UniPV, UniCT).*

The internal investigation revealed that the *University Milano-Bicocca* has the most significant number of active collaborations with firms, followed by *Scuola Superiore Sant'Anna* of Pisa and *Sapienza University* (*figure 26, a*).

Figure 26. The first evidence from the TTO dataset



As evidenced in *figure 26b*, the sample showed a clear dynamic for the companies' foundation year: incumbent firms cohabit with newcomers, but a relevant number of organizations were born between 2014 and 2023.

Even if the percentage of respondents was not entirely relevant (46/87), 31% of the organizations said they realized quantum devices (*figure 26, d and c*). In comparison, the number of companies in Quantum Computing, and Quantum Sensing and Metrology had a similar percentage (around 25%).

Collaborative research (27%) is the most common tool to transfer knowledge from the academic institution and back to the firms, together with *joint research projects* (20%), and informal contacts (13%). *IPRs (5%) and Consulting (6%)* show a tiny percentage of citations as mechanisms to share experience and know-how among companies and academic organizations.

To compile a list of companies representative of the national QST industrial environment, thereby expanding the sample of Italian organizations considered as much as possible,

the second phase of the *NQSTI* research continued with an investigation into information about EU research and development projects. The *Cordis* dataset[76], established in 1994, provides free access to EU-funded research and innovation, featuring data on projects, topics, and publications supported by the EU's research programs.
Science-based firms form public-private partnerships to join EU projects to address the most pressing challenges through concerted research and innovation initiatives. European Partnerships are a key implementation tool of *Horizon Europe* and significantly contribute to achieving the Union's political priorities, reducing the fragmentation of the research and innovation landscape[77].
Particularly, *tables 6* and *7* describe the Italian companies' participation in *Horizon Europe* projects in Quantum Science and Technology[78]. In *table 6*, all the companies with more than one participation in *Horizon Europe* are described; while in *table 7*, the role "coordinator" has been chosen to classify the main private participation in the European last framework program.

Table 6. The Italian companies with more than one participation in Horizon Europe

	City	Project
COMMPLA SRL	Pisa	***INSTAR***
		InDiCo-Global
		NGI TRANSOCEANIC
		OPENVERSE
DAY ONE SRL	Roma	***NEXUS***
		SPECTRUM
		PRISMA
E 4 COMPUTER ENGINEERING SPA	Scandiano (RE)	***DECICE***
		MaX
EPHOS SRL	Milano	***QLASS***
		FUTURE
ERICSSON TELECOMUNICAZIONI SPA	Roma	***NANCY***
		ALLEGRO
FORESEE BIOSYSTEMS SRL	Genova	***SiMulTox***
		TwistedNano
LEONARDO SPA	Roma	***CARIOQA-PMP***
		MUQUABIS
		MaX
MICRO PHOTON DEVICES SRL	Bolzano	***QSNP***

[76] https://cordis.europa.eu. Accessed May 2024.
[77] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/european-partnerships-horizon-europe_en. Accessed September 2024.
[78] *Commpla srl, Day One srl, Trust-IT Services srl, and Warrant Hub spa* are highlighted in another color as they serve as supporting firms to the research projects: *Commpla* and *Trust-IT Services* work as software and product developers for digital marketing services; *Day One* and *Warrant Hub* are strategic consulting partners for funding and other marketing services for deep tech companies.

		SEQUOIA
OSPEDALE SAN RAFFAELE SRL	Milano	*PolArt*
		KATSIM
QTI SRL	Firenze	*QuNEST*
		PROMETHEUS
		QPIC1550
TELECOM ITALIA SPA	Milano	*QuNEST*
		NextGEM
		NOUS
		QSNP
		ALLEGRO
THALES ALENIA SPACE ITALIA SPA	Roma	*LaiQa*
		PASQuanS2.1
		QUDICE
		Qu-Pilot
THINKQUANTUM SRL	Vicenza	*QSNP*
		QUDICE
		Qu-Pilot
TRUST-IT SERVICES SRL	Pisa	*InDiCo-Global*
		NGI TRANSOCEANIC
		OPENVERSE
		INSTAR
WARRANT HUB SPA	Correggio (RE)	*INPHOMIR*
		HORTIQD
		GREENER

Table 7. The Italian companies that figure as Horizon Europe Project Coordinators

	City	Project
BEDIMENSIONAL SPA	Genova	*GREENCAP*
CAMBRIDGE RAMAN IMAGING SRL	Verona	*CHARM*
EPHOS SRL	Milano	*FUTURE*
FORESEE BIOSYSTEMS SRL	Genova	*SiMulTox*
G.E.M. ELETTRONICA SRL	San Benedetto Del Tronto (AP)	*INPHOMIR*
LEVELQUANTUM S.R.L.	Milano	*levelQuantum*
NIREOS SRL	Milano	*HYPERIA*
QTI SRL	Firenze	*QPIC1550*

Leonardo Quantum Lab

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Description of the firm and mission:

Leonardo is a global industrial group that creates multi-domain technological capabilities in the Aerospace, Defence and Security sector. With over 60,000 employees worldwide, the company has a significant industrial presence in Italy, the UK, Poland and the US. It also operates in 150 countries through subsidiaries, joint ventures and investments. A key player in major international strategic programmes, it is a technological and industrial partner of governments, defence administrations, institutions and companies.

Based on the dual application of technologies, *Leonardo* designs and creates products, systems, services and integrated solutions both for the defence sector and for public and private customers of the civil sector, both in Italy and abroad.

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Leonardo has plenty of cooperations with National, European and International Academic Institutions and Research Centers. In a framework of Open Innovation also cooperation with SMEs and startups is strong. *Leonardo* strongly encourages this cooperation and in particular *Leonardo Labs*, the company centralized Research Center has deep relation with high tech startups, Academic Institutions and Research Centers. Non-exhaustively, among the most active collaborations on Quantum in Italy we can mention *INRIM, Sapienza, CNR, UniPD, and UniBA* and internationally *Fraunhofer IOSB and IAF in Germany, Herriot Watt University in UK, Onera in France.*

Who are your direct competitors?

Our direct competitors are all companies operating in Aerospace, Defence and Security market sectors.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges to be faced?

Quantum supply chain is generally at its early stage anywhere now as such technologies are currently reaching in some cases a reasonable TRL that real applications out of the labs are now under consideration. Many hot issues should be faced, among them:

1) robust and coordinated interactions between SME and startups, generally providing high tech IP and big enterprises able to act as system integrators allowing tech to enter classical markets (TLC, IT, Defence, Space, etc);
2) talent supply and quantum educated human resources to be available in reasonable number;
3) enabling technologies like photonics or cryo-cooling to be accessed by quantum enterprises.

What are the main areas of application for quantum technologies? What are the target markets?

Sensor systems are surely among the first areas for applications, referring to Quantum sensing pillars. In particular, Quantum Imaging and Quantum sensing for Navigation are two big opportunities. Also Quantum Communications could be a close opportunity, though Quantum Key Distribution, one of first use cases, should propose also solutions to few open issues raised by National Security Agencies. Quantum Computing is a long run and a challenge still open for future 1 or 2 decades.

Can you provide examples of real use cases?

GNSS (Global Navigation Satellite System) denied Navigation. Imaging in Degraded Visual Environment. Crypto keys distribution without asymmetric algorithms (among others).

Who are your current customers and what are your potential customers?

Leonardo customers are consolidated entities referring to the Aerospace, Defence and Security market. They will be the same in the future, hopefully getting advantage of incorporation of Quantum technologies in heritage systems.

TASI, Thales Alenia Space Italia

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Description of the firm and mission:

Thales Alenia Space Italia S.p.A. (here below *TAS-Italia* or *TASI*) is a company incorporated under the laws of Italy, having its registered office, the principal place of business and the administration at Via Saccomuro, 24, 00131 Rome, Italy. *TAS-Italia* is a subsidiary of *Thales Alenia Space S.a.S.* (100%), jointly managed and coordinated by *Thales S.A.* (67%) and *Leonardo S.p.A.* (33%), is a key European player in space telecommunications, navigation, earth observation, exploration and orbital infrastructures. With over 35 years of experience in developing space systems, *TAS-Italia* is involved in all aspects of the space domain. Drawing on decades of experience and a unique combination of skills, expertise and cultures, *TAS-Italia* delivers cost-effective solutions for telecommunications, navigation, Earth observation, environmental management, exploration, science and orbital infrastructures. Governments and private industry alike count on *TAS-Italia* to design satellite-based systems that provide anytime, anywhere connections and positioning, monitor our planet, enhance management of its resources, and explore the Solar System and beyond.

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

TASI have an extensive and continuously developing network of collaborations aimed at ensuring state-of-the-art and effective research and development initiatives over a wide range of technologies; in particular, in the frame of quantum technologies, *TASI* shaped its strategy around strategic academic and industrial partnership as a mean to build credible and sustainable roadmaps towards quantum technologies introduction in *TASI* product lines. *TASI* decided to start from National excellence and then, of course, establish solid relationships also at European and international level. In particular we found that Italy provides really relevant competencies in terms of research capability and state-of-the-art approaches. At the moment of writing, non-exhaustively, some of the most active collaborations in Italy are with *INRIM*, *Sapienza*, *CNR*, *UniPD*, *FBK*, *GSSI* and *UniBA* also outside the frame of *NQSTI*; on industry side the collaborations are mostly in the frame of Quantum Communication projects and involve actors like *Leonardo*, *Telespazio*, *ThinkQuantum* and *OfficinaStellare*.

Who are your direct competitors?

TASI direct competitors are the other Space Large System Integrators as defined by *ESA* (European Space *LSI*).

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges to be faced?

TASI's Vision on the Development of the Supply Chain and Quantum Technology-Based Solutions:

TASI has embarked on its journey into quantum technologies with a full understanding that it is a long-term commitment, especially regarding the actual integration of quantum solutions into its products. The landscape is not completely homogeneous, and there are some *'low-hanging fruits', such as quantum key distribution systems for cryptographic keys*. However, in general, quantum technologies still remain at a relatively low Technology Readiness Level (TRL), even more so when considering solutions suitable for operations in orbit or deep space.

Among the major challenges on the path to developing quantum technologies is the *transition from prototyping to the production of industrial-level components and equipment* that can pass both process and product qualifications. This objective is indeed challenging and goes beyond the mere willingness of entities to incorporate the state of the art in research into industrial solutions. It also *requires access to adequate production facilities and the necessary materials for manufacturing*.

The maturity level and the still very limited commercial demands naturally lead to reflections on sustainability; in this sense, as observed in other sectors, the potential applications across various domains are certainly an essential factor in mitigating such risks and encouraging the establishment of active industrial production entities.

What are the main areas of application for quantum technologies? What are the target markets?

TASI has identified several potential applications for quantum technologies across all major domains within its business scope: *navigation, earth observation, telecommunications, exploration, and science*. This indicates the *pervasive potential* and significant impact that quantum technologies can have in the space sector.

There are specific areas of development with higher priority, driven primarily by market demand, which currently comes mainly from institutional clients. From our perspective, there's a *strong impetus in the telecommunications domain*, particularly for leveraging quantum technologies to enhance the security of links used for exchanging sensitive data. We also observe a growing interest in applications related to sensing and metrology.

Given the substantial uncertainty associated with technology maturity and the necessary investments to ensure long-term initiative continuity, the primary areas of intervention are likely to be critical infrastructures and sectors. At the same time, we anticipate a surge in the utilization of quantum technologies from their adoption in various application and industrial components, which are less specialized compared to final applications. A notable example of this is the *integration of Quantum Random Number Generators (QRNG) into commercially available smartphones*.

Can you provide examples of real use cases?

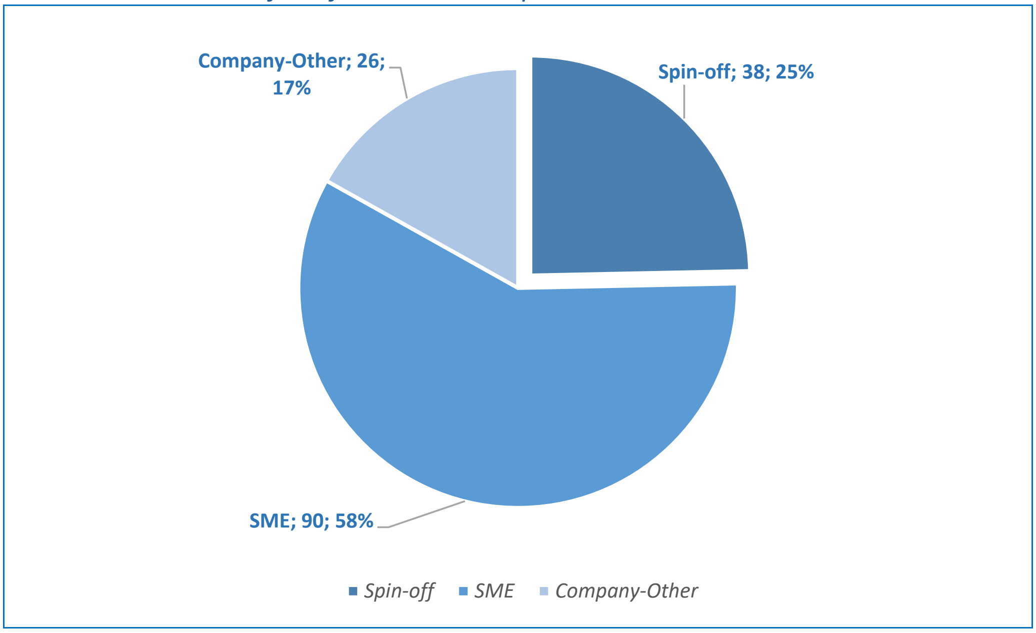
In the previously mentioned sectors and application domains, *TASI* has identified several real use cases of significant interest due to their potential transformative impact. These use cases serve as reference points for *TASI* to gauge technological evolution and are typically used as benchmarks to define investment strategies, supply chain considerations, and overall sustainability and risk assessments. In particular some space relevant use cases for quantum technology are: *quantum enhanced radiofrequency antennae, high stability inertial sensors, high accuracy and stability time and frequency standards, secured data transfer using quantum keys, blind quantum computing/networking, gravity and magnetic fields sensing, quantum enhanced pointing/acquisition and tracking for laser links*. Beyond these specific use cases, *TASI* has always considered it is essential to associate work on vertical applications with the careful selection of base technological platforms. This dual focus aims both to maximize opportunities for reuse and to minimize the breadth of the potentially involved supply chain. Selecting and evaluating suitable platforms also aids in reducing risks, particularly those associated with the process of making technologies space-ready.

Sometimes, these platform choices require sacrificing optimal performance to ensure better survival chances under the extreme conditions in which spacecraft operate, as well as the stresses of launch. Currently, platforms that are of significant interest include *platforms that can operate at ambient temperatures or are intrinsically easy to integrate into compact photonic systems*. Examples include *Rydberg atoms and diamond-based solutions* that offer resilience and versatility for space applications. Cold atom-based technologies, which are continually monitored for their promising applications in quantum sensing (gravimetry for example) and timing that is crucial for new generation navigation systems and extra-terrestrial infrastructures. While superconducting-based technologies are continually evaluated, they currently hold a lower priority for the specific applications and use cases *TASI* is considering. Beside platform selection, fabrication techniques, means and facilities are also an enabling critical aspect of moving QT from lab to production in particular. Areas are of particular interest are: *photonic integrated circuits and nanostructured materials*.

Who are your current customers and what are your potential customers?
Current customers are National and European Institutions, future customers could include also private operators for example in the frame of telecommunications. This analysis only addresses direct and specific request of quantum based features but a great deal of QT potential, and its sustainability, will come from the use of the technology to gain an advantage in building solutions also in classical domains.

3.3 The Italian QST System of Innovation: the evidence from the *NQSTI* datasets

Figure 27. The dimension of the firms in the sample



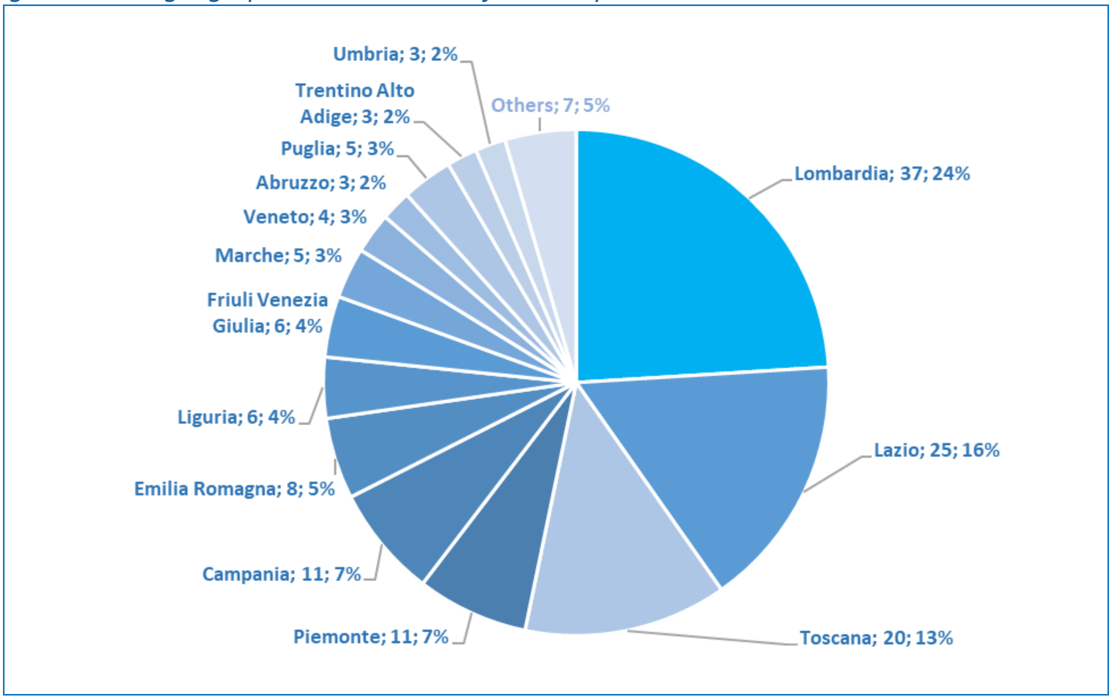
After completing the dataset with information available in institutional reports, in consulting and technological literature, specialized magazines, and the companies participating in TT and technological events, the scientific literature on QST was collected (see Bibliography). The reports describing QST sector structure in a general way or presenting specific industrial fields (sensing, computing, imaging) were then investigated. Still, to have an idea of the companies directly involved in the QST research, the datasets belonging to *Quantum Flagship* (*Quantera*[79]), *QUIC* (*Quantum Industry Consortium*[80]) and *EPO* (*European Patent Office*) reports (*EPO*, 2023a; *EPO,* 2023b) have been analyzed[81].

[79] Quantera, Quantum Landscapes Database. Accessed July 2024. https://quantera.eu/wp-content/uploads/D6.1_Database_updated-version-_Feb2021_no_contacts-1.pdf
[80] European Quantum Industry Consortium, QUIC Member List. Accessed September 2024. https://www.euroquic.org/members-list/
[81] Refer to Appendix 1, "Methodology", for a detailed description of the research phases.

The total number of companies active in the Quantum fields or having a collaborative research project with an academic partner in the first *NQSTI* analysis is ***154***. A number beyond any possible esteem made by Spoke 8 "Technology Transfer" components at the beginning of the *NQSTI* project.[82]

Of the Italian (or having a production or research subsidiary in Italy) companies around ***58%,*** 90 firms, ***are SMEs*** (Small and Medium enterprises). As highlighted in the previous paragraph, the *Cordis* classification also gave us a dimensional variable to draw some possible analyses (see *figure 27*).

Figure 28. The geographical distribution of the sample



Consequently, around 17%, ***26 organizations***, are ***large companies***. *We can highlight the limited number of big firms in relation to the disruptive characteristics of quantum technology*. There is a growing need at the national level to communicate more effectively and demonstrate the advantages and use cases.

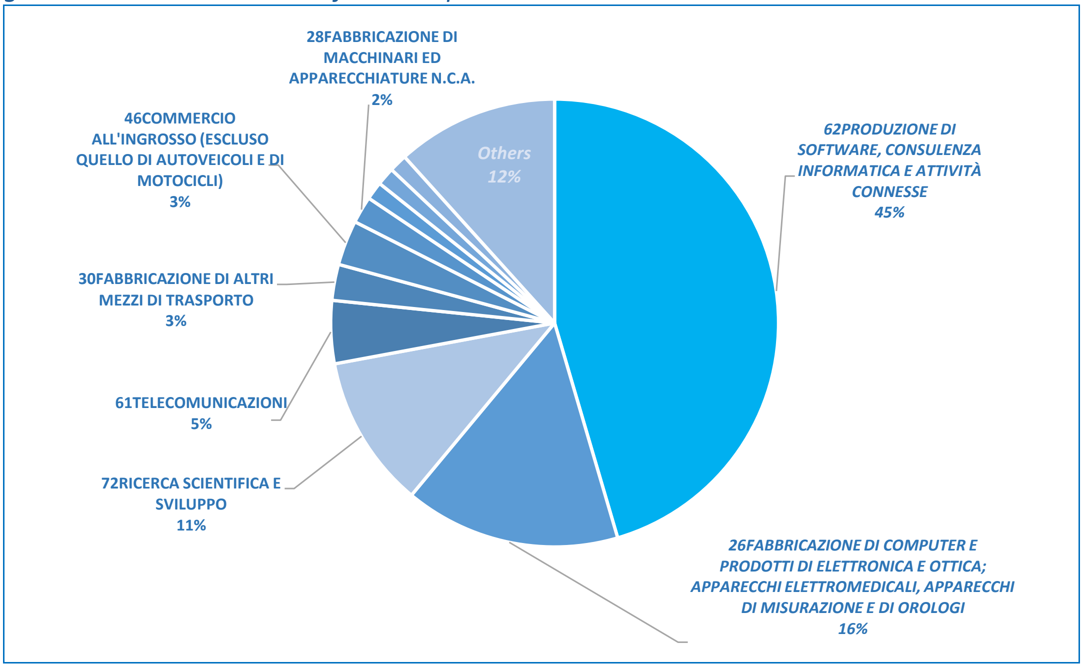
It is also worth noting the number of **spinoffs** that represent almost 25% of the total sample (**38 companies**)[83]. A specific paragraph will be dedicated to discussing peculiar academic backgrounds.

Lombardia hosts almost a quarter of the total sample, as 37 Quantum Science and Technology companies populate this region (*figure 28*). Lazio shows 16% of the private organizations, 25 firms. The total amount could be overestimated, as many companies have headquarters in the Italian capital. Still, Toscana hosts 20 companies, representing 13%

[83] The authors considered startups with a website, valid Information in newspapers, or research programs (already registered on the official website of the Italian Camera di Commercio) for the analysis.

of the total. So only three regions are home to more than 50% of all the QST companies (53%).
Emilia-Romagna (8), Campania (11), and Piemonte (11) show low percentages, but the number of local firms could be promising considering specific QST fields.
Istat, the *Italian National Institute of Statistics*, is a public research organization that organizes the official classification of economic activities to facilitate investigations into industrial sectors, to promote the comparison and collaboration with other European Countries, and to coordinate research and industrial-oriented policies (see *box 18*).
It is interesting to discuss results from this specific classification: almost 45% of the sample belongs to the voice "Production of software, informatics consulting and connected activities" (70 companies, see *figure 29*). Still, 16% is in the voice "fabrication of computer and electronic and optic products, electro-medical apparatus, and watches, and other measurement machines" (24 firms). "Scientific research and development" represents 11% (17 companies) of the sample, while "Telecommunications" represents around 5%. Almost 20% of the firms belong to the other voices inside the *Istat* codes.

Figure 29. The ATECO codes of the companies

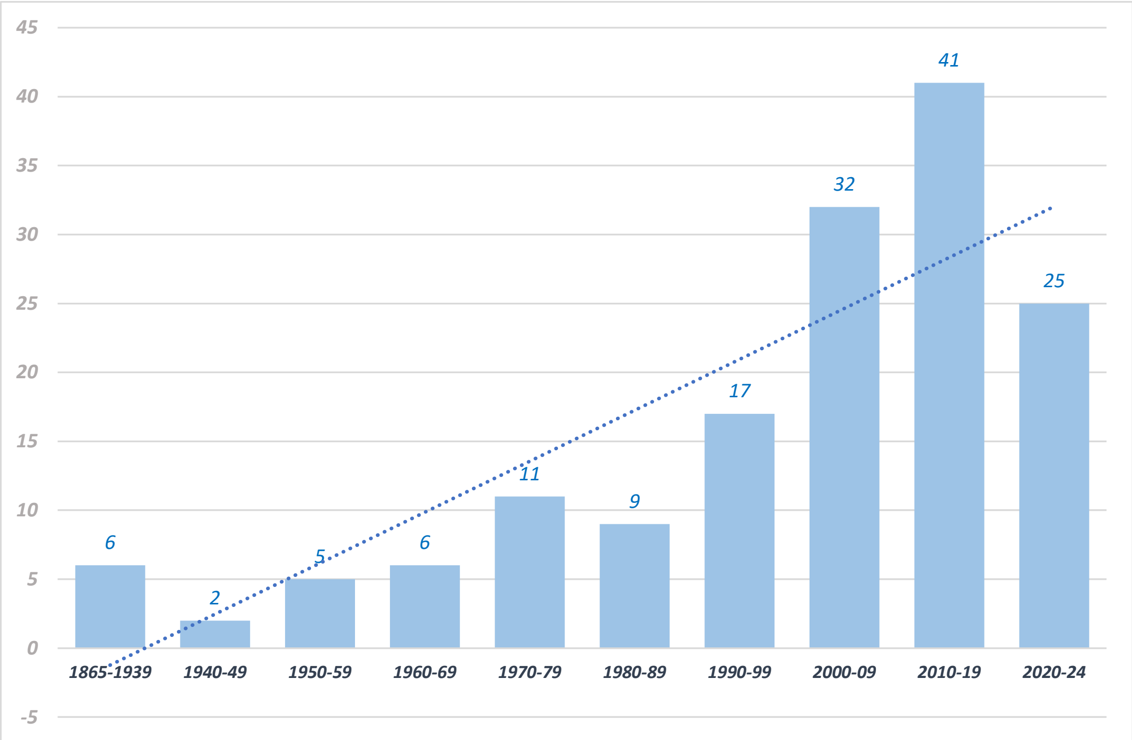


Box 18. The Classification of Economic Activities, ATECO (2007)

Since January 2008, Istat has adopted the Ateco (2007) classification of economic activities. The migration of economic statistics to the new classification follows a specific calendar for individual statistical surveys, and the same is true for all EU countries.
This classification is the national version of the European nomenclature, Nace Rev. 2, published in the Official Journal of 20 December 2006 (Regulation (EC) no 1893/2006 of the European Parliament and the Council of 20 December 2006).
Ateco 2007 has been set out and approved by a specially convened Steering Committee. In addition to Istat, which coordinates it, it requires the participation of several institutional figures: the Ministries

concerned, the Bodies that manage the primary administrative data sources on enterprises (the Revenue Agency, Chambers of Commerce, social security institutions, etc.), and the leading business associations.
Working in close collaboration with the Revenue Agency and Chambers of Commerce, a single classification has been made. For the first time in the world of official statistics, the Revenue Agency and Chambers of Commerce adopted the same classification of economic activities. This result represents a significant step forward in integrating and simplifying the information gathered and handled by Public Administration.
An automatic coding tool allows users to assign an *Ateco 2007* code according to a brief description of the economic activity supplied by the users. The tool also allows users to browse the whole classification text and to identify parts of the classification in which a specific word has been entered by the user.
Source: https://www.istat.it/en/classification/ateco-classification-of-economic-activity-2007/, accessed in October 2024.

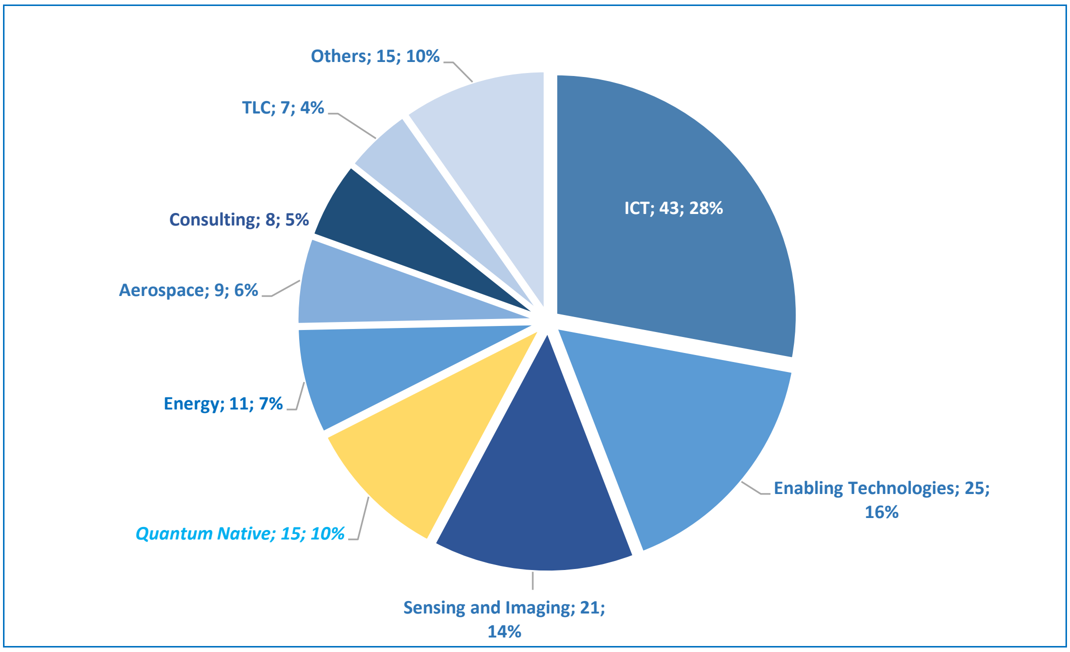
Figure 30. The year of birth of the firms in the sample



The analysis of the years of establishment of the Italian Quantum Science and Technology organizations shows a clear development path (see *figure 30*). First, it is evident that companies with a long history cohabit with firms of recent establishment and startups.
While until the end of the year 1980-89, the number of new companies remained constant (6-11 firms each year), it grew almost exponentially, reaching a peak in 2010-2019 (41 companies).
Undoubtedly, the trend is the consequence of the technological shifts experienced in quantum science over the last 30 years, driven by the discovery of principles of isolation and entanglement of quantum objects. Scientists learned to observe and control matter at the microscopic level, manipulating large ensembles of particles and trapping an electron or an atom emitting a single photon. These properties of quantum can now

theoretically and practically be translated into new applications, new processes, and innovations for the industrial and end users.
The author already underlined the limits of the classification of QST by verticals; the analysis tries to understand the main areas of interest of the companies of the *NQSTI* dataset. As evidenced in *figure 31,* the *Information and Communication Technologies* industry holds the most significant share with a percentage of 28%, representing 43 companies involved (both software and hardware). *Enabling Technologies* represent 16%, with 25 firms active in the sector. *Sensing and Imaging*, however, shows 21 companies, representing 14%. *Quantum Native Enterprises* form a group of 15 firms representing 10% of the total.
Two of these organizations (*SeeQC* and *Xanadu*) have joint laboratories in Italy. Therefore, 13 Italian companies were born through the development of quantum technology (*1 in Sensing and Imaging, 3 in Telecommunications, 3 engineer Quantum Software, 3 operate in Quantum Computing, and 3 develop Key Enabling Technologies*).

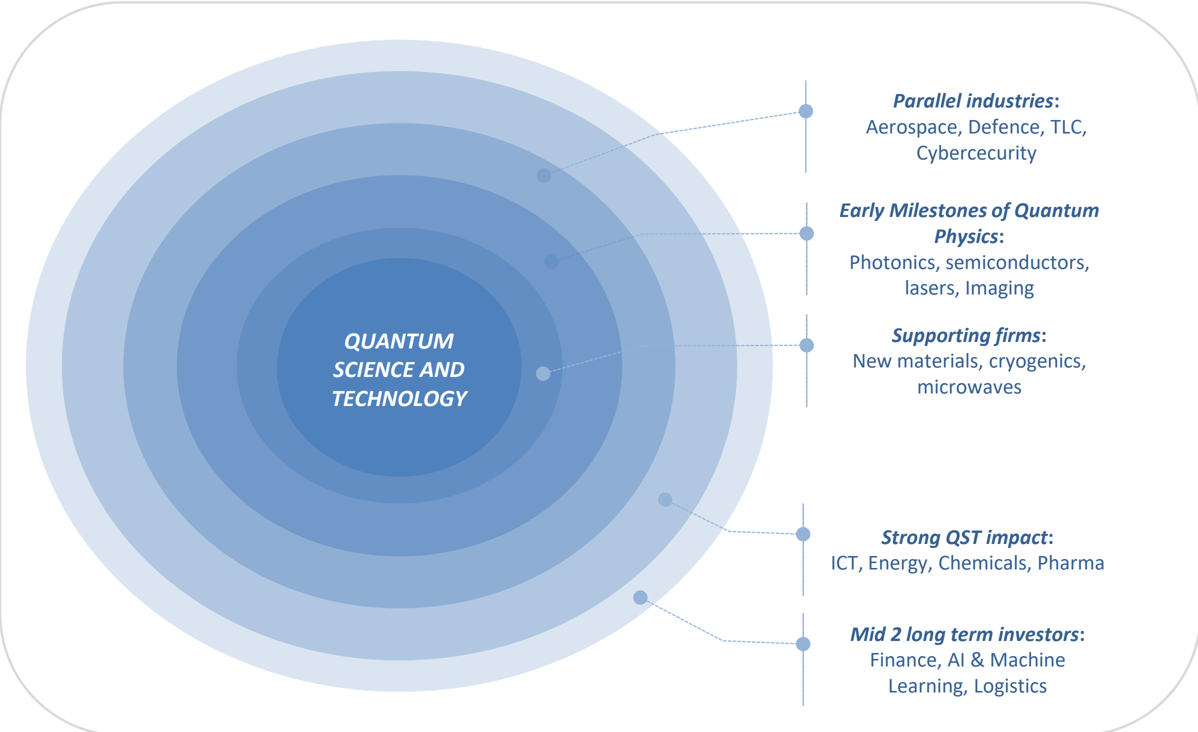
Figure 31. The Technological Industries of the companies



It is worth noting *that almost 15 companies belong to another sector of specialization*. As anticipated earlier in the text, all the private organizations involved in QST European research projects are analyzed (*Horizon EU*). Different companies have the chemical sector, pharmaceuticals, medical imaging, and others as core activities. Several firms, indeed, are consulting companies, managing, writing, or accounting research projects or acting as enablers between industrial and academic partners (as described in the *Cordis* dataset previously analyzed).

The difficulties in classifying many of the sample companies, the investigation of the mission, the analysis of participation in European projects, the collection of primary data, the investigation of several case studies, and newspaper articles led the author to offer a *qualitative representation* of the companies' economic activity (see *figure 32*).
The *model is organized around concentric levels* that define the intensity of quantum science and technology in the activities of the companies (from central to peripheral roles). Organizations whose mission refers to quantum science have been established in the last 10 years, and they will be described better in the spinoff paragraph. To this *core ensemble* are associated organizations providing supporting technologies to research and the industrial supply chain. At the first level (second circle around "quantum core"), there are the firms of supporting sectors, such as those that develop research and production activities in new materials, advanced cryogenic systems, or microwave apparatus.

Figure 32. A quantum-intensity representation: evidence from the Italian dataset



The second level of proximity is represented by the firms that produce transistors, lasers, electronic systems, and photonics, which we defined as "Early Milestones of Quantum Physics". Parallel industries such as aerospace, defense, and cybersecurity, do not move directly along the QST value chain; they develop quantum research and technology for space, for telecommunication, and to guarantee national security.
Industries where QST would have a strong and immediate impact are just beginning to investigate quantum research, with specific collaborations. These sectors involve not only ICT and logistics, but also the pharmaceutical and chemical sectors, as well as the diagnostic landscape (including NMR and others). "Final users", as well as other

classifications described in the report, are often integrated into the QST sector as they develop specific technological projects and have an industrial target to reach.
Finally, the last circle describes industries where QST will have a mid-term impact. Companies pursue a technological competitive advantage and want to be a “first mover” in the competitive arena.

3.4 The spinoffs sample: bridging the gap to commercial development

Several contributions in economic literature emphasize spinoffs’ role in launching new products and services from scientific research. They can represent an effective *trait d’union* between the scientific discoveries and the market along the technological value chain. Spinoffs, in particular, represent an alternative instrument for commercializing academic knowledge. This mechanism does not damage open science and allows society to reap the economic benefits at regional and national levels.

Rappert, Webster, and Charles (1999) define university spinoffs as those firms whose products and services have developed on technological ideas or scientific know-how that has been generated in the academic environment by a member of the faculty, staff, or by a student who created (or co-created with others) the business. The founder can also leave the university to develop a new company or start an entrepreneurial activity while remaining in the academic institution. It is not relevant whether this person or these people are a full-time student, or professor, or the distance in time that passes from initial research to commercial development, but whether the research conducted within the research organization was necessary for the company to create that product or service.

Research spinoffs represent a bridge between public research and the market. They are those subjects capable of "translating" scientific activity so that it can be managed by companies already on the market, adverse to a specific type of research risk.

The *NQSTI* dataset focuses specifically on academic spinoffs, investigating the year of establishment, the academic organization(s) that gave birth to the entrepreneurial activity, and the companies’ missions (see *table 8*).
The primary evidence emerges from the spinoffs sample (see *figure 33*). In line with the general data, Lombardia and Toscana show the most significant number of spinoffs, with 10 academic organizations. Still, Campania and Veneto see QST sectors populated by 6 and 4 young companies, respectively (see *figure 33a*).
Even if the trend of these last years is relevant, as 13 new organizations were born between 2020 and 2024, 19 companies established their activity between 2010 and 2019. An ulterior phase of investigation could reveal other academic members inside startups of the general sample, as 65 are the QST firms were founded after 2010 (see *figure 33b*).

From the first analysis of the spinoffs sample, it emerged that companies divide themselves proportionally into 3 main industries: *ICT* (10), *Sensing and Metrology* (10), and *Enabling Technologies* (9). This could testify to data inconsistent with the global QST trend, or a specific characteristic of the Italian academic environment.

Figure 33. The Spinoffs of the sample – Main data

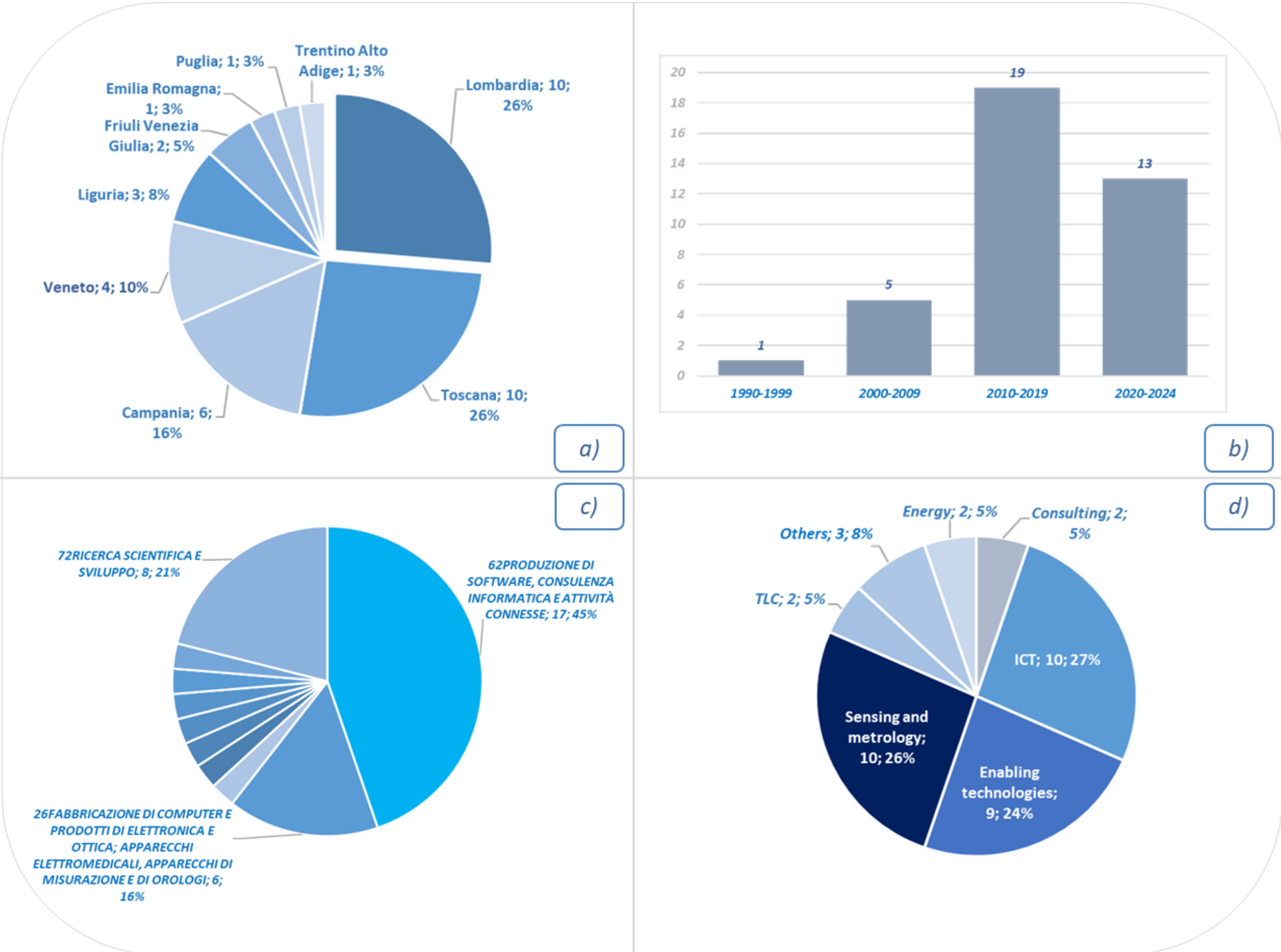


Table 8. The spinoffs of the sample

Spinoff	*Organization of origin*	*City*	*Region*	*Website*	*Activity/Mission*	*Markets Served*	*Year of birth*
Aindo	*Scuola Internazionale Superiore di Studi Avanzati (SISSA) di Trieste*	Trieste	Friuli Venezia Giulia	www.aindo.ai	AI-Based Solutions / to enable artificial intelligence to add value to society while respecting our rights and freedoms	***ICT***	2018

AtomSensors	*Università di Firenze*	Sesto Fiorentino	Toscana	www.atomsensors.com	Measurement instruments based on the use of laser cooling techniques, trapping and manipulation of neutral atoms for applications such as: identification of oil deposits, tectonic/geodynamic prospecting, study of sedimentary deposits, archaeological research, volcano monitoring, measurement of polar ice thickness, inertial navigation	***Sensing and metrology***	2015
BEDIMENSIONAL	*Graphene Labs dell'Istituto Italiano di Tecnologia di Genova*	Genova	Liguria	www.bedimensional.com/it	Energy Storage and Conversion, Coatings, and Composites / Innovate industrial processes and create new performing solutions	***New materials - Energy***	2016
Bright101	*Sant'Anna*	PISA	Toscana	www.bright101.it	Industrial development of optical systems with LED or laser sources	***TLC***	2019
CAMBRIDGE RAMAN IMAGING	*University Of Cambridge, Politecnico di Milano*	Verona	Veneto	www.cambridgeramanimaging.com	Chemometric Imaging for Cellular Analysis / To offer highly precise and detailed imaging of tissues and cells, allowing for more accurate diagnoses of diseases and a better understanding of their underlying mechanisms.	***Medical devices***	2005
COHAERENTIA	*Politecnico di Milano*	Milano	Lombardia	www.cohaerentia.com	*Cohaerentia* has developed an innovative diagnostic system that allows real-time monitoring of plants, machinery or civil infrastructures to improve the quality and efficiency of production processes in manufacturing industries and security in the civil sector	***Sensing and metrology***	2015
CUBIT	*Università degli Studi di Pisa*	Cascina (PI)	Toscana	cubitlab.com	Consulting / Adopting an operational model which integrates technological research and industrial experience with a continuous process of innovation and technology transfer, capable of increasing the competitiveness of companies.	***Consulting***	2007
Digital Superconducting Quantum Machines (DSQM)	*CNR - Consiglio Nazionale delle Ricerche*	Pisa	Toscana	www.dsqm.it	Specializing in superconducting technologies, DSQM offers a comprehensive range of services including fabrication, cryogenic measurement capabilities, superconducting device design, and cryogenics electronics	***ICT***	2022
DYNAMIC OPTICS	*CNR - Consiglio Nazionale delle Ricerche*	Padova	Veneto	www.dynamic-optics.it	Development of optical and photonic technologies / Providing unique innovative transmissive wavefront modulators, ultra-high reflectivity deformable mirrors and solutions for wavefront sensing metrology.	***TLC***	2017
EMOLED	*Università di Firenze, LENS and IFAC of CNR*	Firenze	Toscana	emoled.com	Medical Devices / Developing highly innovative medical devices, the result of advanced research in the field of photonics	***Medical devices***	2014
EPHOS	*CNR - Consiglio Nazionale delle Ricerche*	Milano	Lombardia	ephos.io	Integrated Photonic Circuits / Minimizing signal loss, enabling customers to build scalable quantum infrastructures.	***ICT***	2022
FORESEE BIOSYSTEMS	*Polimi*	Genova	Liguria	foreseebiosystems.com	Gas Analysis and Biosensors / Developing innovative solutions for the assessment of in-vitro cardiotoxicity.	***Medical devices***	2021

GEOMATICS RESEARCH & DEVELOPMENT	*Polimi*	Lomazzo	Lombardia	www.g-red.eu	Geodesy and Remote Sensing Services / Structure displacement monitoring, Ground displacement monitoring, Gravity field modelling and inversion, Atmospheric sensing	***Sensing and metrology***	2000
GLASS TO POWER	*Milano Bicocca*	Rovereto	Lombardia	www.glasstopower.com	Glass-based energy conversion technologies / To develop transparent, aesthetically pleasing photovoltaic glazing that can be invisibly integrated into the architecture of buildings to align them with theNear Zero Energy Building (NZEB) standards, restoring and improving the living comfort of those who occupy them	***New materials - Energy***	2016
GRAFTONICA	*Milano Bicocca*	Milano	Lombardia	www.graftonica.it	Solutions and consulting in technology and medicine / Use of new methodologies in order to compatibilize and disperse inorganic nanometric fillers within polymer matrices	***New materials -Health***	2015
Infibra Technologies	*Sant'Anna*	PISA	Toscana	www.infibratechnologies.com/it	Development of technologies and solutions in the field of optical fibers / Designing and manufacturing of next-generation fiber optic sensors systems, while also offering engineering services. Energy, Oil & Gas, Transportation and Civil Engineering are our target markets, with solutions even suitable for harsh environments	***Sensing and metrology***	2014
Level Quantum	*Milano Bicocca*	MILANO	Lombardia	www.levelquantum.eu/en	Advanced IT Solutions / providing unconditional security to communications	***TLC***	2022
Micro Photon Devices	*Polimi*	Bolzano	Trentino Alto Adige	www.micro-photon-devices.com	Development of single-photon devices for scientific research, medical, and industrial applications / Production and commercialisation of advanced single-photon counting modules with unmatched photon-timing capabilities and overall performance	***Sensing and metrology***	2004
NARRANDO	*Università di Salerno*	SALERNO	Campania	narrandosrl.weebly.com	Dosimeters for Radiology	***New materials -Medical devices***	2017
NEWRONIKA	*Università degli Studi di Milano e Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico.*	Milano	Lombardia	newronika.com	Advanced Neurostimulation Solutions / Restoring brain and body functions with neural devices	***New materials -Medical devices***	2013
NIREOS	*Polimi*	Milano	Lombardia	www.nireos.com	Optical Instruments / High Tech Solutions in Spectroscopy and Photonics	***Sensing and metrology***	2018
Photon Technology Italy (Photec)	*CNR, Federico II, and Shanghai Institute of Microsystem and Information Technology, Chinese*	Napoli	Campania	www.cnphotec.com	SNSPD, superconducting electronics, cryogenic setups, cryogenic solutions	***Sensing and metrology***	2023

	Academy of Sciences						
PicoStats	*Università di Trieste*	Trieste	Friuli Venezia Giulia	picosats.eu	Innovative solutions for satellite communication, maritime navigation, Earth observation, and space sustainability / aspiring to an interconnected world where people can use space-derived resources to improve community life in a sustainable way	***Sensing and metrology***	2018
Planckian	*SNS and Università di Pisa*	PISA	Toscana	www.planckian.co	Quantum-powered energy management	***New materials - Energy***	2022
PPQSENSE	*CNR - Consiglio Nazionale delle Ricerche*	Sesto Fiorentino	Toscana	www.ppqsense.com	High-Quality Electronics for Laser Systems / aiming to contribute to the ecological transition and the emergence of the Net Zero carbon initiative by providing new technologies to researchers and industries	***Energy***	2016
Promete	*CNR - Istituto Nazionale per la Fisica della Materia*	Napoli	Campania	www.promete.it	Research and development in advanced technologies / R&D projects that have as their ultimate goal to promote the growth of competitiveness of SME	***ICT***	1997
QSensato	*UniBA*	Bari	Puglia	www.linkedin.com/company/qsensato	Technology is based on atomic-photonic chips that exploit the properties of quantum mechanics to detect minimal variations in electric and magnetic fields, making unprecedented precision in measurements possible.	***Sensing and Metrology***	2024
QTI - Quantum Telecommunications Italy	*CNR - Consiglio Nazionale delle Ricerche*	Firenze	Toscana	www.qticompany.com	Advanced technologies for quantum telecommunications / developing and produce reconfigurable quantum key distribution architectures	***TLC***	2020
QuantumNet	*Unina*	Napoli	Campania	www.quantum-net.it	Development of skills and solutions using quantum technologies	***ICT***	2021
Quantum2Pi	*Unina*	Napoli	Campania	www.quantum2pi.com	Our mission is to develop and implement cutting-edge Quantum Computing solutions that overcome current technological barriers	***ICT***	2024
QUNatech	*Unina*	Napoli	Campania	www.qunatech.com	Superconducting Nanowire Single Photon Detectors	***Sensing/ TLC***	2024
Random Power	*Universita dell'Insubria e AGH University*	Como	Lombardia	www.randompower.eu	Manufacturing of industrial machines and equipment / Design and development of an innovative system enabling data encryption and development of related services	***TLC***	2022
RULEX INNOVATION LABS	*CNR - Consiglio Nazionale delle Ricerche*	Genova	Liguria	www.rulex.ai	Development of explainable AI for understanding and interpreting processed data / Enabling people and organizations to take smart decisions and automate processes by harnessing their own business data and domain knowledge	***ICT***	2014
SMARTEX	*Scuola Superiore Sant'Anna.*	S.Giuliano Terme	Toscana	www.smartlex.eu	Interaction between law, technology, and human capital	***Consulting***	2015

STELLAR PROJECT	*Università di Padova*	Padova	Veneto	www.stellarproject.it	Satellite Communication and Space Sustainability / Starting to expand our activities on data analytics both for terrestrial applications and the space environment providing tools for Space Debris Analysis and monitoring	***Sensing and metrology***	2016
Sybilla Biotech	*Università di Trento e dell'Istituto Nazionale di Fisica Nucleare (INFN)*	Bresso	Lombardia	www.sybillabiotech.com	Development of small-molecule degraders with a novel mechanism of action to discover new drugs for medical needs / Focusing on developing small molecule degraders with a novel Mechanism of Action to find new therapeutics for unmet medical needs	***New materials - Medical devices***	2017
ThinkQuantum	*Università di Padova*	Sarcedo (VI)	Veneto	www.thinkquantum.com	Quantum-based technology solutions for cyber security and communication systems (QKD and QRNG) / Offering quantum-based technology solutions for cyber security and communication systems	***TLC***	2021
VST	*Università degli Studi di Modena e Reggio Emilia*	Modena	Emilia Romagna	ippocra.tech	Telemedicine Equipment	***ICT - Healthcare***	2003

Photon Technology Italy

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"PTI is the first innovative startup in Italy for the production and commercialization of superconducting single photon detectors with unparallel performances. We aim to actively contribute to the Italian ecosystem of scientific and industrial excellence, fostering innovation and collaboration in the field of quantum technologies"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Founded in 2023, *PTI* has already established strong collaborations with leading academic institutions, research centres, and companies—both in Italy and internationally. Our ongoing projects and initiatives involve partners such as the *University of Naples Federico II*, *CESMA*, *CNR-SPIN*, *Think Quantum srl*, *QTI srl*, *Optosmart* srl, *Meditech*, and *Qunatech srl*. We are also actively expanding our network, forging new partnerships with key players in the Italian territory and exploring opportunities in the quantum technology and cryogenics industries.

Who are your direct competitors?

Our direct competitors are *Single Quantum*, *IDQuantique*, *Quantum Opus*, Scontel, *Photon Spot*.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

Europe is increasingly investing in building its own quantum ecosystem to reduce reliance on non-EU tech providers, especially in critical areas like quantum computing, secure communications, and sensors. We're seeing the rise of niche companies and spinoffs across the supply chain, from cryogenics and photonics to qubit control hardware and software stacks. Initiatives like the *European Quantum Flagship*, the *Chips Act*, the Italian PNRR and upcoming European Partnerships on Quantum Technologies are fueling R&D and early-stage industrial scaling.

We believe that Europe still faces the risk of having too many small, disconnected efforts. A unified strategy and interoperability standards are essential. Furthermore, the quantum workforce is still limited. Europe needs to rapidly train engineers, quantum physicists, and technicians while retaining top talent in a competitive global market.
Some critical components, like specific laser systems, superconducting materials, or dilution refrigerators, are still imported and strategic independence will require targeted investment in these fields.

What are the main areas of application for quantum technologies? What are the target markets?

The main target markets for our technology are photonic quantum computing, quantum communication, satellite communication, MIR single photon detection, Lidar, single photon source characterization, quantum optics, imaging, microscopy, and spectroscopy.

Can you provide examples of real use cases?

Extending the distance of quantum key distribution, prevent QKD from photon splitting attacks, measure the photon number distribution of a single photon source, validate boson sampling, and so on.

Who are your current customers and what are your potential customers?

Our current customers are industries and researchers working in the fields of quantum optics and quantum communication. We're focusing on the EU market but we' re also exploring international potential users.

QSensato

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"QSENSATO, the first Quantum Sensing startup in Southern Europe, will bridge the gap between AMO physics and integrated photonics, through the development and commercialization of laser-written vapor cells, atomic-photonic chips and complete atomic quantum sensors"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

QSENSATO is a spinoff of UNIBA. The patented technology on laser-written vapor cells will be licensed by *ICFO* and *CNR-IFN*, the institution where it has been developed during prior research of Dr. Lucivero. We foresee collaboration as well as prototyping for companies such as *Leonardo* and *TASI* and for national assets and research institutions such as the *National Institute of Metrology* (*INRIM*, Torino) and the *European Laboratory for Non-Linear Spectroscopy* (*LENS*, Firenze).

Who are your direct competitors?

We have direct competitors on the fabrication of MEMS vapor cells for atomic quantum sensors, mainly RTOs such as *CSEM* (CH), *Femto-St* (FR) or *Fraunhofer CAP* (Glasgow).

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

The company *SAES Getters* (Milan) can provide dispensers of alkali-atoms.
Challenges:
1) *having an Italian provider of chemical compounds* including alkali metals, such as Rb or Cs.
2) We plan *external prototyping* with companies such as *FEMTPrint* (CH) that uses similar technology of *CNR-IFN* in Milan but with rapid manufacturing, scalable on a wafer scale.
3) In the *supply chain key components* and *packaging services* (ceramics, low-noise electronics, integrated optics) for quantum devices seem are still missing in Italy.

4) We need *infrastructures for deep tech*, inside or close to the Physics department, to increase the TRL of the technology, before eventually using external spaces for production.

What are the main areas of application for quantum technologies? What are the target markets?

The market segments of vapor cells and atomic quantum sensors are: Research Labs (*AMO* Physics/Microfluidics/Chemistry), Space and Defense (*GPS, RF Sensing, PNT, SSA*), Medical Diagnostics (*MEG, MCG, MMG*), Remote Sensing (Drone surveillance, Geomagnetic mappings, *MAD* detection), Lab-On-Chip applications (Low-fields *NMR*, chemical and materials analysis and characterization), Automotive (Inertial sensors, atomic gyroscopes for self-driving vehicles).

Can you provide examples of real use cases?

Integrated atomic frequency reference (for laser stabilization and satellite communications), *chip-scale atomic magnetometers* (for magnetoencephalography and similar), *integrated Rydberg-atoms-based sensors of RF electric fields* (for SSA), *lab-on-chip magnetic microscopy*.

Who are your current customers and what are your potential customers?

Initial customers will be research groups with custom-designed laser-written and/or optical vapor cells. Secondly quantum startups active in the above-mentioned fields of application with a B2B model. Finally big companies (*Leonardo*, *TASI*, *Bosch*, *Thales*), national and European agencies (*ASI*, *ESA*) and/or research centers (*INRIM*, *NIST*, *NASA*).

Planckian

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"The collaborative approach (along the computing value chain) helps drive innovation and ensures that solutions are optimized for real-world applications from the outset"

Description of the firm and mission:

At *Planckian*, we are developing next-gen scalable superconducting quantum processor with the goal of solving the 'wiring problem' that limits quantum computers from scaling to the 1 million qubits needed for practical use. Our chip technology replaces conventional individual qubit control with a global control system, where a specific number of cables can operate across multiple qubits.

Specifically, our architecture keeps wiring at a constant and manageable level, regardless of the number of qubits.

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Planckian actively collaborates with research institutes in Italy and internationally, primarily in Europe and Canada. These collaborations span various activities, mainly focused on experimental research, go-to-market strategies, and funding opportunities. As the technology matures, we anticipate that the company will strengthen partnerships with potential industrial partners to accelerate technology validation through initial real-world use cases.

Who are your direct competitors?

Our competitors include major quantum hardware companies like *IBM*, *Google*, and *Rigetti*, as well as emerging processor vendors who are meeting the growing demand for low-cost, on-premises installations of NISQ (Noisy Intermediate-Scale Quantum) devices. Unlike many current quantum processors, which struggle to scale qubit counts without increasing error rates, our processor features a novel architecture designed for seamless scalability. This architecture ensures that performance improves as the system grows, rather than degrading, allowing us to achieve scalability by design.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges to be faced?

The global quantum computing market is expected to surpass $2 billion by 2030, with an annual growth rate of approximately 14% (Yole Group, 2023). Applications in quantum computing, particularly in physics and molecular simulations, are projected to drive over 50% of the market value by 2030 (*McKinsey*, 2024). While cloud-based platforms remain essential for broadening access to quantum resources, the demand for on-premises installations is rapidly increasing and becoming the preferred choice for users in critical sectors such as defense and industries requiring intensive computing power, like R&D labs and high-performance computing (HPC) centers.

The demand for on-premises installations is being met in two primary ways: (i) *delivering full-stack solutions*, including processors, control systems, and low-level software; and (ii) *providing off-the- shelf processors* directly to customers or through system integrators. Off-the-shelf solutions offer a cost-effective approach for both customers and suppliers and cater to the preferences of many R&D organizations that seek greater control over their supply chains, customized platforms, and internal capability development. Following these trends, the *quantum supply chain is rapidly evolving*, with an increasing number of players focusing on gaining a competitive edge in specific segments of the value chain, such as the *hardware layer, control electronics, cryogenics, middleware, firmware, and software* in quantum computing. By combining this with a co-design approach—where quantum circuits and algorithms are developed to match the specific characteristics of current hardware and problem requirements—quantum computing providers can accelerate technology validation while also building early relationships with potential end-users. This collaborative approach helps drive innovation and ensures that solutions are optimized for real-world applications from the outset.

What are the main areas of application for quantum technologies? What are the target markets? Can you provide examples of real use cases?

Quantum computers are poised to solve complex problems that remain inaccessible to classical computers. This occurs when the time required to solve these problems scales exponentially on classical machines. In extreme cases, solving exponential problems on even the most powerful supercomputers could take millions of years. Typical examples of such problems include combinatorial optimization searches and quantum chemical simulations. Quantum simulations in physics and chemistry are expected to be key applications, as they are governed by many-body quantum physics equations. For instance, typical quantum chemical simulation algorithms can determine a system's minimum energy configuration, or ground state, with greater precision than classical methods. Other quantum algorithms explore how molecules interact (e.g., molecular docking), chemical pathways, and the vibrations and rotations of molecules. In physics, quantum simulations are applied to material design by providing a deeper understanding of crystal structures and the mechanisms of magnetism.

Who are your current customers and what are your potential customers?

Planckian is currently at pre-revenues stage. First potential customers are expected to be those currently in need for first on premises installations (public and private R&D lab, HPC center, etc.) currently served through system integrator.

DSQM, Digital Superconducting Quantum Machines

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"The quantum revolution is unlocking the mysteries of the world at the smallest scale, paving the way for groundbreaking innovations in computing, communication, and sensing that will redefine the limits of human capability and revolutionize industries across the globe"

Description of the firm and mission:

DSQM (*Digital Superconducting Quantum Machines*) is an innovative startup that emerged as a spinoff from the *Italian National Research Council*'s *Nanosciences Institute* (*CNR-Nano*). Its mission is to revolutionize telecommunications and computing by developing ultra-fast, energy-efficient circuits based on superconducting materials. These circuits are designed to enhance the performance of both classical and quantum computers, promising speeds up to 100 times faster than current technologies. By leveraging cutting-edge research, *DSQM* aims to transform fields like supercomputing and quantum computing, with wide-ranging applications from medicine to environmental forecasting.

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Yes, *DSQM* actively collaborates with several leading research institutes and universities to advance its technology. Notable partnerships include:

University of Adelaide: DSQM works with the university on the development of *SQUID* (Superconducting Quantum Interference Device) amplifiers and magnetometers, which are critical for enhancing the sensitivity and functionality of quantum devices.

Scuola Normale Superiore: This partnership focuses on nanofabrication, a key process in creating the ultra-small, precise superconducting circuits that *DSQM* develops.

CNR Nano: *DSQM* collaborates with the *CNR Nano institute* to access cryogenic facilities, which are essential for testing and operating superconducting materials at extremely low temperatures.

In the future, *DSQM* anticipates expanding collaborations with both industrial and academic partners to further enhance quantum computing technologies and develop new applications in telecommunications, computing, and sensor technologies.

Who are your direct competitors?

DSQM operates in a competitive landscape where several key players are developing cutting-edge technologies for quantum computing and superconducting circuits. Notable competitors include:

Imec (*Cryo-CMOS*): *Imec* is advancing *Cryo-CMOS* technology, which integrates traditional *CMOS* technology with cryogenic environments to create efficient quantum computing interfaces. This technology is a significant competitor in quantum computing control systems due to its energy efficiency and potential scalability.

Intel (*Horse Ridge II): Intel's Horse Ridge II* is a quantum control processor designed to manage and simplify the control of qubits at cryogenic temperatures. It is a key player in scaling quantum computing solutions with highly integrated control capabilities.

SeeQC (*RSFQ Quantum Controller*): *Seeqc* is developing a digital quantum computing platform using *RSFQ* (*Rapid Single Flux Quantum*) technology. Its quantum controller integrates quantum and classical processing elements on a single chip, which directly competes with *DSQM's* superconducting circuit innovations in terms of control and energy efficiency.

These competitors are also focused on developing hardware for quantum computing, with specific emphasis on increasing speed, energy efficiency, and scalability.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges to be faced?

The *quantum supply chain outlook faces several notable challenges and uncertainties*, yet it also holds significant opportunities for growth and innovation.

Lack of standards: One of the most pressing challenges is the absence of universal standards for quantum technologies. Unlike classical computing, where clear industry standards (like those for semiconductor design) exist, the quantum field is still in its early stages. This makes it difficult to develop interoperable systems, which in turn hampers large-scale adoption and commercialization across industries.

No clear winner among Quantum Platforms: Currently, multiple quantum computing platforms are being explored, such as superconducting qubits, trapped ions, and photonics. The competition between these technologies creates uncertainty for stakeholders in the supply chain, as it is not yet clear which platform will dominate in the long run. This makes it harder for suppliers, manufacturers, and investors to commit resources toward one approach, slowing down the development of an efficient supply chain.

Small Market Size: The quantum computing market is still relatively small, with much of the research and development happening in academia or within large tech companies. Because quantum technology is not yet widely deployed for commercial applications, the current demand for quantum components and expertise remains limited. This can deter large-scale investment and production capabilities in the supply chain, making it challenging to achieve economies of scale.

Despite these challenges, the quantum supply chain has the potential to grow significantly in the coming years, as quantum technologies mature and find broader commercial applications. As standardization efforts progress and the market grows, we can expect increased collaboration between academic institutions, startups, and large enterprises. The establishment of standards, clearer market leadership, and larger-scale industrial applications will be critical steps in unlocking the full potential of the quantum supply chain. Future growth is likely to be driven by innovations in quantum hardware, control systems, and software, along with emerging use cases in industries such as pharmaceuticals, cybersecurity, and material science.

What are the main areas of application for quantum technologies? What are the target markets?

Quantum technologies have the potential to revolutionize several key industries by leveraging quantum mechanics to solve complex problems that classical technologies struggle to address. The main areas of application include:

1. Quantum Computing

Application: Quantum computing aims at solving problems that are computationally intractable for classical computers. This includes optimization, cryptography, and complex simulations.

Target Markets:

- *Pharmaceuticals*: Drug discovery and molecular modeling, where quantum computers can simulate molecular interactions to accelerate the development of new drugs.
- *Finance*: Risk analysis, portfolio optimization, and fraud detection, where quantum algorithms could significantly speed up calculations.
- *Logistics*: Quantum computers can improve supply chain management, optimize routes, and handle large-scale logistical problems.

2. Quantum Cryptography

Application: Quantum cryptography, especially Quantum Key Distribution (QKD), ensures secure communication by using the principles of quantum mechanics to detect any eavesdropping.

Target Markets:

- *Cybersecurity*: Governments, defense sectors, and financial institutions are potential users of quantum cryptographic systems for secure communication.
- *Telecommunications*: Service providers are exploring QKD for secure data transmission over optical networks.

3. Quantum Sensing and Metrology

Application: Quantum sensors provide highly sensitive measurements of time, gravity, and electromagnetic fields. They can be used for navigation, medical imaging, and geological exploration.
Target Markets:
- *Healthcare*: Quantum sensors could lead to advancements in MRI technology and other medical imaging techniques.
- *Defense*: Quantum-enhanced radar and navigation systems can operate in GPS-denied environments, useful for military applications.
- *Energy and Resources*: Exploration of natural resources like oil and minerals through highly accurate quantum sensors.

4. Quantum Simulations

Application: Quantum simulations are used to model complex quantum systems that are hard to simulate on classical computers. This is particularly valuable in material science and chemistry.
Target Markets:
- *Materials Science*: Developing new materials with specific properties for industries like aerospace, electronics, and manufacturing.
- *Chemical Industry*: Simulating chemical reactions to improve processes and develop more efficient or environmentally friendly chemicals.

5. Quantum Networks and Communications

Application: Quantum networks can potentially lead to the development of a "quantum internet," enabling ultra-secure communication and quantum cloud computing.
Target Markets:
- *Telecommunications*: Quantum internet infrastructure will require hardware and services that connect quantum computers across vast distances.
- *Cloud Computing*: Quantum networks could enable distributed quantum computing, where companies can rent quantum computing power in a similar way to how they use classical cloud services today.

6. Artificial Intelligence and Machine Learning

Application: Quantum algorithms can be applied to improve machine learning models, increasing their accuracy and reducing computational time.
Target Markets:
- *Tech and AI Startups*: Companies developing AI algorithms for various industries may integrate quantum computing to enhance capabilities.
- *Data Analytics*: Quantum machine learning could transform fields like natural language processing, image recognition, and big data analysis.

Can you provide examples of real use cases?

QueSt (Quantum Superconducting Switch) is a groundbreaking RS switch that aims to solve key scalability and efficiency challenges in quantum computing.

Currently, quantum computers require extensive wiring to connect their qubits, which not only limits scalability but also increases power consumption and system costs. *QueSt* addresses this by significantly reducing the number of physical wires needed, compacting them onto a solid-state device, and minimizing heat dissipation. This allows quantum systems to operate with up to 75% fewer wires and drastically reduces downtime by up to 99% after switching events, while using 90% less hardware volume.

Moreover, *QueSt* is compatible with existing *CMOS* infrastructure, which means it can be seamlessly integrated into current quantum computing setups and potentially extend to high-frequency telecommunications and high-performance computing applications. Its ability to operate at high speeds, with nearly no energy dissipation, makes it a critical innovation for next-generation 6G networks and advanced quantum research.

Who are your current customers and what are your potential customers?

Our current customers include *Planckian* (Quantum Startup) and the *University of Adelaide*, where we provide services related to the characterization and fabrication of superconducting devices. These collaborations highlight your role in advancing research in quantum technologies.

As for potential customers, our focus could expand to industries such as:

Quantum computer manufacturers, who are actively seeking high-performance superconducting devices for enhancing quantum processing capabilities. *Cryostat manufacturers*, who require advanced superconducting components to improve cooling efficiency in quantum systems. *Academic institutions*, where ongoing research in superconductivity and quantum computing would benefit from your expertise in device fabrication and testing.

QuantumNet

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“At QuantumNet, we believe quantum technologies are the future of innovation. We support research, spinoffs, and strategic collaborations to accelerate real-world applications and bridge the gap between science and industry”

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

QuantumNet is one of the first Italian innovative startups specialized in **Quantum Computing**.
Born in 2021 from collaboration between *NetCom Group S.p.A* and researchers of the *University of Naples «Federico II»*. In the future, *QuantumNet* aims to expand its collaborations within both industry and academia, focusing on integrating quantum computing into practical applications across sectors like telecommunications, automotive, and finance. We plan to deepen ties with industry leaders and startups to develop cutting-edge solutions that leverage quantum hardware and software. Collaborating with academic institutions, such as the University of Naples Federico II, will help us stay at the forefront of quantum research, and we foresee broadening these partnerships globally.

Who are your direct competitors?

Primarily other companies that focus on the application of quantum computing in specialized sectors like telecommunications, automotive, finance, and public services. These competitors are typically firms that integrate quantum computing with their existing software development and engineering services. They may include large tech corporations with dedicated quantum research divisions, as well as smaller, specialized startups that focus on providing quantum-based solutions for various industries. Additionally, academic research institutions and collaboration-driven firms that bridge the gap between quantum research and practical industrial applications also represent a competitive landscape for QuantumNet.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

The quantum supply chain is growing rapidly, fueled by increasing demand for quantum computing across various industries. However, key challenges include the scalability and reliability of quantum hardware, the shortage of skilled professionals, and the complex supply of materials needed for quantum systems. Additionally, integrating quantum technology with classical computing will require hybrid models. Despite these hurdles, the outlook is positive, with continued investment and research paving the way for transformative changes in the future.

What are the main areas of application for quantum technologies? What are the target markets?

For *QuantumNet*, the main areas of application for quantum technologies include sectors like automotive, telecommunications, media, finance, public administration, defense, and avionics. Specifically, the company focuses on developing solutions for tasks such as algorithm optimization, data analysis, and processing within these industries, leveraging quantum computing’s unique advantages.
The target markets for QuantumNet encompass industries that require high-performance computing and innovative data analysis capabilities. These markets include automotive (for autonomous driving, ADAS,

and predictive maintenance), telecommunications (for network optimization and data security), finance (for complex risk modeling and fraud detection), and public sector applications (like smart cities and infrastructure management). Additionally, the company is aiming at industries involved in the defense and aerospace sectors, where quantum technologies could be crucial for security and communication systems.

Can you provide examples of real use cases?

- Optimization Algorithms for Traffic Light Control in Urban Networks

Efficient traffic light management is crucial for urban mobility, especially in smart city contexts. QuantumNet designs hybrid metaheuristic algorithms combining classical and quantum computing to optimize traffic flow in real time, leveraging the growing capabilities of quantum processors.

- Quantum Classification Models for Anomaly Detection in Industrial Processes

Quantum computing enhances artificial intelligence and machine learning by introducing quantum variational circuits. These models can be used for classification tasks, such as identifying damaged components in production lines or detecting anomalies in telecommunication systems.

- Optimization Algorithms for Enhancing Cultural Site Accessibility

Quantum algorithms like QAOA (Quantum Approximate Optimization Algorithm) help solve complex route optimization problems. QuantumNet applies these algorithms to improve navigation within cultural sites, such as archaeological parks and tourist areas, integrating them into mobile applications to enhance visitor experiences.

- Deep Learning Models for Plant Species Recognition Using Leaf Images

QuantumNet incorporates quantum computing into deep learning architectures for image recognition. These hybrid models are particularly useful in industries undergoing digital transformation, such as agri-food. Specifically, they develop AI-powered tools for identifying hazelnut plant varieties based on leaf images, aiding decision-making in the hazelnut industry.

Who are your current customers and what are your potential customers?

Actually, we're working on research projects and Leonardo activities. QuantumNet targets a broad range of potential customers, including enterprises in finance, energy, telecommunications, and pharmaceuticals, all seeking to leverage quantum computing to optimize complex processes, enhance security, and drive innovation. Public institutions, research centers, and organizations in the defense and aerospace sectors are also key stakeholders, along with tech startups and consulting firms aiming to integrate quantum solutions into their services.

Quantum2pi

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"We envision a future where advancements in Quantum Computing will revolutionize cybersecurity and unlock unprecedented computational power, opening new opportunities for all of humanity. We help companies to become quantum-resistant using Post-Quantum Cryptography and Quantum Key Distribution"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Quantum2Pi actively collaborates with both academic institutions and industry partners. We believe that meaningful innovation in quantum technologies comes from synergistic efforts between research and application. We are currently in discussion with several universities and research centres involved in quantum cryptography, photonic quantum networks, and post-quantum algorithm standardization. On

the industry side, we engage with cybersecurity solution providers that are preparing for the post-quantum transition.
In the future, we foresee deepening collaborations particularly with Telecom operators for quantum key distribution (QKD) networks, Smart card and secure hardware manufacturers to integrate quantum-safe algorithms in embedded systems, AI and cloud computing providers to explore quantum-enhanced machine learning

Who are your direct competitors?

Our competitors vary depending on the focus area. In post-quantum cryptography libraries, our direct competitors include *PQShield*, *Post-Quantum Ltd*, and *Isara Corporation*. In quantum-secure communication, companies such as *ID Quantique*, *QuintessenceLabs*, and *MagiQ Technologies* offer QKD-based solutions. In quantum-enhanced cybersecurity and identity, we monitor emerging competitors building blockchain-based or tokenized quantum-safe identity platforms.
However, our differentiator is the integration of post-quantum cryptography with real-world use cases such as secure messaging (e.g., *QGram*), combining deep cryptographic expertise with ready-to-integrate APIs.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

The quantum supply chain is still in its infancy and highly fragmented. In the next decade, we expect a progressive maturation of specialized suppliers in Quantum hardware; Control systems and FPGAs; Security layers for post-quantum and hybrid protocols; Standardized software stacks (QDKs, simulators, QPUs)
Challenges include: Interoperability between quantum and classical systems; Lack of industry-wide standards; High manufacturing costs and low scalability of quantum components; Talent scarcity in quantum software engineering and system integration.

What are the main areas of application for quantum technologies? What are the target markets?

The primary application areas of quantum technologies include: Cybersecurity: through post-quantum cryptography and QKD. Optimization and logistics: quantum-inspired algorithms for supply chain, routing, and scheduling. Finance: quantum algorithms for risk analysis, fraud detection, and portfolio optimization. AI and ML: enhancement via quantum ML models. Our target markets are: Government and defense; Telecom and secure communication; Banking and financial services

Can you provide examples of real use cases?

Some examples include: *QGram*, our secure messaging app, is designed to use post-quantum cryptography (based on Kyber and Dilithium) for protecting end-to-end communications even against future quantum threats. We are working on a quantum-safe SDK to protect sensitive data in IoT edge devices, allowing secure firmware updates and identity attestation.

Who are your current customers and what are your potential customers?

Currently, our customers include: Cybersecurity software vendors who integrate our post-quantum libraries; Academic institutions piloting QKD and secure communication research using our components. Potential customers include: National cybersecurity agencies; Cloud providers seeking quantum-resilient key management systems; Financial institutions preparing for quantum risk; Telecom operators investing in quantum networks.

Random Power

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"Random Power (RaP!) harnesses the quantum properties of semiconductors for generating endless streams of random bits, made robust by the very same laws of Nature to protect our digital life"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Random Power was born by a genuine act of serendipity while studying the properties of quantum noise in single photon silicon detectors in use in Particle Physics. It is evolving thanks to the support of the EC and through grants like *NQSTI,* involving the mother universities of the spinoff company, research institutions and companies at EU level, sharing trust, skills and knowledge for a common aim. The first elements of the Quantum Random Number Generator (Q-RNG) platform are about to be completed and the second generation is on the way, always through collaborations with mutual benefit.

Who are your direct competitors?

At the moment, there are about twenty companies targeting what we do. Most of them, rely on an external source of entropy, notably light. We exploit endogenous time series of pulses seeded by quantum tunneling in dedicated Silicon structures, with CMOS compliant technologies. This is giving us a competitive advantage, opening the possibility to integrate advanced crypto-functionalities in the same chip.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

The main challenge is certainly adoption. Early adopters have to clearly see the market advantage associated to re-inventing and embodying quantum solutions in their products and services, justifying the investment. Regulators will certainly play a role.

What are the main areas of application for quantum technologies? What are the target markets?

As far as what we specifically do, for sure the development of quantum resilient solutions for cryptography, based on Q-RNG, Quantum key distributions (where applicable) and post-quantum cryptography. Privacy preservation comes at the same level and this is the main subject of our *NQSTI* project, where we explore the value of Quantum Entropy in enforcing Differential Privacy procedures. Monte Carlo simulations and AI training can also benefit from randomness at the higher level.

Can you provide examples of real use cases?

Specifically for cryptography, Q-RNG are the cornerstone of Hardware Security Modules (HSM), generating, storing and distributing cryptographic keys. The same applies to QKD systems and, in a further step, in the so-called Secure Elements, providing encryption and authentication functionalities. Concerning privacy, more and more data are being made available for boosting, for instance, new drug development; making individuals protected requires masking their data adding "noise" and noise addition requires randomness.

Who are your current customers and what are your potential customers?

So far, we had interest by National Security Agencies for cryptographic applications; in future, "randomness as a service" through data center, the development of Differential Privacy Services and Industrial IoT gateways are our target, together with HSM and QKD producers.

Hero

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"Hero specializes in social robotics and digital healthcare, creating AI solutions that genuinely enhance quality of life. As pioneers in developing a framework for human-machine interaction and behavior analysis, we work with a clear mission: using AI to generate real well-being. Quantum technologies are opening new possibilities in social robotics, improving how machines understand and respond to human behavior. These advances support our vision of empathetic AI that builds authentic human connections."

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Hero was founded to redefine the relationship between technology and people. Together with *DotandMedia Srl*, we lead the *QUADRI project*, which integrates quantum computing into social robotics to innovate human-machine interaction.

Our collaborations include leading partners such as *Leonardo*, *IBM*, *Exprivia*, *Novartis*, *SoftBank Robotics*, *University of Bari Aldo Moro*, *Sorbonne Université Paris*, *University of Salento*, and *ComoNExT*. We are always open to new synergies in research, healthcare, and education, with the goal of generating high-impact social innovation.

Who are your direct competitors?

We engage with companies like *LuxAI*, *Furhat Robotics*, *SoftBank Robotics*, *PAL Robotics*, *Hanson Robotics*, and others. Rather than competitors, we see them as potential partners in building a collaborative and forward-thinking ecosystem, especially in the emerging field of quantum robotics.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

The quantum supply chain is still fragmented and in need of a unified strategy, both in Italy and across Europe. While institutional initiatives show growing momentum, there is a clear need for stronger skills, infrastructure, and shared standards. One of the main challenges is the lack of professionals capable of bridging AI and quantum technologies. At *Hero*, we see this integration not as a distant goal, but as a real opportunity. We are committed to building a more resilient and impact-driven supply chain through practical applications like social robotics.

What are the main areas of application for quantum technologies? What are the target markets?

Combining quantum computing with social robotics enables the development of robots that respond faster, more contextually, and with greater empathy. Applications include healthcare, home assistance, personalized education, and human interaction in public and private spaces. Our target markets are hospitals, rehabilitation centers, and educational institutions—any environment where human-centered, adaptive interaction is essential.

Can you provide examples of real use cases?

In the *QUADRI project*, we are developing a system where a humanoid social robot, enhanced by quantum computing-powered machine learning models, can recognize user queries and find appropriate responses. The system is designed to adapt to new information while retaining previous knowledge through incremental learning techniques. Additionally, we are exploring the application of variational quantum circuits to interpret natural language in real-time, improving the fluidity of the dialogue between the robot and the user. These developments demonstrate how our technology can already provide tangible value in people's lives.

Who are your current customers and what are your potential customers?

We collaborate with universities and clinical centers to develop and validate advanced technological solutions. Currently, our partners come from the research and healthcare sectors, but we are expanding our efforts towards public and private organizations in education, care, well-being, and assistance. Our goal is to improve the interaction between humans and technology, putting people and their needs at the center.

Rotonium

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"In a rapidly evolving market, still dominated by centralized, expensive and complex solutions, our edge-quantum approach to photonic qubits at room temperature – supported by a robust patent portfolio, collaborations with research centers of Italian universities and a new tech-transfer model – simplifies access to quantum technologies to industries"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?
Collaborations are central to our business strategy. We are committed to expand partnerships across the various stages of our device development, with a strong focus on miniaturization, room-temperature operation, and scalability. We actively engage with national and international research institutions to jointly develop intellectual property, securing exclusive licensing and purchase rights to maintain technological leadership and competitive advantage.
Our current and planned collaborations include:

a) Quantum photon sources – Partnership with the *Nanoscience Laboratory at the University of Trento* to develop room-temperature integrated quantum photon sources;
b) Quantum circuits and processors – Collaboration with *CNIT* in Pisa to explore and test quantum processor architectures;
c) Integrated detection – Planned collaboration with other Italian research institutions to implement advanced detectors for single photon acquisition and analysis.

Further collaborations will be established regarding quantum software, electronic control and packaging.
Who are your direct competitors?
Our main competitors operate in the field of quantum computation at room temperature or in the photonic quantum computing with a focus on miniaturization. That said our main competitors are:

a) *Quantum Brilliance* (AU-DE) leads in diamond-based, room-temperature quantum accelerators and mobile systems; b) *QuiX Quantum* (NL) develops reconfigurable photonic processors;
c) *ORCA Computing* (UK) focuses on photonic systems with quantum memory and partial room-temperature operations; d) *QCI* (USA) develops full-stack photonic quantum computers for quantum optimization and QRNG-based security tools.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?
The quantum supply chain is still in its early stages and faces significant fragmentation. For photonics, the supply chain is in Europe. For our photonic quantum computing, major bottlenecks include access to specialized foundries for thick silicon nitride wafers, high-purity single-photon sources, and room-

temperature CMOS-compatible detectors. There are also lengthening development time due to long fabrication lead times, lack of optimized PDKs, and limited standardized testing infrastructure. To overcome these challenges, we need in Europe more silicon photonics manufacturing plants and regional design centers to reduce dependency and accelerate development. Coordinated public-private funding are crucial to strengthening the ecosystem and mitigate geopolitical vulnerabilities.

What are the main areas of application for quantum technologies? What are the target markets?

Quantum technologies are poised to transform several strategic sectors. Core application areas include:

a) *Computing & Optimization* – Solving complex problems in logistics, finance, and energy;
b) *Pharmaceuticals & Materials* – Accelerating drug discovery and simulating molecular interactions;
c) *Cybersecurity* – Enabling secure communication with quantum key distribution (QKD) and post-quantum cryptography;
d) *Sensing & Metrology* – Offering ultra-sensitive measurements in medical imaging, navigation, and geophysics;
d) *Aerospace & Defense* – Secure communication, detection systems, and onboard computation in critical applications.

We believe edge-quantum processors will open extensive industrial opportunities once a new wave of lightweight, few-qubit algorithms—tailored to AI and QRNG—comes online. The priority is to target “low-hanging-fruit” applications where incremental quantum power can slash energy use, size, and weight versus classical hardware. Markets such as aerospace and defense could benefit most, gaining resilient, high-performance systems that operate autonomously at the edge while remaining only loosely coupled to the cloud.

Can you provide examples of real use cases?

Rotonium brings quantum computing out of the lab and into everyday technology. *Rotonium’s* room-temperature photonic QPU can be embedded into routers, drones or satellites, acting as a universal quantum co-processor. At the edge they speed up AI algorithms with a fraction of size, energy and weight, improving mission critical applications. Our QPUs enable quantum security through QKD/QRNG across terrestrial and space links. On the Data Centre side, our photonic QPU will complement the GPU with efficient quantum-AI algorithms saving a tremendous amount of energy while improving training and inference. Last, but not least, every quantum sensor will require a local quantum processor running at room temperature like our one.

Who are your current customers and what are your potential customers?

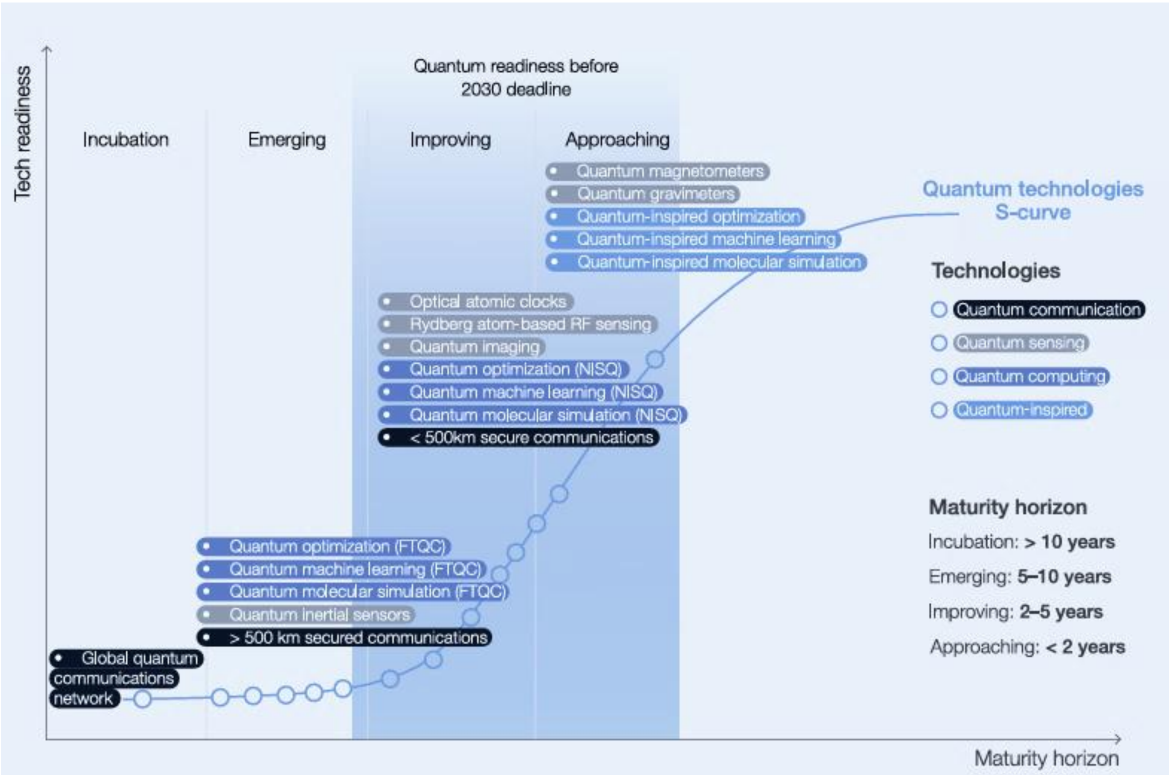
Our potential customers span across industries where room-temperature quantum computing and quantum edge devices provide a competitive advantage. These include:
a) Aerospace and Defense System Integrators,
b) Research Centers,
c) Industrial Edge Computer manufacturers, and
d) Data Centers.

CHAPTER 4. THE QUANTUM TECHNOLOGY: APPLICATION FIELDS AND ITALIAN USE CASES[84]

4.1 Quantum Technology maturity: the S curve

The quantum revolution means a whole new generation of technologies with the potential for far-reaching economic and societal impacts. Several innovations are already in development, while many others will be developed in the next few decades. As emerged earlier in the text, every *pillar* shows its proper growth path and level of maturity.

Figure 34. The S Curve of Quantum Technology



Source: World Economic Forum, 2024.

While the current state of quantum technology is marked by exponential advancements, *quantum sensing* and *quantum communication* solutions work in real-world applications, and full-scale machines are expected in the next decade in *quantum computing*. Quantum devices have begun to scale enough to run minor variants of

[84] Authors of Chapter 4 "Quantum Technologies: Application Fields and Italian Use Cases" are Gaia Raffaella Greco and Raffaele Cecere.

problems that classical computers currently find insurmountable, such as optimizing complex systems, simulating molecular structures for drug discovery, and solving large-scale linear equations (*World Economic Forum*, 2025).

The *World Economic Forum* (WEF, 2024), jointly with *Accenture*, in their Report, "Quantum for Society: Meeting the Ambition of the SDGs", develops an analysis of the Quantum Technology markets, investigating the role of the emerging technologies in achieving the *United Nations Development Goals* (*SDGs*). Particularly, as evidenced in *figure 34*, the International Organization for public-private cooperation longs to represent technology readiness stages of quantum sectors to 2030. *WEF* (2024, 2025) underlines how quantum technology is still a nascent field; thus, breakthroughs could change development roadmaps and accelerate innovations to reach the markets. In the same shape, investment in other prominent technologies could slow down the pace of innovation of QST. Thus, predictions could be helpful instruments to investigate *state-of-the-art* and to communicate to institutional, academic, and industrial stakeholders. However, they do not represent the effective evolution of single technologies.

Quantum sensing is more mature than other quantum technologies and has far-reaching potential. Applications are available in diverse fields such as microelectronics, logistics, and life science (brain injury imaging through magnetoencephalography). The main technologies used in these fields are solid-state spins and neutral atoms. Their impact will be measured by the degree to which the technologies will enable new possibilities or drastically improve existing options in terms of sensitivity, accuracy, or cost-efficiency.

Quantum communication ensures ultra-secure data transmission in a way that current technologies cannot. Several research projects were born with the idea to contribute to constructing a secure global quantum information network. The quantum internet is expected to develop in the next 25 years, when satellites or terrestrial quantum repeaters could constantly amplify the signals to enable transmissions over long distances (see *box 19*).

Box 19. The Quantum Sensing and Quantum Communication share three segments

McKinsey (2021) divides the quantum sensing (QSens) and quantum communication (QComm) markets into segments along the value chain to evaluate their current maturity and potential growth opportunities. Both markets have three segments in common.

- *Components.* This segment consists of hardware building blocks: lasers, detectors, cryostats, specialized fibers, and other technologies. Some companies already generate significant revenue by selling of these products to research groups and startups; others offer products on the wider commercial market, although they have not yet developed push-button solutions that do not require complicated setup or assembly procedures.
- *Hardware.* QSens hardware includes various devices, such as quantum atomic clocks and magnetometers, that measure physical properties using different qubit technologies. For instance, trapped-ion qubits measure time, rotation, and electric-field force; photonic qubits—those that transmit information as optical, rather than electrical, signals—can measure temperature and mechanical position. The QComm hardware market is much less fragmented because these applications all rely on photonics as their qubit technology. It is still very competitive, however, and some players are trying to build the fully functional quantum repeaters and satellite networks required for intercontinental communication.

- *Software.* For QSens, software is used to integrate sensing technologies into applications and services, such as navigation systems. It now contains few players, since it depends on the availability of appropriate hardware. With QComm, most software involves quantum encryption for services such as email or bank transfers. The software segment is relatively immature, but various startups are attempting to scale up their operations. Some organizations have already begun using quantum cryptography, and more could follow, especially in industries where secure communication is paramount.

Beyond components, hardware, and software, the QComm value chain includes two additional segments: *quantum-network operations* and *quantum services*. Network operators, which are now relatively few in number, provide and maintain large-scale quantum networks, including the necessary fiber cables. The need for their services will be largely limited until QComm hardware matures. Within quantum services, various companies now provide advice on the technological and business aspects of QComm.

All quantum applications require supporting technologies, with newly developed systems often finding applications across several fields (see *figure 35*). For example, the photonics equipment needed to run a molecule-based quantum computer also plays a significant role in semiconductor-based photonic integrated circuits (PICs, microchips that use light to transfer information). The component-manufacturing building blocks of supporting technologies often exhibit synergies, such as nanostructuring or optics/photonics measurements. Thus, overlapping supporting technologies can be found in semiconductor, superconductor, laser, and quantum hardware systems, and many more.
Some of the most common STs in quantum technology hardware and software include (*Roland Berger*, 2024):

- Cooling machines can cool entire chips or individual molecules to temperatures close to absolute zero;
- Lasers and optical systems capable of meeting the requirements for optical trapping and addressing single atoms and molecules;
- Microwave sources, analyzers, and transmission lines able to operate in ambient environments and maintain extremely low noise figures over a large frequency range;
- Vacuum equipment (such as pumps and chambers) that allows ultra-high vacuums for cooling and trapping single atoms and molecules;
- Semiconductor fabrication equipment for lithography (optical and electrical), etching, deposition, and implantation. Such supporting technologies are characterized by strong double-digit growth.

As recent market transactions have shown, companies specializing in equipment to manufacture ST components or even in the development of STs themselves are currently highly valued targets for VCs and leading high-tech firms. This automation is driven by growing commercialization and electrification trends, as well as market demand.

Figure 35. The supporting technologies for hardware and software components

1 Cooling systems	• Many QT applications require very low temperatures • Examples are dilution refrigerators or pulse tube coolers	4 Packaging	• Shielding the whole system against physical environment • Often vacuum required • Packaging of electronic components
2 Laser	• Photon generation • Qubit initialization • Qubit control • Excite qubit for readout • Laser cooling	5 Electronic components	• Manipulation qubits • Controlling lasers • Trapping atoms • Controlling quantum gates • Implementing magnetic fields
3 Optical systems	• Qubit manipulation • Guiding photons • Detectiong photons for readout	6 Software systems	• Designing algorithms • Software to control interactions within the whole quantum system

Source: Roland Berger, 2024.

In the following paragraphs, each Quantum Science and Technology pillar will be analyzed, evidencing the definition of the specific vertical, the main uses, the market applications, and the limitations to overcome. As anticipated, a specific focus will be on the Italian use cases, describing companies' missions, European and Italian research projects in which they are involved, and primary financial sources of investment.

Copan Group

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"Quantum technologies have the potential to impact many fields of our society and with the QuBi project we aim to bring this impact to the biomedical and clinical fields"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Copan Group has a long history in innovation and R&D starting back in 1979 when the company was founded. Nowadays, to tackle the increasingly challenging development of new products in the preanalytic and diagnostic fields, we are adopting an open innovation approach where collaboration with different stakeholders is key. In this context, we collaborate daily with Academia, startup, other companies and professionals to create interdisciplinary teams and tackle high impact challenges. In the context of the Quantum-based Bacteria Identification (QuBi) project supported by the *NQSTI* – Spoke 8, we have developed a strong collaboration with the iLAMP labs (Prog. Giannetti) at Università Cattolica del Sacro Cuore – Brescia, expert in ultra-fast spectroscopy, non-linear and quantum options.

Who are your direct competitors?

As we are not yet in the field of quantum technologies, we have not identified direct competitors in this space. For the group core businesses, meaning collection & transport devices and clinical microbiology lab automation, other companies in the same markets are for instance Puritan, Medical wire and Becton Dickinson.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

If we talk about quantum sensing, even before thinking about supply chain, the main effort should be directed to prove the effectiveness and added value of this technology.

What are the main areas of application for quantum technologies? What are the target markets?

From our understanding, being outsider in quantum technologies, we see the main applied and market-ready fields in quantum computing and cryptography. However, we see high potential in the biomedical field where quantum sensing could bring unprecedented level of sensitivity and specificity in detecting, identifying and analyzing pathogens, cellular material and tissues.

Can you provide examples of real use cases?

One of the impactful real cases we identify and on which we build the Qubi project on, is the early identification of bacterial infection in blood sample. The QuBi project, based on the use of quantum single-photon light sources with a broad spectrum, proposes a substantial innovation by enabling the potential detection and identification of bacteria within a few hours. This solution will have a tremendous impact on the management of sepsis patients.

Who are your current customers and what are your potential customers?

Our current customers are mostly clinical microbiology labs, hospitals and healthcare facilities. With this project we aim to consolidate our customers base by bringing added value to our products and services with quantum technologies.

4.2 Quantum Sensing and Metrology: the many applications' fields

Quantum sensors use quantum coherence, interference, and entanglement to determine the physical quantities to be analyzed (Degen *et al.*, 2017).

The use of quantum sensors will provide the most precise and accurate measurements in many fields, improving the performance of consumer devices and services, from medical diagnostics and imaging to high-precision navigation, to Earth observation and monitoring, to future applications of the Internet of Things. According to an estimate by McKinsey (2024b), private sectors such as oil and gas, automotive and assembly, aerospace and defense, MedTech, media and entertainment, as well as the public sector, could be disruptively impacted by quantum sensing after 2030.

Quantum sensors can include gas, solid-state, and single-atom sensors. They have specific properties that make them suitable for specific applications, such as cold atoms for gravimetry and nitrogen vacancy (NV) centers in diamond for high spatial resolution magnetometry.

The imperative is to leverage interdisciplinary expertise and join forces with other fields, such as the signal processing community, to overcome the limitations of sensor sensitivity and resolution and to implement best-in-class control protocols, statistical techniques, and control algorithms in machine learning. Actions to be implemented for developing technologies may concern many fields of application. It is imperative to foster collaboration between scholars and managers to develop a comprehensive value chain across all major categories of quantum sensors, engaging simultaneously in pilot lines to encourage the development and testing of quantum sensors.

High-precision spectroscopy, gravimetry, high-resolution microscopy, magnetometry, clocks and their synchronization, positioning, and thermometry are fields of application of quantum sensors. Superconducting quantum interference devices (SQUIDs), optical pump magnetometers (OPMs), and magnetometry based on nitrogen-vacancy (NV) centers in diamond are the most widely used sensor platforms in the biomedical field (Aslam *et al.*, 2023). In healthcare, the quantum sensors based on a magnetocardiography (MCG) device may help physicians capture a better picture of the heart's electrical activity, which could help to spot unusual patterns or signs of potential health issues. The social impact is not minor, considering that coronary heart disease affects millions of people. In addition, this advance has the potential to significantly increase the use of fetal MCG and enable routine assessment of the cardiac electrophysiology of the fetus, particularly during the first three months, which is when most complications arise.
In particular, the use of highly compact quantum sensors for magnetometry or gyroscopy applications in harsh environments is beginning to spread. In this context, sensing techniques such as the nuclear spin of the nitrogen vacancy (NV) center in diamond are fundamental (Ji *et al.*, 2024), which exploit the dynamics of the NV spin in oblique magnetic fields near the anti-crossing of the NV excited state level to pump the nuclear spin into a quantum superposition state optically. Such techniques overcome the problems of miniaturization, energy efficiency, and non-invasiveness of quantum sensors (Bürgler *et al.*, 2023).
Some of the platforms in quantum sensing concern (Ye & Zoller, 2024):

- Artificial systems such as quantum dots and spin defects in solid-state;
- Opto-mechanical systems;
- Trapped ions;
- Ultra-cold atoms;
- All-optical set-ups involving nonclassical states of light;
- Warm and hot atomic vapors;
- Nano- and micro-mechanical oscillators;
- Superconducting and semiconducting nano-circuits;
- Rare earth ions in solid-state matrix.

Various sensing and metrology applications involve using nitrogen vacancy centers in diamonds, Rydberg atoms, and superconducting circuits for electromagnetic field detection. Other applications include (Ye & Zoller, 2024):

- Advanced magnetometers based on atomic and optical pumping techniques for high-precision magnetic field measurements.
- Temperature, particle, and pressure sensors (spin-qubit-based sensors, precision spectroscopy gas sensors, optomechanical sensors).
- Inertial and gravity sensors,
- Quantum Imaging,

- Atomic clocks.

Quantum sensing is finding practical applications across various industrial sectors because it can detect magnetic anomalies, vibrations, or other physical quantities with extreme precision. Some examples of use cases and companies leveraging this technology include sectors such as predictive maintenance, advanced diagnostics, advanced electronics, and semiconductors.

Technologies such as *SQUIDs* (*Superconducting Quantum Interference Devices*) or NV center sensors (Nitrogen-Vacancy) in diamonds allow for the measurement of microscopic variations in magnetic fields with unprecedented sensitivity. *Advanced diagnostic systems* use these tools to monitor mechanical components or electronic circuits, detect structural stress, material degradation, or electronic malfunctions (Paudel *et al.*, 2024; Wu *et al.*, 2024). This approach enables more accurate predictive maintenance, reducing unexpected downtime and improving machine reliability.

Recent studies show that quantum sensing is particularly effective when magnetic anomalies are difficult to detect using traditional technologies, such as in miniaturized systems or high-performance environments (Dhankhar *et al.*, 2024).

Quantum sensors are used to monitor high-precision industrial machinery, such as turbines, motors, and complex robotic systems. The slightest variations in magnetic fields associated with wear, impending failures, or structural changes can be detected long before they become critical. Some companies utilizing quantum technology in these sectors include *SKF* (a leading company in the bearing industry), which employs advanced sensors to monitor the health status of industrial machinery[85] and *Honeywell*, which has developed quantum sensors for industrial applications, such as detecting defects in aircraft engines or automation systems[86].

In the semiconductor manufacturing sector, quantum sensors can be used to precisely monitor the magnetic fields generated during fabrication processes, allowing for the early detection of defects and preventing production waste. Some examples are *Intel*[87]and *IBM*[88] that explore using quantum sensors for semiconductor diagnostics and detecting anomalies in high-performance manufacturing facilities.

Near-term applications include defect inspection and battery design improvement, *EMF*-based navigation for aircraft and drones, corrosion monitoring for pipeline integrity, and cardiac diagnostics using biomagnetics. Other applications include temperature measurements in small cells and organisms, improved bioimaging, and a better understanding of disease through spectroscopy.

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[85] *SKF*. (n.d). SKF Supergrip Bolts. Accessed October 2024. https://www.skf.com/it/industries/marine/skf-coupling-systems/skf-supergrip-bolts

[86] *Honeywell*. (n.d). Our Quantum Technology Enables High-Quality Qubits. Accessed October 2024. https://www.honeywell.com/us/en/company/quantum

[87] *Intel.* (n.d). Quantum Computing Systems Achieving Quantum Practicality. Accessed October 2024. https://www.intel.com/content/www/us/en/research/quantum-computing.html

[88] IBM. (n.d). Bringing useful quantum computing to the world. Accessed October 2024. https://www.ibm.com/quantum

In the medium term, quantum sensors are expected to be used for navigation when GPS is unavailable, long-wavelength communications using atoms as antennas, signal receivers and amplifiers for radar, and temperature monitoring in transformers. Targeted photodynamic therapy for cancer treatment and a better understanding of disease at the cellular level are also envisioned.
Long-term applications include increased energy conversion efficiency in solar panels, object identification using cameras, calibration and inspection of electrical standards beyond fifth generation (5G), magnetometers for fusion reactors, and personalized medicine. Other developments include on-chip safety and fault monitoring, microscopy to verify high-value artifacts and mind-machine interfaces (*McKinsey*, 2024a).

Planetek

Established in 1994, *Planetek Italia* provides solutions to exploit the value of geospatial data throughout data life cycle, from acquisition, storage, and management up to analysis, and sharing.[89]. The *Planetek Group* consists of four companies: the parent company, *Planetek Italia S.r.l.*, *Planetek Hellas e.p.*e., and two university spinoffs (*GAP* s.r.l. and *GEO-K* s.r.l.), which specialize in the processing of remote sensing data from optical and radar sensors. Its main areas of expertise include:

- *Satellite, aerial, and drone data processing* for cartography and geographical information production.
- *Continuous monitoring services using satellite data* for tracking the Earth's surface, infrastructure, construction sites, urban dynamics, and marine-coastal areas to support decision-making and operational activities.
- *Design and development of Spatial Data Infrastructures (SDI)* for storing, managing, and sharing of geospatial data.
- *Development of real-time geolocation solutions* using positioning systems such as GPS, Galileo, GNSS, and indoor localization systems.
- *Software development for satellite data and image processing*, both on-board satellites and ground segment infrastructures.

The main example is the *Qu3D project* (Quantum 3D Imaging with high speed and high resolution), which aims to design and implement radically new 3D imaging devices—quantum plenoptic cameras—that leverage quantum correlations between photon pairs. These cameras enable ultra-fast, non-scanning 3D imaging and refocusing capabilities, like traditional plenoptic devices used in microscopy, but with enhanced performance in terms of spatial resolution (diffraction-limited), large depth of field (DOF), and ultra-low noise.

[89] *Planetek* (n.d). Azienda. Accessed September 2024. https://www.planetek.it/azienda/chi_siamo/profilo

Key elements of the project include state-of-the-art single-photon sensor arrays and the challenging task of accelerating the acquisition and processing of large datasets using high-performance computing and parallel processing on GPUs.

Cutting-edge techniques such as compressed sensing, machine learning, and quantum tomography algorithms will be explored.

Given the significant scientific, industrial, and social potential of high-speed, high-resolution, and low-noise 3D imaging, *Qu3D* is expected to generate new diagnostic and imaging tools across various fields. These include *quantum plenoptic microscopes* and *endoscopes for biophotonics and biomedical imaging*, *quantum spatial imaging devices*, and *quantum 3D cameras for security and industrial inspection applications*. The research is anticipated to open new scientific and technological opportunities and play a transformative role in both technology and society (see *box 20*).

The *Qu3D project* is led by *INFN* (Italy) and involves *Planetek Hellas* (Greece), *Palacky University Olomouc* (Czech Republic), and *École Polytechnique Fédérale de Lausanne* (Switzerland). It is funded under the *QuantERA framework*, a network of 32 organizations across 27 countries, coordinated by the National Science Centre, Poland, supporting international research in quantum technologies (QT)[90].

Box 20. The interview with Cristoforo Abbatista, Head of SpaceStream SBU

Cristoforo Abbattista
Head of SpaceStream Strategic Business Unit
Planetek Italia srl – Bari
Aerospace Company developing Systems for Space and Ground Segment
http://www.planetek.it
E-mail: *abbattista@planetek.it*

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Currently, our collaborations are mostly with research institutes like *University of Bari* (Physics department and *Politecnico of Bari* in the field of Quantum Computing, Metrology and Imaging.

Being part of the *QuIC* as a founding member we strongly believe in partnership with companies providing Quantum technologies. Actually, we are users and integrators of them.

Who are your direct competitors?

Aerospace Companies dealing with complete Systems and Services. HW components companies or pure IT companies are not direct competitors

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges to be faced?

First of all, the development of the technologies and their TRL improvement. Then training of the current working people and incorporation of young people already used to manage Quantum techs. That is also the reason for which *Planetek* is currently funding a *master in Quantum techs from the University of Bari* whose goal is not preparing students for the academic professional path, but to train them for working into an industrial company. The master can be found here: https://www.masterquantum.it/it/home-2/

[90] *Planetek* (n.d). Qu3d - Quantum 3D Imaging at high speed and high resolution. Accessed September 2024. https://www.planetek.it/progetti/qu3d_quantum_3d_imaging_at_high_speed_and_high_resolution

What are the main areas of application for quantum technologies? What are the target markets?
For what regards *Planetek* we are strongly interested in applications for Earth Observation Satellites (and there is our interest in Imaging and metrology) and EO data processing and simulation.
Can you provide examples of real use cases?
In the field of Imaging the most interesting case is exploiting entanglement for having a clear image even in harsh conditions (turbulence for example) or with scarce illumination conditions (a few photons).
In the field of Quantum Computing there are a lot of use cases in the field of simulation of planetary data, Digital Twins, and inversion problems.
Who are your current customers and what are your potential customers?
Actually, we have no customers using our quantum based solutions, but potential customers are all the current customers, going from Private to institutional ones.

Geomatics Research & Development

Daniele Sampietro, PhD
Applied Geophysics Manager
GEOMATICS RESEARCH & DEVELOPMENT
website: *www.g-red.eu*
E-mail: *danele.sampietro@g-red.eu*

"Quantum science and technology are opening new frontiers in measurement and sensing, enabling levels of precision and sensitivity that were previously unattainable. We strongly believe that structured support to academic spinoffs is essential to turn research breakthroughs into societal and industrial value and a stronger integration between public research, specialized SMEs, and institutional funding can accelerate the transition from lab prototypes to real-world impact"

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?
Geomatics Research & Development srl actively collaborates with leading institutions such as the *National Institute of Geophysics and Volcanology (INGV)*, academic partners, and international consortia through EU and National projects. Currently, we are involved in various research projects focused on quantum-based gravity sensing technologies. The QUAKE-G project, for example, involves developing algorithms to automatically analyse data from a network of quantum gravimeters. We are already collaborating with companies and institutions leaders in the field of quantum gravity sensing such as *eXail* (which realised the first commercial quantum gravimeter) or the *Observatoire de Paris*. Looking ahead, we foresee expanding collaborations to include satellite data providers, public agencies responsible for natural hazard mitigation, and companies in civil engineering and infrastructure.
Who are your direct competitors?
Our direct competitors are mainly international actors — both public and private — as research groups and specialized technology providers working on data processing systems. These include academic research groups, spinoffs, and space-oriented tech firms. However, due to the emerging nature of the quantum sensing market, we often view these players as potential collaborators within shared consortia or mission-driven alliances.
What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?
The quantum supply chain in gravimetry is still in a nascent stage, with many components — such as vacuum systems, laser sources, and control electronics — sourced from specialized suppliers. The main challenges are miniaturization, robustness for field deployment, and cost reduction. Building a European supply chain that ensures long-term availability and integration capabilities will be a key enabler for the

broader adoption of quantum sensors. Projects like QUAKE-G, which aim to develop operational algorithms and integrate ground and satellite data, also highlight the importance of software and data fusion tools as part of this supply chain.

What are the main areas of application for quantum technologies? What are the target markets?

In our field, the main applications are geophysics, Earth observation, and subsurface exploration. Target markets include energy, civil engineering, environmental monitoring, and national agencies responsible for geodetic infrastructure. Quantum technologies can provide a step-change in how gravity anomalies are measured, with implications for resource detection and risk assessment.

Can you provide examples of real use cases?

In the *QUAKE-G project,* we are developing an automatic algorithm to separate local and regional gravity signals using data from a permanent network of quantum gravimeters. These measurements can detect changes in groundwater levels or volcanic magma movements. By integrating these with satellite gravity observations (e.g., GRACE-FO), we aim to enhance temporal resolution and improve models of the water cycle and crustal dynamics.

Who are your current customers and what are your potential customers?

At present, our work is primarily research-driven, with funding and collaboration from public institutions and research agencies. Our potential customers include geophysical survey companies, government bodies, space agencies, and private firms in energy and infrastructure that require advanced subsurface sensing capabilities.

MPD, Micro Photon Devices

Micro Photon Devices Srl (MPD), based in Bolzano, is a spinoff of *Politecnico di Milano*.[91] The company, founded in 2004, specializes in advanced photon detection technologies. It focuses on single-photon counting and picosecond timing, producing state-of-the-art single-photon counting modules with superior photon-timing capabilities. *MPD's* Silicon *Single-Photon Avalanche Diode* (*SPADs*) combines high detector performance with miniaturization and low power consumption; further, compound semiconductor *SPADs* extend photon counting to the near-infrared range, up to optical fiber wavelengths.

In addition to standard single-photon counting and timing modules, *MPD* offers custom designs for specific applications. The company handles the entire engineering and production process, from prototyping to shipping, and develops electronic instrumentation to complement its photon detectors.

MPD's expertise in SPAD fabrication and active quenching electronics has led to a comprehensive range of SPAD modules with high photon detection efficiency (PDE) and low internal noise, ideal for applications like confocal microscopy, fluorescence, luminescence, and time-correlated single-photon counting (TCSPC).[92]

MPD has been profitable since 2006 and exports 95% of its products worldwide. It is actively involved in research initiatives, such as the *European Union's Horizon 2020* projects, contributing to quantum technologies like photonic quantum key distribution (*QKD*) systems and integrated quantum devices.[93]

MPD stands out in quantum technology because it specializes in photon counting, a critical component in quantum communication and sensing. *MPD* highlights its role in advancing photonic quantum technologies, which are crucial for applications such as quantum cryptography, imaging, and scalable quantum networks.

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[91] *Politecnico di Milano* (n.d), Industria, Spin-off. Accessed July 2024. https://www.deib.polimi.it/ita/spin-off/dettagli/5

[92] *Micro Photon Devices* (n.d), Products. Accessed July 2024. http://www.micro-photon-devices.com/Products

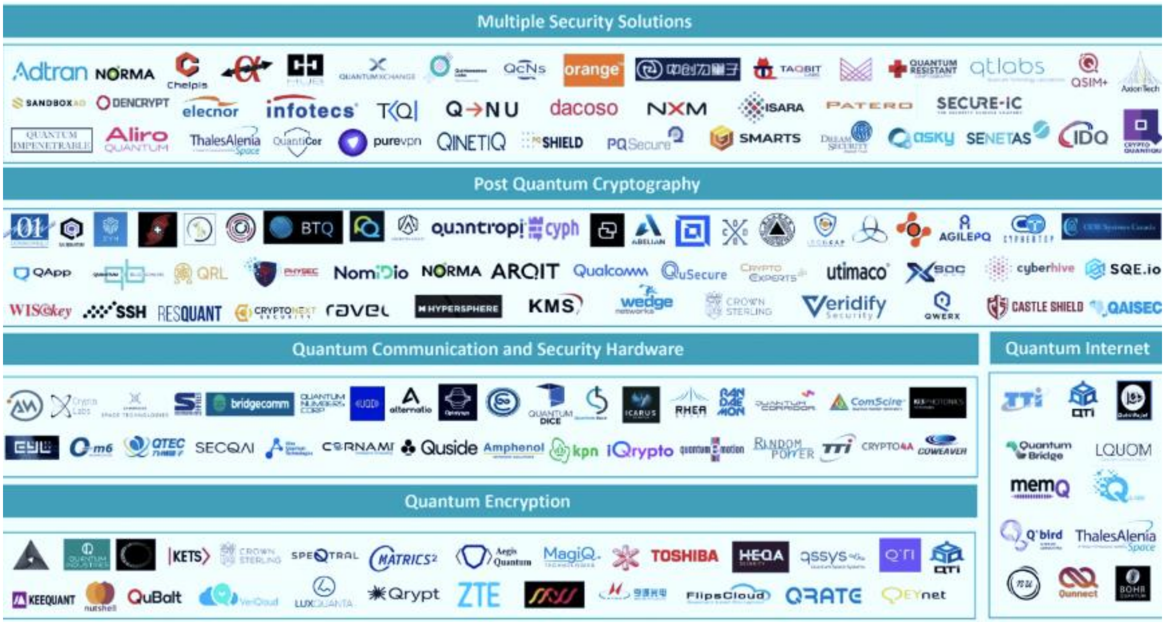
[93] *Quantum Uniqorn (n.d)*. Micro-Photon-Devices S.r.l. (Italy) – (MPD). Accessed July 2024. https://quantum-uniqorn.eu/micro-photon-devices-s-r-l-italy-mpd/

MPD's SPAD offers several cutting-edge applications, including: Particle Sizing, Confocal Microscopy, Ultra-Sensitive Fluorescence, Luminescence, Time-correlated single photon counting, Single Molecule Detection, Astronomic Observations & Adaptive Optics, Optical Range Finding, *LIDAR* & *LADAR*, Quantum Cryptography & Quantum Optics, Single-photon source characterization, and Optical testing of integrated circuits.

4.3 Quantum Communication: the QKD global projects

The secure transfer of quantum information across space is known as quantum communications. Quantum cryptography could ensure the communications security, even with unlimited (quantum) computing power. The aim is to develop tools and protocols for exchanging quantitative information among distant users. Currently available technologies focus on the quantitative key distribution over relatively short distances. One of the applications of quantum communication is encryption and data security (Yan *et al.*, 2022).

Figure 36. The Quantum Communication Market Map: main actors



Source: Quantum Insider, (2024)[94].

China and Russia have successfully tested the longest quantum communication network established, over 3,800 kilometers. The most commonly used techniques are trapped ions, rare earth ions, and atomic vapors (McKinsey, 2024b).

In Europe, the goal is to develop a European-wide quantum network that integrates and expands the current digital infrastructure as a basis for a future quantum internet. The

[94] *Quantum Insider*, "TQI Exclusive: Quantum Communications and Security Marketing Map", March 15th, 2024. https://thequantuminsider.com/2024/03/15/tqi-exclusive-quantum-communications-and-security-marketing-map/

studies aim to enhance performance by combining quantitative communication with traditional ones and developing products for market launch.
Building a quantum network requires advances in several key technologies, including physics, computer science, and engineering, to control and manipulate particles such as photons. Efforts are also required to create quantum repeaters that can generate long-distance entanglement across the fiber network, entanglement distribution satellites, and end nodes such as computers and phones (see *figure 36*).
Key features of quantum communication include traditional cryptographic methods, new secure approaches against quantum computer attacks, and the creation of effective security keys.
Sectoral use cases include financial transactions, medical records, critical infrastructure protection, e-government, defense, e-commerce, and voting. Specifically, quantum cryptography can improve the security of sensitive data and communications in various sectors, while securing access and computation in cloud environments. Other than quantum data protection (encryption, authentication), further applications regard advanced primitives (unclonable data, quantum currency, etc.), and quantum remote sensing (*Quantum Flagship*, 2024).
Quantum Key Distribution (QKD) is a technology that leverages the principles of quantum mechanics to ensure the secure distribution of cryptographic keys. One of its main advantages is detecting potential eavesdropping during key transmission, offering a level of security unattainable with traditional methods based on classical cryptography.
The main fields of application of Quantum Key Distribution (QKD) are (Cao *et al.*, 2022; Dijkstra, 2024; Madje and Pande, 2024):

1. *Government and military communications*: to protect sensitive communications and prevent the risk of eavesdropping.
2. *Banking and financial sector*: to manage large volumes of critical transactions requiring maximum security.
3. *Healthcare*: to protect medical data from cyberattacks and safeguard privacy.
4. *Telecommunications*: to secure networks, protect communications between customers, especially regarding 5G, and look ahead to future developments like 6G.
5. *Energy*: to protect and transmit data between various network's nodes, preventing targeted attacks to disrupt the energy supply.
6. *Internet of Things* (IoT) *and connected devices*: to ensure the security of communications between these devices, especially in industrial settings or smart cities, where security is crucial to prevent hacker attacks that could compromise essential services.

Despite its advantages, QKD faces some challenges (Cao *et al.*, 2022):

- **High costs**: The infrastructure required for QKD is still costly compared to traditional cryptographic methods.
- **Limited distance**: The secure transmission of quantum keys through optical fiber is limited to a few hundred kilometers, although satellites can help overcome this issue.
- **Integration into existing networks**: Adopting QKD requires significant modifications to current network infrastructures, which can be complex and costly (see *figure 37*).

Figure 37. The Quantum Communication Technology Maturity

Verticals	Technical target state for commercialization	Technology maturity	Required milestones and breakthroughs
QKD solution (including QRNG)	Integrate QKD hardware and management layer into existing infrastructure and advancing technologies (eg, repeaters) for long-range secure communication. Prepare-and-measure QKD is relatively more mature than entanglement-based QKD[1]	Lab – Commercial	Technologies to extend range and key rate, enable error correction, and improve implementation of entanglement-based protocols
PQC	Implement the standardized PQC algorithm across organizations in a crypto-agile manner, allowing for updates with new algorithms if weaknesses are discovered (eg, NIST has standardized the PQC protocol, and the EU is expected to follow this trend)	Lab – Commercial	Demonstration of error-corrected QC could increase demand and adoption for PQC
Modular interconnect	Connect qubits to expand their computational power, evolving from initial experimental configurations to deployable, commercial applications	Lab – Commercial	Scalable, low-loss, fast-switching interconnects between modules
Regional networks	Focus on QComm links among regional data centers, developing quantum repeaters for secure, long-distance transmission and entanglement sources	Lab – Commercial	Repeaters with high key rate, entanglement generation, and capacity for error correction
Quantum global internet	Deploy satellite-based QComm and develop a full-scale quantum internet to connect distant quantum computing resources	Lab – Commercial	High-fidelity quantum channels (eg, satellite and fiber), mature repeaters, scalable quantum computers
Quantum communication services	Create user-friendly solutions for customer success, incl programming interfaces and protocols, leveraging implementation that is efficient and automated where possible	Lab – Commercial	QComm and network infrastructure

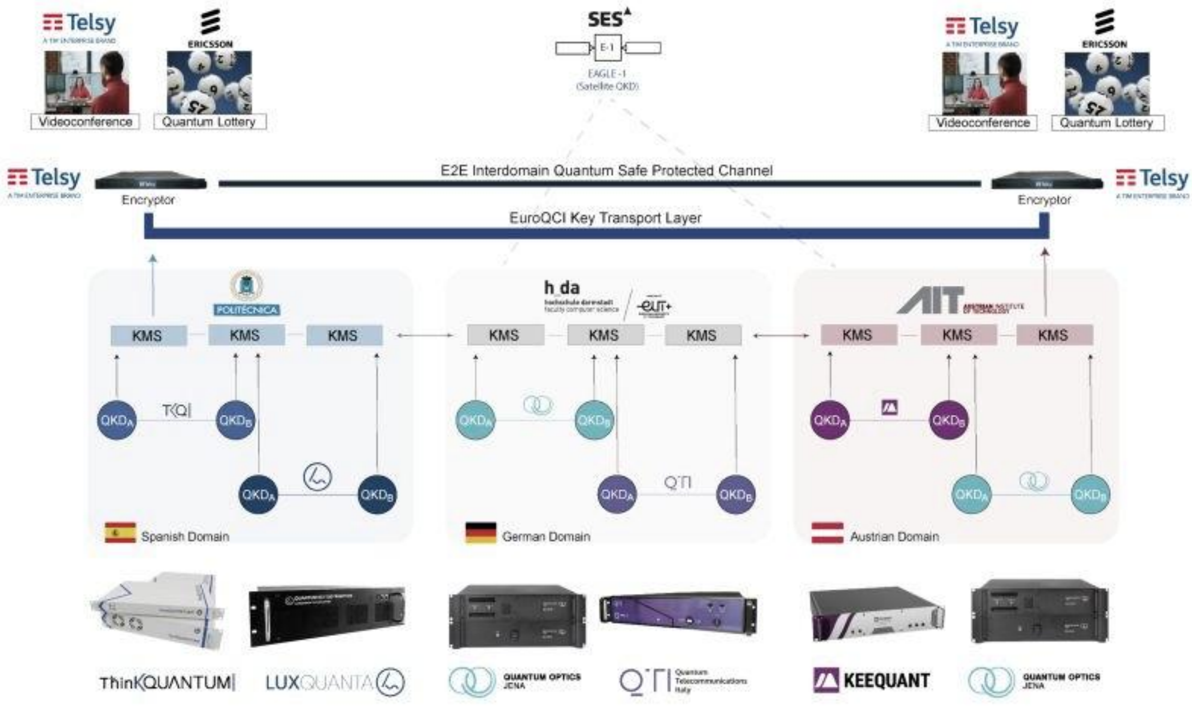
Source: McKinsey (2025).

Discussing specific use cases of Quantum Key Distribution (QKD), several projects have been implemented across Europe[95]. *SECOQC* (Secure Communication based on Quantum Cryptography) is the European project that focuses on creating secure communication networks based on quantum cryptography[96]. Still, Euro QCI (*European Quantum Communication Infrastructure*), is the QKD network that longs to support secure key exchange via terrestrial and satellite links (*figure 38*). The image illustrates the cutting-edge infrastructure for Quantum Key Distribution (QKD), designed to enable secure communication based on the principles of quantum mechanics, ensuring theoretically unbreakable encryption. This interconnected network spans Spain, Germany, and Austria, forming a multi-domain architecture where each country operates its own QKD systems and Key Management Systems (KMS) as local nodes.
In Spain, the network is managed by the *Polytechnic University of Madrid*. It utilizes advanced QKD devices from providers such as *ThinkQuantum*, with its *ThinQKD* modules,

[95] *Cordis*. (2024). Final Report Summary - MULTIPLE-ACCESS QKD (Multiple-Access Quantum Key Distribution Networks).
https://cordis.europa.eu/project/id/277110/reporting
[96] *Cordis*. (2023). Effettuata dimostrazione di comunicazione sicura in rete.
https://cordis.europa.eu/article/id/29965-totally-secure-network-communication-demonstrated/it

and *LuxQuanta*, known for its *NOVA LQ® CV-QKD system*. *LuxQuanta's* contributions have been pivotal in showcasing multi-vendor interoperability in collaboration with four QKD providers and three KMS developers. This demonstration highlighted the system's scalability, technological maturity, and capability to address modern cybersecurity challenges through a robust and interoperable architecture. The Spanish domain employs advanced protocols such as BB84 and entanglement-based methods for secure key generation and exchange (*LuxQuanta*, 2024).

Figure 38. The Euro QCI Transport Layer



Source: LuxQuanta (2024).

In Germany, the domain is operated by the *Hochschule Darmstadt* and integrates technology from *Quantum Optics Jena*, specializing in quantum cryptography optics. This domain ensures secure local and cross-border key exchanges, contributing to the network's overall resilience. Similarly, Austria's domain, led by the *Austrian Institute of Technology* (AIT), features *KeeQuant*'s innovative QKD hardware, which blends quantum algorithms with conventional cryptography to enhance system security (*Austrian Institute of Technology* , 2024).

A critical aspect of this infrastructure is the satellite component, provided by *SES* with its *EAGLE-1 system*[97]. This technology overcomes the range limitations of terrestrial networks, enabling secure quantum key distribution across vast distances and facilitating

[97] *SES*. (2024). *EAGLE-1*: Advancing Europe's Leadership in Quantum Communications. https://www.ses.com/newsroom/eagle-1-advancing-europes-leadership-quantum-communications

international connectivity between national domains. These satellite links work seamlessly with terrestrial QKD networks, forming a cohesive, scalable infrastructure.
Additionally, the network supports advanced applications such as secure videoconferencing and 'quantum lotteries', leveraging encryptors developed by *Telsy*, a *TIM* Group subsidiary. These encryptors operate in tandem with QKD to safeguard communications against potential breaches. This advanced setup reflects the collaboration of European technology leaders, including *Quantum Telecommunications Italy (QTI)*, which bridges the gap between QKD and classical encryption systems. Continuous quantum key flow between KMS nodes ensures the real-time availability of secure keys, enabling critical applications across government, finance, and healthcare sectors. Moreover, in Lisbon, *Telsy*, *QTI* (*Quantum Telecommunications Italy*), and *MEO* further expanded QKD use cases by establishing a secure quantum connection between two governmental institutions in Portugal. This project validated the feasibility of deploying QKD for critical applications like exchanging sensitive data, demonstrating practical interconnectivity using *Telsy's* encryptors and *QTI's* technologies. It underscored the scalability and operational readiness of QKD in real-world scenarios, further supported by *TIM* Group's extensive expertise in cybersecurity[98].
By integrating diverse technologies and providers, this QKD network exemplifies Europe's leadership in quantum communication. Its combination of terrestrial and satellite components offers unprecedented security, positioning Europe as a global leader in quantum cryptography. This infrastructure not only bolsters telecommunications security of but also opens avenues for innovative quantum-based applications, ensuring resilience and scalability for the future.
Italy is beginning to develop and implement QKD solutions in critical sectors such as telecommunications, defense, finance, and healthcare. Leading companies like *Leonardo*, *TIM*, and *Telsy* work with research institutes to test QKD applications nationally. Although the technology is still experimental, pilot projects and European collaborations reflect a clear commitment to adopting quantum technology to secure Italian infrastructures.
One significant initiative is *OpenQKD*, a European project involving various Italian partners, including universities and research institutes, are involved. The project aims to develop a test network for quantum key distribution across Europe, including Italy. Cities like Rome and Milan are being considered potential hubs for QKD infrastructure in Italy, which aims to protect sensitive communications in sectors like banking and telecommunications.[99]
Still, *Open Fiber* company, in partnership with the *Scuola Superiore Sant'Anna,* is the protagonist in a structural project (*Rigoletto*) focused on optical communications and Quantum Key Distribution[100]. *Rigoletto* is a structural project in collaboration with *Polimi*

[98] *TIM*. (2024). *Telsy* implements Quantum Key Distribution with QTI and MEO on terrestrial and submarine fibre optics in the Lisbon metropolitan area.
https://www.gruppotim.it/en/press-archive/market/2024/PR_Telsy_QTI_and_MEO_QKD_Lisbon.html
[99] *OpenQKD*. Who we are. Accessed September 2024.
https://webmagazine.unitn.it/evento/dphys/14739/progetto-qtn-quantum-science-and-technology-in-trento.
[100] *OpenFiber*. (2023). Un'infrastruttura per la trasformazione digitale.

(*Polytechnic University of Milan*), focused on communication security through quantum technology. *Open Fiber* is involved in defining network architecture, QKD (Quantum Key Distribution), fiber sensing, and field experimentation. *Rigoletto* aims to develop an energy-efficient optical network, new optically integrated devices, and an innovative data plan for a fiber optic infrastructure supporting QKD capacity enhancement. Additionally, it plans to develop a platform for monitoring data transmission and conversion and to build a framework for an AI-assisted network (see *box 21*).
The project has not yet entered the testing phase. After this phase, the results are expected to involve partners and promote the adoption of the proposed solutions (Meta, 2024).

Box 21. The Italian Quantum Backbone: First Permanent Multi-Node Quantum Communication Network Inaugurated in Naples

Recently, Naples has become a focal point for developing and implementing Quantum Key Distribution (QKD), an innovative technology that promises to revolutionize communication security. QKD leverages the principles of quantum mechanics to ensure that cryptographic keys used for encrypting communications are secure against cyberattacks.

The inauguration of the first permanent national multi-node quantum communication network in Naples marks a significant technological achievement involving the *University of Naples Federico II* and other prominent institutions. The network will connect the *Italian Quantum Backbone* (*IQB*) node at the *CNR* Area in Pozzuoli with the *Federico II University* Campus in San Giovanni a Teduccio and *Leonardo's* laboratories in Pomigliano.[101]

The project is supported and coordinated by the *Ministry of Enterprises and Made in Italy* (*MIMIT*) through the *Meditech 4.0 Competence Center*, with participation from institutions such as *CNR-INO*, *INRiM*, and companies like *Leonardo*, *QTI*, *TIM*, *Telsy*, *ThinkQuantum*, *Cisco*, and *Exprivia*.

The network has a substantial impact on the development of new technologies. The quantum communication network enables the experimentation of new protocols for telecommunications and sensitive data transmission, ensuring an intrinsically unbreakable exchange of information due to quantum mechanics. This technology could transform sectors such as telemedicine, government communications, critical infrastructure management, and autonomous driving.

Regarding goals and prospects, the network aims to become a reference point for businesses and research institutes, fostering the development of innovative industrial solutions and integrating quantum technologies with transmission systems and cybersecurity. The project represents the evolution of previous projects *QUANCOM* and *QUID* and integrates into the *European Quantum Communication Infrastructure* (*EuroQCI*).

Additionally, the inauguration strengthens ties with Canada and is a step towards intercontinental developments. With projects like the *Quantum Computing Academy* and the *Doctorate in Quantum Technologies*, Campania Region is at the forefront of quantum technologies. The region plans significant investments in the Quantum Valley, with resources of about 100 million euros.

https://openfiber.it/app/uploads/2023/06/B2B-Activities-portfolio.pdf

[101] Unina (2024). A Napoli, la prima rete di comunicazione quantistica metropolitana permanente. Retrieved from: https://www.unina.it/-/52867403-a-napoli-la-prima-rete-di-comunicazione-quantistica-metropolitana-permanente. Consulted in September 2024.

To support the local economy, the *Municipality of Naples* also leads the *CTE Infiniti Mondi*, Naples Innovation City project, which includes laboratories dedicated to Quantum Computing and 5G, reinforcing experiments initiated within the *Emerging Technologies Houses*.

Here are some examples of Italian companies involved in implementing Quantum Key Distribution (QKD): *Quantum Telecommunications Italy*, *Level Quantum*, *ThinkQuantum*, and *Italtel*.

QTI - Quantum Telecommunications Italy

QTI (*Quantum Telecommunications Italy*) is an Italian company focused on quantum communications, particularly developing and producting Quantum Key Distribution (QKD) systems. Founded in October 2020, QTI is a spinoff of the Italian National Institute of Optics of the National Research Council (CNR-INO). Its technologies include atomic and quantum optics, solid-state lasers, and optical telecommunications to create secure and reconfigurable quantum networks.

In 2021, QTI participated in the first intergovernmental quantum communications project involving Italy (Trieste), Slovenia (Ljubljana), and Croatia (Rijeka), demonstrating its QKD technology on three nodes over a crow-fly distance of 95 and 100 km. The partnership with Telsy, a cybersecurity company of the TIM Group, was of great strategic importance for the company. This partnership has enabled the company to offer end-to-end encryption systems suitable for various applications, including the private, governmental, and military sectors.[102]

Moreover, QTI is involved in several prominent projects, including the Italian implementation of the European Quantum Communication Infrastructure (EuroQCI), called QUID. This initiative aims to establish secure quantum communication networks across Italy using technologies like Quantum Key Distribution (QKD). The company collaborates with entities such as *TIM*, *Telsy*, and research institutes to advance quantum networking capabilities[103].

QTI's main product line is the Quell-X family, which consists of three versions[104]:

- *Quell-X*: This core product generates quantum-secure keys and is compatible with third-party encryption units.
- *Quell-XC*: This end-to-end encryption system integrates high-speed encryption units with quantum keys for secure data transmission.
- *Quell-XR*: Designed for academic and research use, it provides raw key data for custom post-processing protocols.

QTI also offers *QKME* (Key Management Entity), a network device for secure key storage and distribution, and *QSDN* (Software Defined Network), which integrates *QKD* with *SDN* for a highly secure and programmable network solution. QTI is also involved in projects such as *QPIC1550*[105], which aims to develop a universal quantum photonics platform that supports communications, computing, and quantum metrology applications.

QTI's QKD systems protected sensitive communications during the 50th G7 Summit, which took place in Fasano, Puglia, from June 13 to June 15, 2024.

Specifically, *Telsy* and *QTI* provided secure quantum connectivity for sensitive communications.

[102] *Quantum Telecommunications Italy*. (n.d). Who we are. Accessed July 2024. https://www.qticompany.com/who-we-are-qti/

[103] *Inrim*. (2023). *Quid*: The Implementation Of Quantum Communication Network In Italy Begins. https://www.inrim.it/sites/default/files/2023-06/Press%20Release%20QUID_DEF_ENG_20230606_2.pdf

[104] *Quantum Telecommunications Italy.* (n.d). Products. Accessed July 2024. https://www.qticompany.com/products/

[105] *Qpic1550*. (n.d). About. Accessed July 2024. https://www.qpic1550-project.eu/about/

Communications between the press centre at the Fiera di Bari and journalists at Borgo Egnazia in Fasano, some 80 km away, were protected by *QTI*'s *Quell-X quantum key distribution systems* and *Telsy's TelsyMusaX* cryptographers.
The use of the technology was a practical application of QKD technology as a tool to address the need to protect live communications and maintain accurate reporting in the context of media coverage of the G7 summit[106].
QTI's focus on secure quantum communication aligns with the global push for enhancing data security against cyber threats. Its contributions to projects like *EuroQCI* and *QUID* underscore the growing importance of quantum technologies in safeguarding critical infrastructures, making it a key player in the field. QTI highlights the practical application of quantum mechanics in enhancing cybersecurity and digital sovereignty.

Level Quantum

LevelQuantum is a startup based at the *PoliHub* in Milan, specializing in applied quantum technologies, focusing on computer security. Its mission is to eliminate existing cryptographic weaknesses using quantum technologies. The company was founded in 2022 by three scientists with extensive backgrounds in quantum photonics and information processing: Magdalena Stobińska (CEO), Adam Buraczewski (CTO), and Giulio Busulini (General Manager).
The company specializes in developing of advanced quantum key distribution (QKD) technologies for secure communications. They offer solutions such as fiber-based *QKD*, free-space *QKD*, and *QKD* over satellite, which aim to improve the security of data transmissions using the principles of quantum physics[107].
Finally, the startup was also selected by *NATO* to be part of the *DIANA* programme[108] and was named by *Wired* as one of the ten Italian startups to follow in 2024[109]. Its strategic role in quantum communications and cybersecurity, a rapidly evolving field, makes it an example of Italian excellence in deep-tech technologies, with potential for global transformation in data protection and encrypted communications. The company highlights the link between academic innovation and practical applications with global impact.

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[106] *Quantum Telecommunications Italy*. (2024). I sistemi QKD di QTI per proteggere le comunicazioni al vertice del G7 2024. Accessed July 2024.
https://www.qticompany.com/qtis-qkd-systems-to-secure-communications-at-the-g7-summit-2024/
[107] *LevelQuantum*. (n.d.). Technology. Accessed September 2024.
https://www.levelquantum.eu/en/technology/
[108] *LevelQuantum*. (n.d). *LevelQuantum* selected by *NATO* for *DIANA* program. Accessed September 2024.
https://www.levelquantum.eu/en/levelquantum-selected-by-nato-for-diana-program/
[109] *Wired*, Antonio Piemontese, “10 startup italiane da seguire nel 2024”, 26th December, 2024.
https://www.wired.it/gallery/startup-italia-10-2024-intelligenza-artificiale/

ThinkQuantum

Marco Lamonato, MBA
Business Development
ThinkQuantum
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"Quantum cryptography emerges as the natural evolution of security in response to the capabilities of quantum computers; within the quantum landscape lies both the challenge to current encryption and its most promising solution."

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

ThinkQuantum is involved in several projects at different TRL levels, both within Italy and at a larger scale with partners from the European Union, with the aim to explore and develop the technology into the next steps.

Who are your direct competitors?

We compete on a global scale with companies that go after fields of application of Quantum Key Distribution (QKD) and Quantum Random Number Generation (QRNG), both in terrestrial and space domains. In this regard, *ThinkQuantum* is a unique case of competences and proven technology spanning on multiple areas and domains.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

When it comes to technologies like QKD and QRNG, the applications that can be targeted are geopolitically sensible, for this reason relying on an European supply chain (and in turn an Italian one) for all critical components is strategic going forward.

What are the main areas of application for quantum technologies? What are the target markets?

For Quantum Random Number Generators (QRNGs), the main areas are enhancing classical cryptography and improving the efficiency of Monte Carlo simulations across various fields like finance and chemistry. Quantum Key Distribution (QKD), on the other hand, primarily targets the secure communication market. It achieves this by using quantum mechanics to generate and distribute cryptographic keys, thereby significantly bolstering the security of information transfer.

Can you provide examples of real use cases?

A significant real-world example is the EuroQCI (European Quantum Communication Infrastructure) initiative. This ongoing project, involving the majority of European Union member states, aims to establish a secure, Europe-wide QKD infrastructure. The goal is to create a network that protects sensitive governmental data and critical infrastructure by leveraging quantum-generated and distributed cryptographic keys.

Who are your current customers and what are your potential customers?

Governments and institutions are among the early adopters, large enterprises of different fields within the private sector are coming next.

Italtel

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"At *Italtel*, Quantum Technologies are a strategic pillar shaping the future of secure communications. We focus on Quantum-safe solutions to strengthen cybersecurity, foster trust, and transform innovation into tangible impact for the quantum era."

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

Italtel actively collaborates with companies and research institutes in Italy and abroad through initiatives promoted by *NQSTI*, *ACN*, *NATO*, *MISE*, and *MIMIT*, contributing to the advancement of Quantum-Safe Communications. The company participates in several European and National research projects where Quantum-Safety plays a key role.

Italtel acts as an industrial enabler, integrating quantum-safe solutions into real-world infrastructures and collaborating with universities and innovation hubs to foster skills and technology transfer in quantum technologies.

A strategic partnership with Quantum Bridge Technologies enables *Italtel* to deliver scalable, interoperable, and quantum-secure communication systems that integrate DSKE, PQC, and QKD, while embracing a Crypto Agility approach. Looking ahead, *Italtel* aims to further strengthen and expand collaborations in Quantum Technologies and cryptography, enhancing data protection across all environments - in transit, at rest, and in use.

Who are your direct competitors?

Our direct competitors provide comprehensive end-to-end capabilities spanning Quantum Threat Risk Assessment, Mitigation Strategy, and Execution. Their offerings cover cryptographic asset assessment, quantum-related risk evaluation, and quantum-safe migration planning. They also address compliance requirements and deliver technologies and services that ensure a secure transition to quantum-safe infrastructures with minimal disruption.

What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?

At *Italtel*, we design security solutions that anticipate future challenges by integrating quantum-resilient technologies and adopting a crypto-agile strategy, ensuring adaptability as threats and algorithms evolve. The transition toward a quantum-safe ecosystem presents key challenges, including maintaining backward compatibility, managing progressive migration, and ensuring coordination across a supply chain where standards, certifications, and interoperability frameworks are still taking shape.

What are the main areas of application for quantum technologies? What are the target markets?

We are assessing and implementing a broad spectrum of Quantum Technologies tailored to specific operational contexts, focusing primarily on secure communications and data protection. Our main areas of application include quantum cryptography and key management to ensure data confidentiality, integrity and authenticity across critical infrastructures, and digital ecosystems. *Italtel* offers consulting services for quantum risk assessment and migration planning, supporting organizations in their journey towards quantum resilience.

Can you provide examples of real use cases?

Representative use cases addressing protection across multiple network layers include secure WAN/LAN interconnection through Zero Trust architectures; quantum-safe data center environments ensuring protection for sensitive data in transit; interoffice communications supporting business continuity across distributed and multi-cloud infrastructures; hybrid quantum-classical networks integrating classical and quantum technologies.

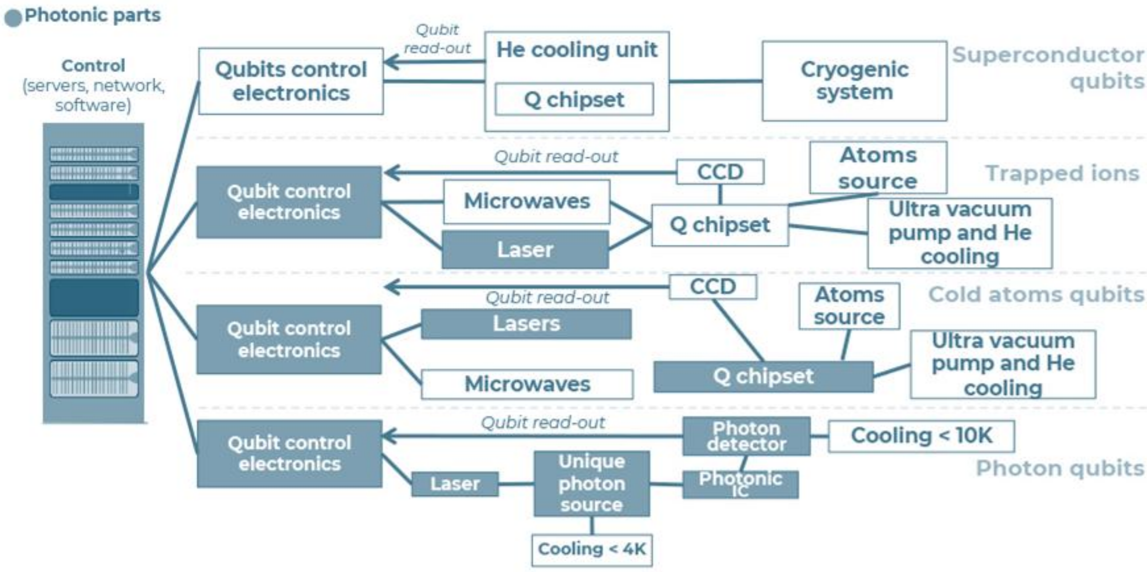
Who are your current customers and what are your potential customers?

Our current and potential customers are primarily organizations operating in sectors where the protection of data, communications, and digital identities is most critical. As quantum computing moves closer to practical deployment, it introduces new classes of cybersecurity risks, particularly the potential for malicious exploitation of quantum capabilities. Consequently, the adoption of quantum-safe security technologies is progressing in a risk- and impact-driven manner, starting with highly sensitive domains such as finance, defence, telecommunications, and critical infrastructure. Italtel's customer base also includes public sector entities and large enterprises, reflecting our reliability and expertise in supporting compliance with evolving regulatory frameworks. Our risk-based approach ensures tailored solutions that address specific industry needs and facilitate a smooth transition to quantum-safe environments.

4.4 Quantum Computing: the different qubits

Quantum computing's foundational unit, the **qubit**, comes in various forms, each with unique strengths and challenges. These include atomic systems such as **trapped ions** (utilized by companies like *IonQ* and *Quantinuum*), **cold atoms** like rubidium and cesium (e.g., *Pasqal* and *Atom Computing*), **superconducting circuits**, and **photonic qubits** (e.g., *PsiQ*). Despite ongoing advancements, no single qubit platform dominates, suggesting that future quantum systems might integrate multiple technologies to maximize performance (see *figure 39* and *table 9*).

Figure 39. The different architectures of quantum computers



Source: Yole Intelligence, 2024.

Moreover, we can list several **types of Quantum Computers** (*YoleGroup*, 2024):

- **Quantum Emulators** simulate quantum systems and are typically used in academic and preliminary research.

- **Quantum Annealers**: focused on optimization problems, they seek low-energy states within a given computational problem.
- **Universal Quantum Computers** can execute a wide range of algorithms via quantum gates but are currently constrained by noise and scalability issues.
- **NISQ Devices**: near-term systems operate with limited circuit depth and without error correction. While imperfect, they are expected to outperform classical supercomputers for specific tasks.

The initial generation of quantum computing devices operates within the *Noisy Intermediate Scale Quantum* (NISQ) regime, characterized by noisy qubits and no quantum error correction. Future objectives include correcting such quantum errors and, in the longer term, interconnecting such devices via a quantum internet that connects the innovations developed in quantum computing and quantum communication (Abbasi *et al.*, 2024).
Companies vary in the way they measure quantum volume, but it seems to be a sign of progress that apples-to-apples quantum volumes are doubling or even growing more quickly every couple of years. However, it is unclear if we need a quantum volume of a thousand, a million, or a billion to make QTs that can be used for multiple real-world applications.
A war is underway between technological standards to define the one to adopt for quantum computer hardware. In particular, the efforts of the main players in the sector aim at common objectives to make hardware accessible. In fact, they aim to (Gill *et al.*, 2024):

- Improve *NISQ* technology by integrating error correction techniques;
- Build architectures to assemble quantum computers, even small ones, thanks to 3D printing and developing, at the same time, large-scale industrial production structures;
- Facilitate the interaction between quantum computers;
- Increase the quality of qubits;
- Implement solutions to control a greater number of qubits simultaneously in line with the development of quantum processors;
- Boost the integration of these control devices (user interfaces, qubit interfaces);
- Reduce time and costs by reducing dependence on materials and components from outside Europe by reducing dependence on materials and components from outside Europe.

Wired [110] underlines how time is an uncertain factor: current projections indicate the need for at least ten years to achieve a true competitive advantage from quantum computing compared to the classical computational approach, while ensuring an adequate return on investment. Daniele Dragoni, coordinator of the quantum

[110] *Wired*, Gianluca Dotti, "Il futuro delle tecnologie quantistiche in Italia", January 11th, 2024. https://www.wired.it/article/tecnologie-quantistiche-aziende-italia-imprese-startup/

computing research unit at *Leonardo Labs*, states that very few companies today can invest in such a cutting-edge and futuristic field, because there is still no direct return. Moreover, Lara Faoro, Quantum Research Scientist at *Google AI Quantum*, explains, "When working with hundreds of qubits together, there are interference phenomena and other complications, so efforts are being made to optimize materials and improve error correction codes". [111]

Table 9. A comparison of quantum computers

Type of qubit	*Example company*	*Number of physical qubits demonstrated**	*Company goals*	*Pros*	*Cons*
Photons in a silicon chip	***PsiQuantum***	2	A commercially sound, fault-tolerant computer by the end of 2027. It implies one million physical qubits and hundreds of logical qubits.	Fast computation; detectors require chilling to only 4 kelvin and can be compatible with classical chips.	Photons are hard to manipulate, and systems require large overheads because sources are probabilistic and photons are easily lost.
Loops of superconducting metals	***IBM***	>1,000	Thousands of logical qubits are doing commercially functional calculations.	Fast operations; can be manufactured using familiar methods.	Work close to absolute zero; relatively quick to 'decohere' (lose their quantum state).
Ions trapped with magnetic fields	***Quantinuum***	56	Aiming for hundreds of logical qubits by 2030.	Stable, long-lived qubits that operate at temperatures of around 4 K; flexibility to reconfigure connections between qubits.	Slower operations; require a high vacuum; could prove hard to scale up.
Neutral atom trapped by lasers	***QuEra Computing***	Around 256	100 logical qubits by 2026, made up of 10,000 physical qubits.	Densely packed, long-lived qubits that can be moved to connect flexibly and operate with only laser cooling.	Operations might be slow.

[111] *Wired*, Sandro Iannacone, "Il computer quantistico è "come un telescopio", ma siamo ancora alla preistoria", February 13th, 2023.
https://www.wired.it/article/computer-quantistico-tecnologia-obiettivi-applicazioni/

Type of qubit	*Example company*	*Number of physical qubits demonstrated**	*Company goals*	*Pros*	*Cons*
Silicon spin	***Intel***	12	Designing a successor to its current quantum chip. The company has an internal roadmap for scaling up qubits.	Densely packed qubits; manufacturing might be compatible with classical chips.	Qubits are relatively quick to decohere and can be hard to read out.

*Qubit number alone does not indicate the capability of a quantum computer.
Source: Gibney (2024).

Of particular interest are the different types of qubits in superconducting electronic circuits, such as Transmon, which represent a significant advance due to their reduced sensitivity to charge noise (Berke *et al.*, 2022). In spin-based systems, technologies such as nitrogen vacancy centers in diamonds and semiconducting quantum dots show great promise, especially for the stability and precision they can offer. In addition, the section on systems based on neutral atoms and ions highlights the sophistication of manipulation and control techniques, such as using Rydberg atoms and ion traps, that enable precise management of quantum states.
Including photonic systems and emerging concepts such as topological qubits demonstrates the breadth of research underway to find robust and scalable solutions. The section on quantum state control technology is crucial as it addresses the practical challenges of manipulating qubits and implementing quantum logic gates (see *figures 40 and 41*).

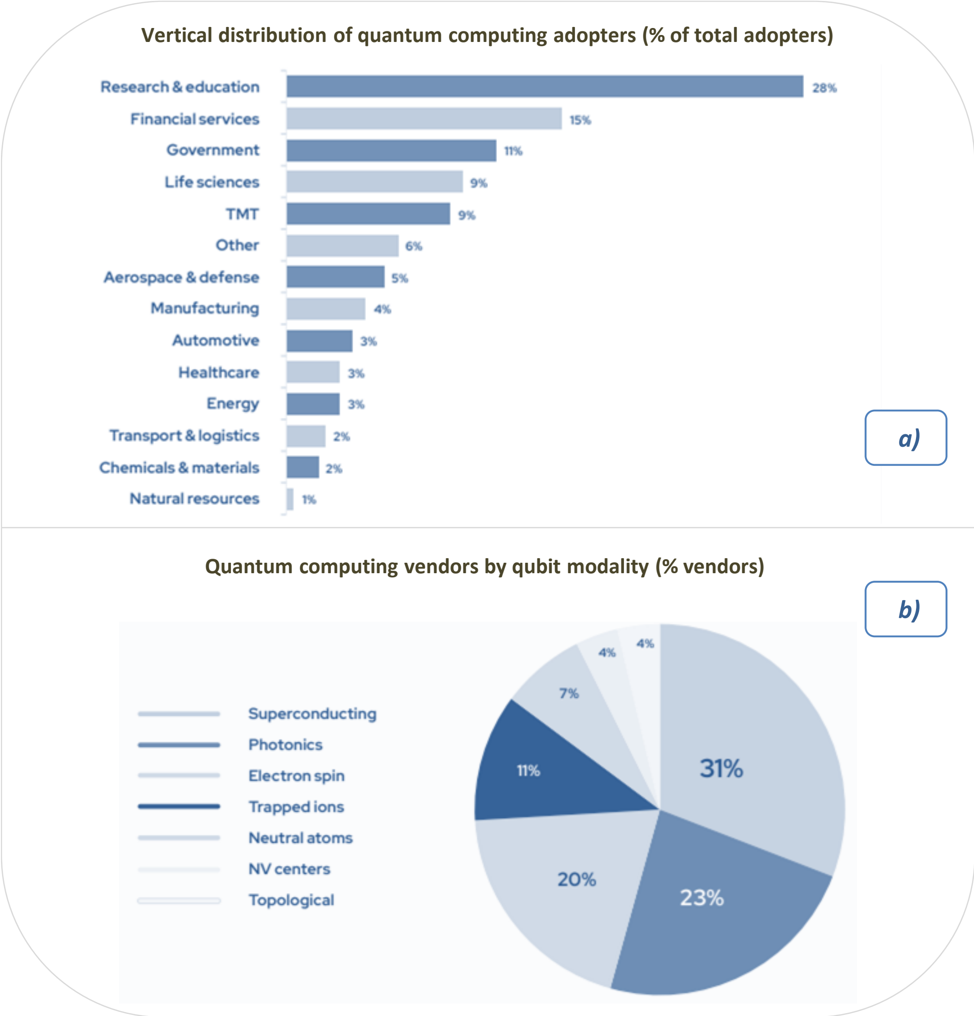
Figure 40. The Quantum Computing Supply Chain: the main actors

Source: Quantum Insider, 2025[112].

[112] Matt Swayne, "The Quantum Supply Chain: Mapping the Market and Key Players", March 29th, 2025, *Quantum Insider*.

Finally, discussions on hybrid quantum systems and technology integration highlight the importance of creating a quantum ecosystem that can interact effectively with existing classical technologies. This integrated approach is critical to the future development and practical application of quantum computing (*Quantum Flagship*, 2024; *CEN-CENELEC, 2023b*).

Figure 41. The main Quantum Computing adopters and the percentage of vendors typology



Source: IQM et al., 2025.

The applications of quantum computing are numerous and span various innovative sectors (see *boxes 22, 23,* and *24*). With respect to high-performance computing through quantum computing, the main applications involve fluid dynamics (Jaksch *et al.*, 2023) and materials analysis in the aerospace sector, cloud computing, big data, and the use of quantum algorithms in the advanced services industry (Bayerstadler *et al.*, 2022).
In this context, *Airbus* has launched a global challenge to explore how quantum computing could be used to solve complex engineering problems in aerospace, such as

The Quantum Supply Chain: Mapping the Market and Key Players route optimization, aerodynamic design, and advanced material simulations. Additionally, *Airbus* is investigating how quantum computers could accelerate simulations involving computational fluid dynamics (CFD) and materials, significantly reducing the development time for new vehicles[113].

Box 22. Finance: some use cases

Applications of quantum technologies could help perform complex operations related to the study and forecasting of financial markets, such as portfolio optimization, studies on option pricing and risk management, or credit risk analysis. Other key areas regard security in transactions as money laundering prevention and fraud detection (Faccia, 2020; Orús *et al.*, 2019; Orrell, 2020; Arraut *et al.*, 2019).

According to a report by *Cassa Depositi e Prestiti* (*CDP*, 2024), the quantum computing techniques currently under development focus primarily on leveraging this additional computational power to achieve more accurate results in less time. Specifically, in the case of Portfolio Optimization, integrating Quantum Computing procedures into existing schemes could make the portfolio evaluation process faster and more accurate, thanks to the increased computational capabilities available to analysts.

In this context, the technology developed through Quantum Annealers, whose leading vendor is *D-Wave*, currently appears to be the most effective for addressing the problem. The *Quadratic Unconstrained Binary Optimization* (*QUBO*) formulation, which uses only binary variables, allows for the easy handling of even non-linear constraints in the problem's input data. To apply this solving method on a Quantum Annealer available today, optimization solvers break the problem into smaller sub-problems and then find the best global solution. From a practical standpoint, the algorithm starts by identifying an initial solution to a highly simplified version of the problem and evolves, gradually approaching the optimal solution.

Quantum Computing offers promising applications also in pricing derivative instruments such as American, Asian, European, and Bermudan options. Traditionally, option pricing is performed through *Monte Carlo simulations*, which are time-consuming, especially for complex models. *Quantum Monte Carlo Integration* (*QMCI*), based on the *Quantum Amplitude Estimation* (*QAE*) algorithm, significantly speeds up these simulations. *QAE* allows for estimating the expected value of a function with quadratic speed-up compared to classical methods, improving both accuracy and speed. In option pricing, data is encoded into qubits, and through quantum operations, the financial option's temporal evolution is simulated. Finally, the measurement of a quantum state provides the estimated option's payoff. This approach reduces the input data needed and offers faster, more accurate results. [114]

Terra Quantum collaborated with *HSBC* to apply hybrid quantum technologies to optimize finance challenges, enhance efficiency, and manage complex problems like collateral optimization. Still, *Terra Quantum* and *Cirdan Capital* have partnered to optimize exotic option pricing with quantum software, achieving up to 75% faster calculations than standard methods. Quantum-powered solutions in the future will be ready for efficient risk assessment and potential savings in financial trading thanks to this advance (*IQM et al.*, 2024).

Box 23. Energy: some examples

A concrete application of quantum computing is the problem of allocating solar and wind power plants. The goal is to find optimal locations for solar and wind power plants that minimize plant opening and transportation costs for a given energy demand and resource availability. The potential of this technology is receiving increasing attention from the energy industry. One of the areas in which quantum simulations can benefit is solar conversion (BCG, 2023). Indeed, quantum technologies find applications in renewable energy, especially in double-sided roofs, wind energy conversion, waste-to-energy plants, and floating solar (Nuvvula *et al.*, 2022).

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[113] *Airbus* (2024), "Quantum technologies: a potential game-changer in aerospace". https://www.airbus.com/en/innovation/digital-transformation/quantum-technologies.

[114] *CDP*, (2024), "Quantum Finance. Una panoramica delle possibilità attuali e prospettive future". https://www.cdp.it/resources/cms/documents/CDP_Studio_Quantum_Finance.pdf.

Moreover, quantum computers perform parallel computations using less energy because they operate at lower temperatures. Some applications include smart grids in sustainable smart cities (SSCs) (Safari & Ghavifekr, 2022).
The two projects that improved LNG logistics, predicted CO2 emissions from biomass plants, and evaluated complex derivatives in energy trading demonstrated practical use cases for quantum technology in the energy sector.
POSCO Holdings' new tech hub intends to investigate and develop quantum AI algorithms with *PASQAL*. By combining the AI technology of the *POSCO Group* and the quantum computing technology of *PASQAL*, the two companies intend to focus their capabilities on the development of novel technologies, such as the optimization of the hydrogen reduction steel production process (*HyREX*) and the development of secondary battery materials (IQM *et al.*, 2024).
A new quantum material developed by *Lehigh University* shows an external quantum efficiency (EQE) of up to 190% in solar cells, exceeding the theoretical limits of traditional silicon-based cells. This breakthrough is due to material "intermediate band states", which allow it to absorb sunlight more efficiently and generate more than one electron per absorbed photon. This innovation could significantly enhance solar energy technologies (Kastuar and Ekuma, 2024).
Finally, we can observe that quantum materials offer promising solutions to energy transmission and data storage challenges. These materials, governed by quantum mechanics, exhibit unique properties such as zero electrical resistance in superconductors and energy-efficient electron behavior in spintronics. They could reduce energy loss in computer chips, improve data storage, and enhance energy transmission efficiency. Researchers are exploring topological materials and superconductors, aiming to overcome limitations, such as needing room-temperature superconductors, to unlock their full potential (Law, 2023).

Finally, advanced Artificial Intelligence applications, such as machine learning techniques (Krishnan, 2023) and predictive maintenance (advanced mechanics, automotive, aerospace, and energy systems), autonomous driving (automotive and aerospace), and decision support systems (healthcare and advanced services industries), also benefit from quantum computing.
Zapata Computing has developed *Orquestra*, a platform that executes quantum and classical data mining workflows and machine learning. The platform is used in applications including process optimization, quantum chemistry, and drug discovery, all of which require the management and analysis of large amounts of data[115].
The development progress in quantum computing concerns various technologies at the hardware, software, and middleware levels. However, this division can be purely indicative, given that technological diffusion requires total development.

Eniquantic

Eniquantic is a joint venture launched in 2024 through a collaboration between *Eni* and the startup *ITQuanta*. *Eniquantic's* shares will initially be held 94 percent by Eni and 6 percent by ITQuanta. To manage the new company, President Prof. Massimo Inguscio (*ITQuanta*) and CEO Dr. Dario Pagani (*Eni*) have been appointed. This project represents the second venture belonging to *Eniverse* initiatives (Eni's corporate venture builder). It allows Eni to strengthen its leadership in high-performance computing for industrial use.
Its mission is to develop advanced quantum computing technologies. The company aims to build an integrated quantum machine, both hardware and software, capable of tackling and solving complex

[115] *Zapata AI.* (2024). Orquestra. Accessed October 2024.
https://zapata.ai/EarlyAccess/

challenges such as mathematical optimization, simulation and modeling of physical systems, and artificial intelligence applications.
This initiative seeks to push the boundaries of quantum computing, applying it to critical areas including energy efficiency, materials discovery, and high-performance simulations in various industries[116].
The company offers applications across various industries, primarily focusing on the energy sector, aiming to improve the efficiency of energy resources and support the transition toward renewable sources. *Eniquantic* leverages the computational power of Eni's High-Performance Computing (HPC) systems to explore interactions between classical and quantum computing architectures. Additionally, it tests algorithms that simulate quantum computing processes, enhancing problem-solving capabilities and driving innovation in energy and beyond[117].
This initiative represents a significant step forward in Eni's innovation and digitalization strategy, strengthening its leadership in the industrial application of advanced technologies like quantum computing. *Eniquantic* plays a key role in discovering new materials and optimizing operations across the entire energy value chain, enhancing efficiency and sustainability throughout its processes[118]. *Eniquantic* represents an example of how quantum technologies can help in solving complex, real, and current problems such as energy transition and sustainability. It also represents a model for collaboration between large companies and innovative startups to accelerate the adoption of disruptive technologies.

Ephos

Ephos, founded in 2022 as a spinoff of the Italian National Research Council (CNR), is a multinational company with headquarters in the United States and production facilities in Italy (Milan)[119]. The company is dedicated to building the essential infrastructure for quantum technologies. It designs and manufactures glass-based integrated photonic circuits that power the most advanced quantum processing, communication and sensing devices for AI data centres and quantum computers. Particularly, *Ephos* focuses on minimizing signal loss to help customers create scalable quantum infrastructures. Using its proprietary femtosecond laser writing process, it designs and manufactures glass-based quantum photonic chips, managing every step from material sourcing to benchmarking.
Ephos has been selected by NATO from a pool of approximately 1,300 applicants to participate in NATO's Defense Innovation Accelerator for the North Atlantic (DIANA)[120]. *Ephos* received non-dilutive funding of €450,000 from DIANA and support from the *European Innovation Council*. These funds were used to launch an advanced manufacturing facility in Milan's MIND district, named FAB-1, the world's first dedicated to quantum photonic circuits in glass. FAB-1 has enabled *Ephos* to provide customers with advanced photonic chips from a trusted, secure supply chain.
Ephos' goal in DIANA, as stated by its CEO Andrea Rocchetto, was:
"*To build the essential infrastructure for innovation related to quantum technologies. The rapid and safe realization of the next generation of emerging and disruptive technologies requires the best of*

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[116] *ENI* (2024). Nasce *Eniquantic*: la nuova società di Eni per lo sviluppo tecnologico del quantum computing. Accessed September 2024.
https://www.eni.com/it-IT/media/comunicati-stampa/2024/07/cs-eniquantic.html.
[117] *Forbes*, Redazione di Forbes, "Eni investe nel quantum computing: nasce *Eniquantic*", July 16th, 2024.
https://forbes.it/2024/07/16/eni-investe-quantum-computing-nasce-eniquantic/
[118] *La Stampa*, Redazione, "*ENI* accelera sul quantum computing: nasce *Eniquantic*", July 15th, 2024. https://finanza.lastampa.it/News/2024/07/15/eni-accelera-sul-quantum-computing-nasce-eniquantic/NzdfMjAyNC0wNy0xNV9UTEI
[119] *Ephos*. (n.d). *Company*. Consulted July 2024.
https://ephos.io/
[120] *Ephos*. (2023). *Ephos* joins *NATO's DIANA* to build the essential infrastructure for Allied innovation in quantum technologies. Consulted July 2024.
https://ephos.io/newsroom/ephos-joins-natos-diana-to-build-the-essential-infrastructurefor-allied-innovation-in-quantum-technologies/

government, academia, and the private sector. We are privileged to join the cohort of innovators who will pioneer NATO's emerging technology ecosystem".
About fundings, *Ephos* closed in 2024 an $8.5 million seed funding round, led by *Starlight Ventures* and involving investors such as *Collaborative Fund*, *Exor Ventures*, and *NATO's Defense Innovation Accelerator* for the North Atlantic (*DIANA*)[121].
On July 25, 2025, the company has secured a €41.5 ($49 million) million grant from the *Ministry of Enterprises and Made in Italy*, under the *EU Chips Act*, to build its new manufacturing facility in Italy. The project, named Fab-2, represents a total investment of €104.9 million ($123 million) and will establish the world's first facility for processing advanced optical materials on glass. *Ephos* will scale production of its first-of-its-kind process for manufacturing ultra low-loss, fast-switching photonic chips on glass substrates. As already underlined, these chips serve as a key building block of AI data centers, high-performance computing (HPC), and quantum computers, addressing the rapidly growing demand for advanced chip technologies.
"As artificial intelligence reshapes our economies and geopolitical landscapes, advanced chip manufacturing has become a critical strategic asset. With Fab-2, we are leveraging Europe's exceptional engineering talent to deliver the essential components that power AI infrastructure," says Andrea Rocchetto, co-founder and Chief Executive Officer of *Ephos*.
Ephos represents an example of how Italy and Europe are trying to compete in the global quantum technology landscape by combining local innovation and institutional support. Its technology addresses fundamental challenges in quantum computing and energy efficiency, potentially impacting areas such as artificial intelligence, defense, and telecommunications.

Box 24. Logistic: some examples

Quantum computing could simplify logistics through real-time route optimization and strengthen infrastructure through scenario simulations (BCG, 2023; *IQM et al.*, 2024). The use of quantum technologies means, in fact, efficient delivery to customers and planning of vehicle routes. Quantum computing can solve highly complex optimization problems far more efficiently than traditional methods, such as the "Traveling Salesman Problem," a classic challenge in logistics. Transportation companies must determine the optimal route to deliver goods while minimizing time, costs, and resources. Classical computers face computational limits with large datasets, while quantum computers can simultaneously explore many more solutions thanks to parallel computing. Various solutions are related to using quantum annealers (Jain, 2021; Warren, 2020). Still, hybrid quantum algorithms such as DBSCAN (Density-Based Spatial Clustering of Applications with Noise) and the solution partition solver are used to solve vehicle routing problems (Borowski *et al.*, 2020).
Another potential application of quantum computing is in the modeling and simulating complex logistics networks, such as the supply chain. In a global scenario, supply networks must account for thousands of interconnected variables, including demand fluctuations, delivery times, material availability, and weather conditions. *IBM* is developing a quantum algorithm that can simulate complex scenarios for supply chain management.[122]
The *BMW Group*, *Airbus*, and *Quantinuum* joined forces to accelerate research into sustainable mobility using quantum computers. This collaboration aims to harness the power of quantum computing to

[121] *Ephos*. (2024). *Ephos* Raises $8.5M Seed Round and Opens World's First Facility for the Design and Production of Glass-Based Quantum Photonic Chips. Accessed November 2024.
https://ephos.io/newsroom/ephos-raises-8-5m-seed-round-and-opens-worlds-first-facility-for-the-design-and-production-of-glass-based-quantum-photonic-chips/
[122] *IBM*. (2024). Supply chain planning and analytics.
https://www.ibm.com/products/planning-analytics/supply-chain-planning?utm_content=SRCWW&p1=Search&p4=43700068108624254&p5=p&p9=58700007558656354&gad_source=1&gclid=CjwKCAjwxY-3BhAuEiwAu7Y6s7HV8jeMLQq5LUlBJqcu3e4RqVgbCWk1_gxcEqHnOqNmMpnENp2esxoCE9MQAvD_BwE&gclsrc=aw.ds

address challenges in *sustainable transportation*. Indeed, one of the principal types of computational problems is machine learning, and quantum computing addresses them in various fields of application. The principal applications of this technology are in the automotive industry and in the field of artificial intelligence, including generative, foundation, and horizontal AI (Perazzo *et al*., 2024; *BCG*, 2023).

In emergencies like natural disasters, quantum models can help predict impacts and optimize resource redistribution. *Terra Quantum* and the *Honda Research Institute Europe* developed a quantum machine learning solution to facilitate routing during catastrophes. In a simulated quake, the solution successfully predicted vehicle escape routes, outperforming conventional ones. Many real-time variables are processed, with the goal of being implemented in various urban scenarios.

Quantum computing and quantum sensors are opening new avenues for logistics and transportation, enhancing efficiency, safety, and the ability to manage complex systems. These technologies are not yet fully mature, but they are making significant strides, and companies across various industries are already exploring their potential applications. Specifically, quantum sensors can measure physical parameters such as time, gravity, and acceleration with extreme precision. This technology is crucial for autonomous vehicles, drones, and intelligent transportation systems, as it improves the accuracy of navigation and measurements compared to traditional sensors. For example, quantum sensors can enhance the navigation of autonomous vehicles operating in areas without *GPS* signals or in dense urban environments, where precision is critical. These sensors allow for tracking positions based on Earth's gravitational field variations or using highly accurate atomic clocks.

Still, predictive maintenance is crucial in air and rail transportation to prevent failures and reduce downtime. Thanks to the power of quantum computing, it is possible to analyze a vast amount of sensor data collected from engines and other systems to predict when maintenance is needed accurately. For example, *Airbus* is exploring the use of quantum computing to improve the efficiency of its predictive maintenance operations, aiming to identify weaknesses in systems before they cause problems[123].

Exprivia

Exprivia S.p.A. is an Italian ICT company that designs and develops innovative software technologies and services for the finance, healthcare, energy, aerospace, cybersecurity, and telecommunications markets. The firm, founded in 2004, focuses on artificial intelligence, big data, cloud computing, cybersecurity, and the Internet of Things (IoT), and supports companies in optimizing processes and digitazing operations. *Exprivia* is located in Molfetta (Bari, Puglia) and operates globally by developing cutting-edge solutions.

Pietro Noviello
Exprivia Research Manager
Website: *https://www.exprivia.it/*
Email: *Pietro.noviello@exprivia.com*

"Sourcing specialized skills is a major challenge. Quantum computing requires a high level of technical and scientific expertise, which is currently limited to a niche of experts."

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?

[123] *Airbus*. (2024). Quantum technologies. A potential game-changer in aerospace. https://www.airbus.com/en/innovation/digital-transformation/quantum-technologies#:~:text=The%20Airbus%20Quantum%20Computing%20Challenge,Bristol's%20Quantum%20Technology%20Innovation%20Centre

Exprivia actively collaborates with other companies and research institutes in the field of quantum technologies. We have been working on these technologies since the end of 2018, through our participation in the **Quantum Systems and Technologies for IT Security in Communication Networks** (*QUANCOM*) funded project, together with the main national research institutes in the field: *PoliMi*, *CNR* (INO, ICAR, IIT, IEIIT), *ASI*, *INRIM*, the *University of Padua* and some SMEs in Southern Italy.

Thanks to our involvement in the development of the *Metropolitan Multi-Node Quantum Communication Network* in Naples, we have collaborated with companies such as *CISCO*, *TELSY*, *QTI* and *ThinkQuantum*.

In terms of future collaborations, *Exprivia* intends both to consolidate the current network and to expand it through collaborations with startups and key players in the quantum science sector in general, with the aim of bringing innovative use cases to the market.

We are working with the partners of the *Meditech* consortium to strengthen and develop the Naples network and to identify new projects to connect the Naples network to the *MUR* network established in Matera and, ideally, to a future quantum network in Bari.

Who are your direct competitors?

Exprivia is an IT company focused on the integration of technologies and software systems. Currently, in the quantum field, it has acquired some expertise in quantum communication and quantum security and is trying to integrate QKD into application use cases.

We are not aware of any other company in Italy with the same expertise of *Exprivia* in the field of Quantum Key Distribution (QKD). *Leonardo* and *TIM* are using QKD, but for different purposes.

There are also companies active in this field in Europe that are more focused on the production of QKD technologies, such as *Toshiba* and *ID Quantique*.

In your opinion, what is the outlook for the quantum computing supply chain? What challenges do you see ahead?

The supply chain outlook for quantum computing is very promising, but it faces significant challenges. On the one hand, growing attention from governments, technology companies and research institutions suggest that quantum computing will become increasingly central in the coming years. Investment in hardware, software and infrastructure is increasing, with many companies working on the development of essential components such as stable qubits, advanced quantum sensors and cryogenic cooling systems. However, there are significant challenges ahead. First, *scalability* is a critical hurdle: building systems with enough qubits while maintaining consistency and reducing errors is a major technological barrier. Furthermore, *manufacturing quantum hardware* requires specialized materials and complex infrastructure, which could cause *supply chain bottlenecks*, especially with growing demand. Another key issue is *standardization*. As quantum computing is still in its infancy, there are different and non-standardized approaches. The lack of recognized technical standards makes interoperability between different components and platforms difficult, slowing progress. Finally, *sourcing specialized skills* is a major challenge. Quantum computing requires a high level of technical and scientific expertise, which is currently limited to a *niche of experts*. In summary, the quantum computing supply chain has enormous potential, but realizing it will require overcoming technical, manufacturing and training hurdles, as well as developing a more standardized and integrated ecosystem.

What are the main areas of application for quantum technology? Which markets are being targeted?

Quantum technologies are revolutionizing many sectors, offering unprecedented opportunities for innovation and competitiveness. Key areas of application include:

Quantum computing: Rapid advances are enabling complex problem solving, improved supply chains, drug discovery and materials innovation. Key sectors: aerospace, defence, finance and energy.

Quantum communications: With a focus on data security, Quantum Key Distribution (QKD) ensures unbreakable communications. Key sectors: defence, banking and critical infrastructure.

Quantum Sensing & Metrology: Enables precise measurements, benefiting aerospace, healthcare and energy. Quantum sensors improve imaging, environmental monitoring and resource exploration.

Quantum Simulation: Facilitates modelling of complex phenomena, driving materials innovation in semiconductors, batteries and alternative energy.

Quantum financial services: Improves portfolio management and risk analysis, giving financial institutions a competitive edge because quantum computers can process vast amounts of data much faster than classical systems.

Aerospace & Defence: Improving navigation, detection and security of military communications, with quantum radar and cryptography playing a key role.

In summary, quantum technologies are transforming industries from logistics to defence, and *public-private collaboration* will be essential to unlock their full potential.

Could you provide examples of real use cases?

QKD is useful in any scenario where confidentiality, security, and the ability to detect eavesdropping are paramount. The technology is particularly relevant for high-stakes environments where future-proofing against quantum computing threats is necessary. Here are several potential use case scenarios where QKD could be applied:

Data Centers Offsite Backup and Business Continuity: To assure business continuity, the primary site of a Datacentre could add a new centre ("Backup site") and regularly perform a remote backup of the primary site. In case of data loss at the primary site data is recovered from the secondary site.

Banks and financial institutions: QKD can ensure that sensitive financial data, such as transactions and client information, is exchanged securely between branches or during interbank communications.

Classified communications: Governments, defence agencies, and military organizations can use QKD to protect sensitive and classified information from being intercepted by foreign actors or malicious insiders.

Critical Infrastructure as Power grids, Water supplies, and other critical systems: QKD can be employed to safeguard communications in critical infrastructure systems, such as Supervisory Control and Data Acquisition (SCADA) systems, that control utilities. Securing these systems is crucial to prevent cyberattacks that could disrupt national infrastructure.

Hospitals and research institutions: The transmission of highly sensitive medical records and research data between hospitals, clinics, and research facilities can be protected with QKD.

During the *QUANCOM* project, *Exprivia* has developed two use cases:

In the *first use case*, two emerging standards, such as *ETSI-QKD* and *ETSI-MEC* (*Multiaccess Edge Computing*) have been integrated to ensure the security of the transmission of sensitive data in healthcare domain. In fact, a concrete application is the continuous monitoring of patients suffering from cardiovascular problems and the analysis of chest X-rays to diagnose diseases such as COVID or other pneumonias. In these scenarios, quantum cryptography ensures confidentiality and data integrity.

In the *second use case*, the development of *digital signatures using quantum cryptography* techniques has been implemented. As the traditional digital signature, based on asymmetric cryptographic schemes, is potentially vulnerable to future quantum computers, the technical and scientific community is exploring solutions to strengthen its security. One interesting strategy is to integrate Quantum Key Distribution (QKD) technology into the digital signature process. In healthcare, this technology can be used to securely sign assertions issued by authorized entities accessing the electronic health record and requesting interoperability services. Although quantum digital signature protocols are still under development and not very efficient, the combined use of classical and quantum techniques offers an improvement in security without disrupting the current infrastructure.

IT Svil

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"IT Svil promotes collaboration between research, industry and institutions as a key process for accelerating the development and adoption of innovative technologies such as quantum technologies. In fact, it has founded 2 spinoffs in collaboration with UNISA: INNOVA4TECH and X-For."

Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?
IT Svil constantly collaborates with both public and private research organizations as well as other private companies. In particular, for quantum research it collaborates with the *Department of Computer Science* of *Università degli Studi di Salerno* (UNISA) and the company *BC Soft srl*. For the future, the goal is to increase the collaboration with *UNISA* as an innovative project such as the realization of a quantum computer is envisioned.
Who are your direct competitors?
Our competitors are mainly private companies that want to apply quantum technology to areas such as cybersecurity or prediction of critical systems.
What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?
The main challenge concerns the deployment of services related to quantum technologies with particular reference to computing systems, which is why an increase in deep tech infrastructure is deemed necessary, resulting in lower costs and freedom of choice for providers.
What are the main areas of application for quantum technology? What are the target markets?
Our main areas of interest are: cybersecurity and prediction using QL techniques. *IT Svil* intends to approach the Digital Healthcare, Environment (i.e. pollution) and Utility sectors.
Can you provide examples of real use cases?
With reference to the utility market, a project is being implemented to predict power outages so that operators can develop responses well in advance.
Who are your current customers and what are your potential customers?
In relation to quantum technologies, *IT Svil* is in the investment phase and now cannot name customers who currently make use of this technology. Relatively to potential customers, the goal is to introduce quantum technologies to our current Digital Health customers.

Lutech

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"Lutech sees quantum technologies as the next frontier for accelerating AI, alongside High-Performance Computing systems. These technologies have the potential to transform security, optimization, and advanced modeling. To create sustainable

solutions for enterprise applications, collaboration with universities, startups, and technology partners is crucial. We are actively monitoring advancements in various technologies and working with Innovation Centers to identify and expedite emerging needs"

Description of the firm and mission:
Lutech is a leading European ICT company offering integrated solutions across cloud, cybersecurity, AI, and digital platforms. It supports clients through every phase of digital evolution—from advisory to implementation and operations.
With over 5,000 professionals, *Lutech* delivers tailored services for sectors such as energy, manufacturing, finance, and public administration. Its vertical and horizontal capabilities span smart grids, *ERP*, digital twins, and hyperautomation.
Lutech collaborates with top technology providers (e.g., *Microsoft*, *IBM*, *AWS*, *Nvidia*) and operates innovation hubs like the *Lutech Campus*, which fosters advanced R&D and talent development in emerging tech domains.
Does your company collaborate with other companies and research institutes? What potential future collaborations do you foresee?
Lutech is actively investing in Quantum Computing through strategic initiatives and partnerships.
Lutech explores quantum optimization for logistics, workforce scheduling, and post-quantum cryptography. It leverages platforms like *Eviden Qaptiva*, *IBM QISKIT*, *Pennylane* and contributes to standardization efforts via *NIST* and *NSA*. As a member of the European Quantum Industry Consortium (QuIC), *Lutech* promotes industrial applications of quantum technologies and develops training programs for future quantum professionals. We've been part part of *Politecnico di Milano Observatory* and through *Politecnico di Bari*, we are involved in PhD programs and joint research projects focused on quantum optimization and cryptography. A *Master in Quantum Science & Technology* was held to align internal competencies and explore next steps for collaboration.
Who are your direct competitors?
Other system integrators in Quantum Computing space.
What, in your opinion, can be an outlook for the quantum supply chain? What are the challenges?
The quantum supply chain is becoming a global ecosystem, demanding a mix of advanced capabilities from material science to precision engineering. A key challenge is developing fault-tolerant systems through robust hardware error correction, while also shrinking quantum components to make them scalable and practical. Progress depends on aligning innovation, manufacturing, and infrastructure to support reliable quantum technologies at scale.
What are the main areas of application for quantum technology? What are the target markets?
All contexts with highly complex mathematical problems (numerical and matrix computation acceleration, NP hard problems,…) e.g. minimization of routing functions, fulfilment, optimization of resources, simulation and prediction upon data to be generated synthetically. Target market are: logistic, pharma, finance and energy.
Can you provide examples of real use cases?
Neural networks optimization, molecular modelling, topological routing, fault location and isolation upon a complex network, global state optimization in structures.
Who are your current customers and what are your potential customers?
We're envisaging different industries with specific vertical use cases.

4.5 Quantum Simulation: the several challenges

Quantum simulators are highly controllable quantum devices that enable individuals to gain insights into the properties of intricate quantum systems or address specific computational challenges that are inaccessible to conventional computers (Johnson *et al.*, 2014). These machines could find applications in diverse domains such as quantum chemistry, nuclear physics, material science, fluid mechanics, logistics, routing, and, more broadly, optimization (see *box 25* and *box 26*). Specifically, in materials science, quantum simulation is useful in producing batteries, drugs, and catalysts.

Box 25. Quantum Simulation: the* European Patent Office *definition

Quantum simulation is the modelling of a complex quantum mechanical system by another system under controlled conditions to systematically study and predict the behaviour of the simulated system. *Quantum simulation is distinguished from universally programmable quantum computing, which is computing using quantum phenomena*. In contrast to what happens in a universally programmable quantum computer, *the relationships and interactions of individual elements in quantum simulators are determined by hardware structures*.

While a quantum computer executes a series of instructions, a model system is prepared in a quantum simulator in a particular state and then left to develop according to the laws of quantum mechanics under the conditions determined by the structure and the set-up of the simulator.

In a quantum simulator, there is no need for intervention during the time in which the model system develops. Accordingly, coherence problems are less complex to manage than in a universally programmable quantum computer.

Quantum simulators based on the laws of quantum physics may make it possible to overcome the shortcomings of conventional supercomputers. With these devices, the physical and chemical properties of complex structures and chemical compounds may be simulated, leading to new products and applications in the fields of pharmacy and chemistry and physics and engineering.[124]

Inventions directed to methods of simulation typically comprise features which fall under the category of mathematical methods. If patent protection was sought for these activities as such, i.e. without any technical aspect, they would be excluded from patent protection under the EPC. Methods related to quantum simulation are at least partially computer-implemented and do not fall under this exclusion criterion if they provide a further technical effect, i.e. have technical character.

The technical character of quantum simulation, as a specific kind of simulation, may be established by the interaction with an external physical entity at the input or output side of the simulation. The technical character may also be established by a specific implementation of the simulation, including hardware implementation, or by an intended technical use of simulation data. By contrast, calculated numerical data reflecting the physical state or the behaviour of a system or process existing only as a model in a computer (in the quantum simulator) usually cannot contribute to the technical character of the invention, even if it reflects the behaviour of the real system or process adequately. The technical or non-technical nature of features of the invention for which patent protection is sought also plays a role during the assessment of the inventive step. Applicants cannot rely on non-technical features to establish an inventive step, but these features may be used in formulating the objective technical problem to be used when the existence of an inventive step is assessed.

Source: extract from EPO, 2023b

There are several challenges faced by actors involved in the development of these technologies.

- *Co-design and Co-development*: Collaboration between industrial end users and quantum hardware/software manufacturers is key to rapidly creating quantum simulators that meet specific sectors' needs. Such co-development efforts are a central theme in projects

[124] *EPO* (2023b) suggests for further reading: J.P. Dowling and G.J. Milburn, "Quantum technology: the second quantum revolution", Philosophical Transactions of the Royal Society A 361, 2003, 1655-74; D. Hangleiter et al., "Analogue Quantum Simulation: A New Instrument for Scientific Understanding", Springer Cham, 2022; T.H. Johnson et al., "What is a quantum simulator?", EPJ Quantum Technology 1, 2014, 1-10.

like *HPCQS* (*High-Performance Computer and Quantum Simulator hybrid*), which integrates quantum technology with classical HPC systems to address scalability and integration issues (Mandrà *et al.*, 2021).

- *Verification, Certification, and Benchmarking*: Developing algorithms to ensure the reliability and accuracy of quantum simulators is an ongoing effort. Current studies emphasize the importance of benchmarking to compare quantum and classical simulations realistically (Altman *et al.*, 2021).
- *Control, Scalability, and Integration*: Improving hardware and system controls, integrating quantum simulators into high-performance computing (HPC) clusters, and enhancing scalability remain significant hurdles. Initiatives like the European Quantum Flagship and similar programs often highlight these goals to push the boundaries of quantum simulation (Mandrà *et al.*, 2021).
- *Hybrid Quantum-Classical Architectures*: Quantum simulators are increasingly being designed to work with classical computing systems, creating hybrid architectures that can solve complex problems beyond the reach of classical methods alone (Zhao, 2024).

Specifically, in *table 10*, Daley *et al.* (2022) summarize the state of the art and near-term prospects for simulation of quantum systems by classical, analogue quantum, and digital quantum simulators.

Table 10. The summary of the state of the art in simulation of quantum systems

	Classical Simulation	***Analogue Quantum Simulation***	***Digital Quantum Computing***
Platforms	Classical supercomputers	Neutral atoms (optical lattices or tweezer arrays), Ions, Superconducting systems, Quantum Dots, Photons,...	Neutral atoms (optical lattices or tweezer arrays), Ions, Superconducting systems, Quantum Dots, Photons,...
Universality	Yes (up to restricted system sizes or timescales) due to exponential scaling in time (and potentially memory)	Limited to available physical models	Yes (with error correction, requiring substantial scaling up from current systems)
Quantum advantage	No, and the cost grows exponentially with system size or simulation time	Regimes of practical quantum advantage are now for real scientific problems, with potential opportunities for industrial problems	Quantum primacy for specialized tasks, awaiting practical quantum advantage and eventually fault tolerance
Solvable models	Unrestricted models through the best available classical algorithms	Specific particle (Fermion or Boson) Hamiltonian, Spin Models (Qubits). Potentially, other mathematical problems that can be mapped onto these models	Broad classes of models, solved through algorithms for Quantum Simulation on a general-purpose quantum computer
System Size (2022)	< 50 spins computed exactly, or specialized short-time calculations for larger systems	Platform dependent up to 50-1000 particles or spins	Around 50 noisy qubits are presently available, but no fault-tolerant digital qubits yet

Scalability (Near term)	Exponentially difficult to scale to larger system sizes and longer times, except for specialized problems	Direct path to 103−104 particles within the next 2-3years	A few hundred in NISQ devices, the next step is to bring error-corrected qubits online

Source: Daley *et al.*, 2022.

The hardware technologies used for quantum simulators often overlap with those of quantum computing. Some major technologies include (Altman *et al.*, 2021):

- *Superconducting Circuits*: these are widely used in quantum computing and simulation for their robust qubit coherence times.
- *Ultracold Atomic and Molecular Quantum Gases*: Provide highly controllable systems for simulating many-body physics.
- *Optical Lattices and Tweezers*: Arrays of atoms manipulated with lasers to simulate quantum phenomena.
- *Trapped Ions*: Known for their precision and reliability in quantum state manipulation.
- *Photonic Systems*: Useful in certain types of quantum simulations, especially where light-matter interactions are key.

Box 26. Life sciences: some examples

According to *IBM*, quantum computing holds immense potential for the life science sector, particularly in addressing complex challenges like drug discovery, protein folding, and precision medicine. Classical computers struggle with the vast molecular possibilities and biological processes involved, but quantum systems can more effectively analyze and simulate these complexities.

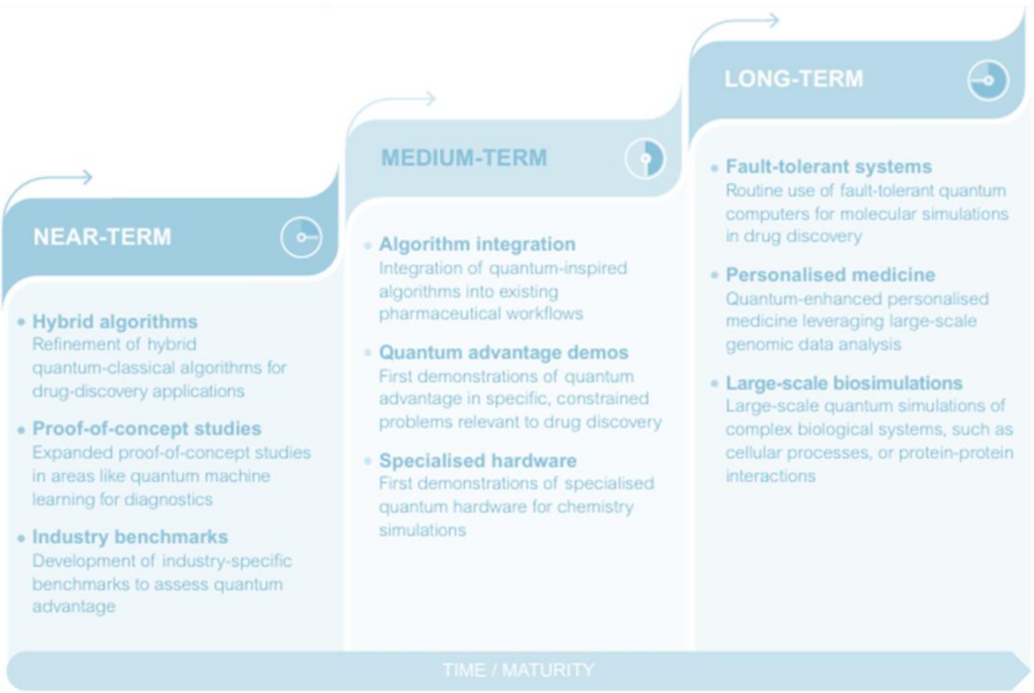
Quantum technologies offer powerful tools to tackle biological systems' complexity and computational challenges. They accelerate simulations, improve multi-scale models, and open new possibilities for studying biological networks and evolutionary processes (Pyrkov *et al.*, 2024).

Bayer plans to accelerate *in silico research* and development with *Google Cloud's high-speed processors* to perform large-scale quantum chemistry calculations. *Moderna* and *IBM* are collaborating to use generative artificial intelligence and quantum computing to advance the mRNA technology at the heart of the company's Covid vaccine (IQM *et al.*, 2024).

Variational quantum algorithms (VQA) can model multi-scale dynamics (Cordier *et al.*, 2022). Quantum computing is linked to the physics of spin glasses and self-organizing phenomena, which are useful for understanding evolutionary transitions in biological systems. Spin glasses, which feature states of frustration and competition, have been used to model biological processes such as aging. Quantum Ising machines, based on spin glass models, have been proposed as tools to solve complex problems in the biological science, overcoming classical computational limitations. Finally, biological networks, such as protein interaction networks, can be analyzed using quantum walks, which leverage quantum coherence to enhance information diffusion. This approach can lead to a better understanding of biological mechanisms and complex interactions, surpassing the limitations of classical methods.

Soon, quantum computing technology could enable patient-specific solutions that consider the unique characteristics of each patient. In fact, human DNA contains an astronomical amount of information that needs to be processed. Data analysis is only possible with powerful technology such as quantum computing. By processing this data, optimal genomic sequencing could be performed, allowing a better understanding of each case. F*igure 42* summarizes healthcare and pharma discovery trends, evidencing near, medium and long-term expected technological advances.

Figure 42. The Quantum Computing for healthcare and pharma: expected application progression trends



Source: *UKRI*, 2025.

Sybilla Biotech

Sybilla Biotech, an Italian biopharma innovator, integrates cutting-edge computational tools with biology to revolutionize drug discovery. Founded in 2017 as a spinoff of the Italian *National Institute for Nuclear Physics* (INFN), the *University of Trento*, and the *University of Perugia*, its creation stemmed from interdisciplinary research at the intersection of **quantum physics, molecular biology, and computational biochemistry**[125]. The leadership team, including co-founder and CEO **Lidia Pieri**, alongside physicists and biologists, pioneered the **PPI-FIT (Pharmacological Protein Inactivation by Folding Intermediates Targeting)** technology.

Sybilla adopts an innovative approach: PPI-FIT technology enables *Sybilla* to target **partially folded proteins**, focusing on transient intermediates in the protein folding process[126]. The technique addresses a longstanding challenge in drug discovery: targeting "undruggable" proteins, which traditional methods cannot efficiently tackle. By leveraging **quantum-inspired modeling**, Sybilla overcomes computational limitations that typically hinder the study of complex, time-sensitive protein structures. The company's first focus has been on cancer-related proteins such as **KRAS** and **Cyclin D1**, notorious for their resistance to conventional drug therapies.

[125] *Sybilla*. (2024). The story of our foundation. https://www.sibyllabiotech.it/our-story/
[126] *Sybilla*. (2024). PPI-FIT. https://www.sibyllabiotech.it/ppi-fit/

Sybilla Biotech secured **€23 million in Series A funding** in October 2022, marking one of Italy's most significant biotech investments. This funding, led by ***V-Bio Ventures***, included notable participants like *Seroba Life Science* and *3B Future Health Fund*. It is earmarked for:

- Expanding its computational drug discovery platform.
- Advancing its clinical pipeline of Folding Interfering Degraders (FIDs);
- Supporting the development of therapeutic applications in oncology[127].

Sybilla Biotech's computational platform shows the tangible impact of quantum-inspired methodologies in biotechnology:

Novelty: Quantum-based simulations facilitate understanding dynamic protein structures, bypassing traditional computational bottlenecks.

Precision Medicine: Their focus on drugging previously inaccessible targets exemplifies how quantum technologies can address unmet medical needs.

Cross-disciplinary Innovation: *Sybilla* demonstrates how quantum concepts can transform industries beyond physics, fostering molecular biology and healthcare breakthroughs.

Sybilla represents the cross-industry potential of quantum physics, showing its transformative application in solving complex problems like drug resistance and accelerating the pace of therapeutic development.

In May 2025, *Sybilla Biotech* appointed former *Bayer* CEO, Dieter Weinand, as Chairman of the Board of Directors. First statement of the pharmaceutical sector veteran were: "*Sibylla*'s unique approach to targeting protein degradation during the folding process has the opportunity to revolutionize this field and open new avenues for recognized but currently inaccessible targets across high-need diseases. The company has made strides in growing the organization, progressing its technology and securing strategic drug discovery collaborations. I look forward to working with the team to reach new corporate and clinical milestones".[128]

[127] Il *Sole24Ore*, Mo.D., "*Sibylla Biotech*, round da 23 milioni guidato da V-Bio Ventures", October 4th, 2022. https://www.ilsole24ore.com/art/sibylla-biotech-round-23-milioni-guidato-v-bio-ventures-AE1Ahh5B

[128] https://www.sibyllabiotech.it/dieter-weinand-new-chairman/

REFERENCES

Abbasi, Q.H, Weides, M., Li, C., & Imran, A. (2024). Dive into the Quantum Realm: Promise of Quantum Communication and What's Next!.
https://www.comsoc.org/publications/ctn/dive-quantum-realm-promise-quantum-communication-and-whats-next

AI4Business (2023), "Tecnologie quantistiche in Italia: oltre 140 milioni di euro dal PNRR", November 23rd 2023.
https://www.ai4business.it/quantum-computing/tecnologie-quantistiche-in-italia-oltre-140-milioni-di-euro-dal-pnrr/

Airbus. (2024). Quantum technologies. A potential game-changer in aerospace.
https://www.airbus.com/en/innovation/digital-transformation/quantum-technologies#:~:text=The%20Airbus%20Quantum%20Computing%20Challenge,Bristol's%20Quantum%20Technology%20Innovation%20Centre.

Alpine Quantum Technologies. (n.d.). AQT Overview.
https://www.aqt.eu/.

Altman, E., Brown, K. R., Carleo, G., Carr, L. D., Demler, E., Chin, C., ... & Zwierlein, M. (2021). Quantum simulators: Architectures and opportunities. PRX quantum, 2(1), 017003.
https://journals.aps.org/prxquantum/abstract/10.1103/PRXQuantum.2.017003

Arqit. (n.d.). Who We Are.
https://arqit.uk/who-we-are.

Arraut, I., Au, A., Tse, A. C. B., & Segovia, C. (2019). The connection between multiple prices of an Option at a given time with single prices defined at different times: The concept of weak-value in quantum finance. Physica A: Statistical Mechanics and its Applications, 526, 121028.
https://arxiv.org/abs/1905.05813

Aslam, N., Zhou, H., Urbach, E. K., Turner, M. J., Walsworth, R. L., Lukin, M. D., & Park, H. (2023). Quantum sensors for biomedical applications. Nature Reviews Physics, 5(3), 157-169.
https://pubmed.ncbi.nlm.nih.gov/36776813/

AWS. (n.d.). Rigetti Quantum Computers on AWS.
https://aws.amazon.com/it/braket/quantum-computers/rigetti/.

Banque de France. (2022). The Banque de France has successfully experimented with Cryptonext Security post-quantum security technologies.
https://www.banque-france.fr/en/espace-presse/communiques-bdf/la-banque-de-france-realise-avec-cryptonext-security-une-experimentation-de-securite-post-quantique

Berke C, Varvelis E, Trebst S, Altland A, DiVincenzo DP. Transmon platform for quantum computing challenged by chaotic fluctuations. Nat Commun. 2022 May 6;13(1):2495. doi: 10.1038/s41467-022-29940-y.
https://www.nature.com/articles/s41467-022-29940-y

Bayerstadler, A., Becquin, G., Binder, J., Botter, T., Ehm, H., Ehmer, T., ... & Winter, F. (2021). Industry quantum computing applications. EPJ Quantum Technology, 8(1), 25.
https://epjquantumtechnology.springeropen.com/articles/10.1140/epjqt/s40507-021-00114-x

BCG. (2023). Quantum Computing Is Becoming Business Ready.
https://www.bcg.com/publications/2023/enterprise-grade-quantum-computing-almost-ready

BlueQubit. (2024). Quantum Computing Hardware: Discover The New Era of Computing.
https://www.bluequbit.io/quantum-computing-hardware.

BOE. (2021). Real Decreto 936/2021, de 26 de octubre.
https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-17505#:~:text=A%2D2021%2D17505-,Real%20Decreto%20936%2F2021%2C%20de%2026%20de%20octubre%2C%20por,de%20Recuperaci%C3%B3n%2C%20Transformaci%C3%B3n%20y%20Resiliencia

Borowski, M., Gora, P., Karnas, K., Błajda, M., Król, K., Matyjasik, A., ... & Kutwin, M. (2020). New hybrid quantum annealing algorithms for solving vehicle routing problem. In International Conference on Computational Science (pp. 546-561). Cham: Springer International Publishing.
https://pmc.ncbi.nlm.nih.gov/articles/PMC7304725/

Bosch. (2023). Quantum technologies: Bosch aims to use sensors to take a leading position.
https://www.bosch-presse.de/pressportal/de/en/quantum-technologies-bosch-aims-to-use-sensors-to-take-a-leading-position-258816.html.

Bova, F., Goldfarb, A., & Melko, R. G. (2021). Commercial applications of quantum computing. EPJ Quantum Technology, 8(1), 2.
https://epjquantumtechnology.springeropen.com/articles/10.1140/epjqt/s40507-021-00091-1

Bürgler, B., Sjolander, T. F., Brinza, O., Tallaire, A., Achard, J., & Maletinsky, P. (2023). All-optical nuclear quantum sensing using nitrogen-vacancy centers in diamond. npj Quantum Information, 9(1), 56.
https://www.nature.com/articles/s41534-023-00724-6

Cao, Y., Zhao, Y., Wang, Q., Zhang, J., Ng, S. X., & Hanzo, L. (2022). The evolution of quantum key distribution networks: On the road to the qinternet. IEEE Communications Surveys & Tutorials, 24(2), 839-894.
https://eprints.soton.ac.uk/454194/1/COMST_00444_2021_final_manuscript.pdf

CDP. (2024). Quantum Finance. Una panoramica delle possibilità attuali e prospettive future.
https://www.cdp.it/resources/cms/documents/CDP_Studio_Quantum_Finance.pdf.

CEN-CENELEC. (2023a). Standardization Roadmap on Quantum Technologies.
https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Quantum%20technologies/Documentation%20and%20Materials/fgqt_q04_standardizationroadmapquantumtechnologies_release1.pdf

CEN-CENELEC. (2023b). Quantum Technologies Use Cases.
https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Quantum%20technologies/Documentation%20and%20Materials/fgqt_q05_quantumtechnologiesusecases_release1.pdf

Cohen W. M., Levinthal D. (1989), Innovation and learning: the two faces of R&D, *Economic Journal*, n. 99, 569-596.
https://www-jstor-org.libezproxy.open.ac.uk/stable/2233763

Cordier, B. A., Sawaya, N. P., Guerreschi, G. G., & McWeeney, S. K. (2022). Biology and medicine in the landscape of quantum advantages. Journal of the Royal Society Interface, 19(196), 20220541.
https://royalsocietypublishing.org/doi/10.1098/rsif.2022.054

Crunchbase News. (2023). Global Funding Data Analysis: AI EOY 2023.
https://news.crunchbase.com/venture/global-funding-data-analysis-ai-eoy-2023/

Daley, A. J., Bloch, I., Kokail, C., Flannigan, S., Pearson, N., Troyer, M., & Zoller, P. (2022). Practical quantum advantage in quantum simulation. *Nature*, 607(7920), 667-676.
https://doi.org/10.1038/s41586-022-04940-6

Debackere K., Veugelers R. (2005), The role of academic technology transfer organizations in improving industry science links, *Research Policy*, n. 34, 321-342.
https://doi.org/10.1016/j.respol.2004.12.003

Dijkstra, E. (2024). Quantum and Military Communication Security: An Analysis of the Opportunities, Risks, Implementation Challenges, and Prospects of Quantum Computing in Military Communication (Bachelor's thesis, University of Twente).
https://essay.utwente.nl/103094/

D-Wave Systems. (n.d.). D-Wave Announces General Availability of First Quantum Computer Built for Business. https://www.dwavesys.com/company/newsroom/press-release/d-wave-announces-general-availability-of-first-quantum-computer-built-for-business/.

Danish Quantum Community (2024). 16 Danish Quantum Use Cases: Practical Insights into Applications of Quantum Technologies Across Industries.
https://www.danskindustri.dk/brancher/di-digital/analysearkiv/brancheanalyser/2024/11/16-danish-quantum-use-cases/

DCG Academy. (2024). OVH launches quantum computer at data center in France.
https://www.datacenterdynamics.com/en/news/ovh-launches-quantum-computer-at-data-center-in-france/.

Degen, C. L., Reinhard, F., & Cappellaro, P. (2017). Quantum sensing. Reviews of modern physics, 89(3), 035002.
https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.89.035002

Dhankhar, R., Singh, N., & Nair, R. V. (2024). Probing the electronic ground state of the nitrogen-vacancy center in nanodiamonds at room temperature. Optik, 172038.
https://inspirehep.net/literature/2831411

Distriq. (2022). Quantum Sherbrooke Innovation Zone Officially Launches with Investments over $435M.
https://distriq.com/en/news/quantum-sherbrooke-innovation-zone-officially-launches-with-investments-over-435m.

EE Times. (2020). France Has a Quantum Plan.
https://www.eetimes.eu/france-has-a-quantum-plan/.

Eindhoven University of Technology (TU/e). (n.d.). Center for Quantum Materials and Technology Eindhoven.
https://www.tue.nl/en/research/research-groups/center-for-quantum-materials-and-technology-eindhoven?utm_source=google&utm_medium=cpc&campaignid=21332749115&adgroupid=&gad_source=1&gclid=CjwKCAjwvIWzBhAlEiwAHHWgvXCc4uNmx4pQlEBECgqAtSPlJaREZYrqZEyUY1rzs7EMWJFhvUwz5xoCCdMQAvD_BwE

ENI (2024). Nasce Eniquantic: la nuova società di Eni per lo sviluppo tecnologico del quantum computing.
https://www.eni.com/it-IT/media/comunicati-stampa/2024/07/cs-eniquantic.html.

Ephos. (2023). Ephos joins NATO's DIANA to build the essential infrastructure for Allied innovation in quantum technologies.
https://ephos.io/newsroom/ephos-joins-natos-diana-to-build-the-essential-infrastructurefor-allied-innovation-in-quantum-technologies/

EPO (2023a), European Patent Office (2023). Quantum computing: Insight report. Epo.org.
https://www.epo.org/en/searching-for-patents/business/patent-insight-reports

EPO (2023b), European Patent Office (2023). Quantum simulation: Insight report. Epo.org.
https://www.epo.org/en/searching-for-patents/business/patent-insight-reports

Euractiv. (2024). Europe's Quantum Tech Sees Rosy Outlook for 2024. https://www.euractiv.com/section/industrial-strategy/news/europes-quantum-tech-sees-rosy-outlook-for-2024-report-says/

European Commission, Draghi M. Report (2024), "The future of European competitiveness - Part B | In-depth analysis and recommendations", pp. 1-328.

https://commission.europa.eu/document/download/ec1409c1-d4b4-4882-8bdd-3519f86bbb92_en?filename=The%20future%20of%20European%20competitiveness_%20In-depth%20analysis%20and%20recommendations_0.pdf

European Commission. (2014): Directorate-General for Research and Innovation, Wellen, D., Vermeulen, E., Andersen, B., Dvorak, I. et al., *Boosting open innovation and knowledge transfer in the European Union – Independent expert group report on open innovation and knowledge transfer*, Publications Office, 2014, https://data.europa.eu/doi/10.2777/72620

European Commission (2016). Quantum Manifesto.
http://qurope.eu/system/files/u7/93056_Quantum%20Manifesto_WEB.pdf

European Commission. (2024). European Quantum Communication Infrastructure (EuroQCI). https://digital-strategy.ec.europa.eu/en/policies/european-quantum-communication-infrastructure-euroqci.

European Policy Centre (2023), "Quantum technologies and value chains: Why and how Europe must act now", G. E. Riekeles, Discussion Paper.
https://www.epc.eu/content/PDF/2023/Quantum_Technologies_DP.pdf

European Research Council. (2021). ERC frontier research contribution to e Europe fit for the digital age.
https://erc.europa.eu/sites/default/files/2022-08/H2020_factsheet_FitforDigitalAge.pdf

Ezratty O. (2024). Understanding Quantum Technologies. arXiv:2111.15352 Quant-Ph [Internet. 7th Edition].
[2111.15352] Understanding Quantum Technologies 2024

Faccia, A. (2020). Quantum Finance. Opportunities and threats.". *Information Technology innovations in Economics, Finance, Accounting, and Law*, *1*(8).
https://www.sciencedirect.com/science/article/pii/S2199853122007880

Feld, S., Roch, C., Gabor, T., Seidel, C., Neukart, F., Galter, I., ... & Linnhoff-Popien, C. (2019). A hybrid solution method for the capacitated vehicle routing problem using a quantum annealer. Frontiers in ICT, 6, 13.
FFG. (n.d.). Quantum Austria.
https://www.ffg.at/en/quantum-austria

Flöther, F., Christopher Moose, C, Tavernelli, I., Fraser, H., Pureswaran, V., (2020). Exploring quantum computing use cases for life sciences.
https://www.ibm.com/downloads/cas/EVBKAZGJ.

Forbes (2024). Eni investe nel quantum computing: nasce Eniquantic.
https://forbes.it/2024/07/16/eni-investe-quantum-computing-nasce-eniquantic/.

Garcell, E. (2024). The promise of quantum computing in manufacturing. https://www.smartindustry.com/benefits-of-transformation/advanced-control/article/55093883/the-promise-of-quantum-computing-in-manufacturing.

Gibney. E., (2024). This billion-dollar firm plans to build giant quantum computers from light. Can it succeed?. Nature.
https://pubmed.ncbi.nlm.nih.gov/39592790/

Gill, S.; Cetinkaya, O.; Marrone, S.; Claudino, D.; Haunschild, D.; Schlote, L.; Wu, H.; Ottaviani, C.; Liu, X.; Machupalli, S. P.; Kaur, K.; Arora, P.; Liu, J.; Farouk, A.; Song, H. H.; Uhlig, S.; Ramamohanarao, K. (2024). Quantum Computing: Vision and Challenges. Cornell University. ArXiv.
https://arxiv.org/abs/2403.02240

GlobeNewswire. (2023). Rigetti Computing Awarded Innovate UK Grant to Enhance Quantum Machine Learning Methods for Anti-Money Laundering Detection.
https://www.globenewswire.com/news-release/2023/11/01/2771203/0/en/Rigetti-Computing-Awarded-Innovate-UK-Grant-to-Enhance-Quantum-Machine-Learning-Methods-for-Anti-Money-Laundering-Detection.html

GlobeNewswire. (2024). Rigetti Computing Awarded Innovate UK Grant to Develop Quantum Machine Learning Techniques for Financial Data Streams.
https://www.globenewswire.com/news-release/2024/01/11/2807928/0/en/Rigetti-Computing-Awarded-Innovate-UK-Grant-to-Develop-Quantum-Machine-Learning-Techniques-for-Financial-Data-Streams.html.

Government of Canada. (2023). National Quantum Strategy.
https://ised-isde.canada.ca/site/national-quantum-strategy/en.

Government of Israel. (2022). IIA to Establish Israeli Quantum Computing Center. https://www.gov.il/en/pages/iia-to-establish-israeli-quantum-computing-center-17-jul-2022.

HPCwire. (2023). Poznan Supercomputing and Networking Center Partners with ORCA Computing for Quantum Photonic Systems Installation.
https://www.hpcwire.com/off-the-wire/poznan-supercomputing-and-networking-center-partners-with-orca-computing-for-quantum-photonic-systems-installation/.

Micro Photon Devices. (n.d.). Products.
http://www.micro-photon-devices.com/Products

Astrid. (n.d.). Quantum Technologies and Cybersecurity.
https://www.astrid-online.it/static/upload/yneo/yneojkda-tfr-quantum-technologies-and-cybersecurity.pdf

Politecnico di Milano. (n.d.). *Spinoff Details: Politecnico di Milano*
https://www.deib.polimi.it/ita/spinoff/dettagli/5

D-Wave Systems. (n.d.). *D-Wave Quantum Computing eBook*.
https://www.dwavesys.com/media/qlgj4hla/dwave_qc_ebook_v18c_0.pdf .

EuroQIC. (n.d.). *European Quantum Internet Alliance.*
https://www.euroquic.org/

IBM. (2022). Bosch Partnering with IBM on Strategic Quantum Computing Materials Science Engagement.
https://newsroom.ibm.com/2022-11-09-Bosch-Partnering-with-IBM-on-Strategic-Quantum-Computing-Materials-Science-Engagement

IBM. (2023). IBM Quantum DC Europe.
https://it.newsroom.ibm.com/Quantum-DC-Europe

IBM. (2024). Supply chain planning and analytics.
https://www.ibm.com/products/planning-analytics/supply-chain-planning?utm_content=SRCWW&p1=Search&p4=43700068108624254&p5=p&p9=587000075586.56354&gad_source=1&gclid=CjwKCAjwxY-3BhAuEiwAu7Y6s7HV8jeMLQq5LUlBJqcu3e4RqVgbCWk1_gxcEqHnOqNmMpnENp2esxoCE9MQAvD_BwE&gclsrc=aw.ds

Intelligence Online. (2024). France. Encryption startup CyferAll plans capital increase, banks on military networks.
https://www.intelligenceonline.com/surveillance--interception/2024/03/25/encryption-startup-cyferall-plans-capital-increase-banks-on-military-networks,110195468-art

IoT World Today. (2024). French Government Gives Nation Quantum Strategy Update.
https://www.iotworldtoday.com/quantum/french-government-gives-nation-quantum-strategy-update

IQM, Ocean & Likestar. (2024). State of Quantum 2024: Understanding the 2023 Trends and Outlook for 2024.
https://www.meetiqm.com/newsroom/press-releases/state-of-quantum-report-2024.

Ireland Quantum Strategy
https://www.gov.ie/ga/foilsiuchan/126b4-quantum-2030-a-national-quantum-technologies-strategy-for-ireland/

Jain, S. (2021). Solving the traveling salesman problem on the d-wave quantum computer. Frontiers in Physics, 9, 760783.
https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2021.760783/full

Jaksch, D., Givi, P., Daley, A. J., & Rung, T. (2023). Variational quantum algorithms for computational fluid dynamics. AIAA journal, 61(5), 1885-1894.
https://arxiv.org/abs/2209.04915

Ji, W., Liu, Z., Guo, Y., Hu, Z., Zhou, J., Dai, S., ... & Du, J. (2024). Correlated sensing with a solid-state quantum multisensor system for atomic-scale structural analysis. Nature Photonics, 1-6.
https://www.nature.com/articles/s41566-023-01352-4

Johnson, T. H., Clark, S. R., & Jaksch, D. (2014). What is a quantum simulator?. EPJ Quantum Technology, 1, 1-12.
https://epjquantumtechnology.springeropen.com/articles/10.1140/epjqt10

Kastuar, S. M., & Ekuma, C. E. (2024). Chemically tuned intermediate band states in atomically thin Cu x GeSe/SnS quantum material for photovoltaic applications. *Science Advances*, *10*(15), eadl6752.
https://epjquantumtechnology.springeropen.com/articles/10.1140/epjqt10

Kaur, M., & Venegas-Gomez, A. (2022). Defining the quantum workforce landscape: a review of global quantum education initiatives. Optical Engineering, 61(8), 081806-081806.
https://arxiv.org/abs/2202.08940

Kim, S. (2023). South Korea to Inject More than $2.3 Billion in Quantum Science, Tech by 2035. The Korea Economic Daily.
https://www.kedglobal.com/tech,-media-telecom/newsView/ked202306270025#:~:text=South%20Korea%20will%20pour%20more,country%20between%202019%20and%202023.

Krishnan, P. (2023). Integrating Quantum Model Computing With Machine Learning: Quantum Algorithms For Accelerating Ai Model Training. Well Testing Journal, 32(2), 44-73.
https://welltestingjournal.com/index.php/WT/article/view/IntegratingQuantumModelComputingWithMachineLearningQuantumAlgori

Kung, H. & Fancy, S. (2021). A Quantum Revolution: Report on Global Policies for Quantum Technology. Cifar.
https://cifar.ca/wp-content/uploads/2021/05/QuantumReport-EN-May2021.pdf.

La Stampa. (2024). ENI accelera sul quantum computing: nasce Eniquantic.
https://finanza.lastampa.it/News/2024/07/15/eni-accelera-sul-quantum-computing-nasce-eniquantic/NzdfMjAyNC0wNy0xNV9UTEI.

Law, S. (2023). Why quantum materials are the answer to our energy transmission and data storage challenges.
https://iee.psu.edu/news/blog/why-quantum-materials-are-answer-our-energy-transmission-and-data-storage-challenges.

LevelQuantum. (n.d.). Technology.
https://www.levelquantum.eu/en/technology/.

LevelQuantum. (n.d). levelQuantum selected by NATO for DIANA program.
https://www.levelquantum.eu/en/levelquantum-selected-by-nato-for-diana-program/.

Li, X., Jones, A.C., Choi, J. et al. Proximity-induced chiral quantum light generation in strain-engineered WSe2/NiPS3 heterostructures. Nat. Mater. 22, 1311–1316 (2023).
https://doi.org/10.1038/s41563-023-01645-7

LuxQuanta.(2024). LuxQuanta presenta l'interoperabilità nella demo QKD multi-vendor alla fiera ECOC.
https://www.luxquanta.com/luxquanta-showcases-interoperability-in-multi-vendor-qkd-demo-at-ecoc-exhibition-n-70-en

Lv, Z., Cheng, C., & Song, H. (2022). Digital twins based on quantum networking. *Ieee Network, 36(5), 88-93.* https://ieeexplore.ieee.org/document/9963997

Madje, U. P., & Pande, M. B. (2024, March). A Conceptual Model of Quantum Cryptography Techniques used to Provide Online Banking Transactions Security. In 2024 International Conference on Trends in Quantum Computing and Emerging Business Technologies (pp. 1-5). IEEE.
https://ieeexplore.ieee.org/document/10545237

Mandrà, S., Marshall, J., Rieffel, E. G., & Biswas, R. (2021, November). HybridQ: a hybrid simulator for quantum circuits. In 2021 IEEE/ACM Second International Workshop on Quantum Computing Software (QCS) (pp. 99-109). IEEE.
https://arxiv.org/abs/2111.06868

McKinsey. (2021). Quantum Computing: An emerging ecosystem and industry use cases.
https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20computing%20use%20cases%20are%20getting%20real%20what%20you%20need%20to%20know/quantum-computing-an-emerging-ecosystem.pdf

McKinsey. (2023). Quantum Technology Monitor.
https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20technology%20sees%20record%20investments%20progress%20on%20talent%20gap/quantum-technology-monitor-april-2023.pdf

McKinsey. (2024a). Quantum Sensing: Poised to Realize Immense Potential in Many Sectors.
https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/tech-forward/quantum-sensing-poised-to-realize-immense-potential-in-many-sectors

McKinsey. (2024b). Steady progress in approaching the quantum advantage.
https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/steady-progress-in-approaching-the-quantum-advantage

McKinsey, Digital, (2025). Quantum communication: Trends and outlook.
https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-communication-growth-drivers-cybersecurity-and-quantum-computing

McKinsey. (2025). Quantum Technology Monitor. https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025

Meta, F. (2024). Open Fiber in campo con il progetto Rigoletto. Carpentieri: “Tecnologie in grado di garantire sicurezza ed efficienza”. Ecco come funzionano.
https://www.corrierecomunicazioni.it/telco/banda-ultralarga/fibra-e-quantum-key-distribution-accoppiata-vincente-per-le-reti-del-futuro/

Mulligan, V. K., Melo, H., Merritt, H. I., Slocum, S., Weitzner, B. D., Watkins, A. M., ... & Bonneau, R. (2019). Designing Peptides on a Quantum Computer. BioRxiv, 752485.
https://www.biorxiv.org/content/10.1101/752485v1

MUR (2020). Programma Nazionale per la Ricerca 2021-2027 (PNR 2021-27).
https://www.mur.gov.it/it/aree-tematiche/ricerca/programmazione/programma-nazionale-la-ricerca

MUR, MIMIT, 2025. Strategia Italiana per le Tecnologie Quantistiche (WIP, Under Public Consultation).
https://www.mur.gov.it/it/strategia-italiana-le-tecnologie-quantistiche

MUR, MIMIT, Osservatorio Quantum Computing and Communication (2025). Ecosistema industriale italiano delle tecnologie quantistiche. Analisi dei risultati della consultazione pubblica condotta dal Ministero delle imprese e del Made in Italy.

https://www.mimit.gov.it/it/normativa/notifiche-e-avvisi/onsultazione-pubblica-in-materia-di-tecnologie-quantistiche

OECD (2011), *TTOs. Roles Performed*, OECD Innovation Platform.
http://www.oecd.org/innovation/policyplatform/48136121.pdf

OECD (2013), *Commercialising Public Research: New Trends and Strategies*, OECD Publishing.
http://dx.doi.org/10.1787/9789264193321-en

OECD (2019), *University-Industry Collaboration: new evidence and policy options*, OECD Publishing.
http://www.oecd.org/fr/innovation/university-industry-collaboration-e9c1e648-en.htm

National Quantum Computing Centre (NQCC). (n.d.). About NQCC.
https://www.nqcc.ac.uk/.

National Research Council Canada. (n.d.). Internet of Things: Quantum Sensors Challenge Program.
https://nrc.canada.ca/en/research-development/research-collaboration/programs/internet-things-quantum-sensors-challenge-program.

National Science Foundation. (n.d.). About NSF.
https://new.nsf.gov/about#:~:text=The%20U.S.%20National%20Science%20Foundation,national%20health%2C%20prosperity%20and%20welfare.

NATO. (2019). NATO's Quantum Technology Initiatives.
https://www.nato.int/cps/en/natohq/news_165733.htm?selectedLocale=en

Niosi, J. (2000). Science-based Industries: A New Schumpeterian Taxonomy, *Technology and Society,* 22, pp. 429-444.
https://doi.org/10.1016/S0160-791X(00)00028-2

Nuvvula, R. S., Devaraj, E., Elavarasan, R. M., Taheri, S. I., Irfan, M., & Teegala, K. S. (2022). Multi-objective mutation-enabled adaptive local attractor quantum behaved particle swarm optimisation based optimal sizing of hybrid renewable energy system for smart cities in India. Sustainable Energy Technologies and Assessments, 49, 101689.
https://www.sciencedirect.com/science/article/abs/pii/S2213138821007037

OpenFiber.(2024). Un'infrastruttura per la trasformazione digitale. https://openfiber.it/app/uploads/2023/06/B2B-Activities-portfolio.pdf.

OpenQKD. (2024). Who we are.
https://webmagazine.unitn.it/evento/dphys/14739/progetto-qtn-quantum-science-and-technology-in-trento.

Orrell, D. (2020). Quantum-tative Finance. Wilmott, 2020(106), 16-23.
https://onlinelibrary.wiley.com/doi/abs/10.1002/wilm.10829

Orús, R., Mugel, S., & Lizaso, E. (2019). Quantum computing for finance: Overview and prospects. Reviews in Physics, 4, 100028.
https://www.sciencedirect.com/science/article/pii/S2405428318300571

Paudel, H. P., Lander, G. R., Crawford, S. E., & Duan, Y. (2024). Sensing at the Nanoscale Using Nitrogen-Vacancy Centers in Diamond: A Model for a Quantum Pressure Sensor. Nanomaterials 2024, 14, 675.
https://www.mdpi.com/2079-4991/14/8/675

Perazzo, P., Di Matteo, S., Dini, G., & Saponara, S. (2024). On hardware acceleration of quantum-resistant FOTA systems in automotive. Computers and Electrical Engineering, 118, 109327.
https://www.sciencedirect.com/science/article/pii/S0045790624002556

Photonics. (2023). Photonic Raises $100M for Quantum Technology. https://photonic.com/news/photonic-raises-100m-for-quantum-technology/.

Photonics. (n.d.). Xanadu Brings Quantum Advantage to the People.
https://www.photonics.com/Articles/Xanadu_Brings_Quantum_Advantage_to_the_People/a68070.

Planetek (2024). Azienda.
https://www.planetek.it/azienda/chi_siamo/profilo.

Planetek (2024). Qu3d - Quantum 3D Imaging at high speed and high resolution.
https://www.planetek.it/progetti/qu3d_quantum_3d_imaging_at_high_speed_and_high_resolution.

Pupillo, L., Ferreira, A., Lipiainien, V. and Polito, C. (2023), Quantum Technologies and Cybersecurity: Technology, governance and policy challenges, Task Force Report, Centre for European Policy Studies (CEPS), Brussels. ISBN 978-94-6138-793-6
https://cdn.ceps.eu/wp-content/uploads/2023/12/CEPS-TFR-Quantum-Technologies-and-Cybersecurity.pdf

Pyrkov, A., Aliper, A., Bezrukov, D., Podolskiy, D., Ren, F., & Zhavoronkov, A. (2024). Complexity of life sciences in quantum and AI era. *Wiley Interdisciplinary Reviews: Computational Molecular Science*, *14*(1), e1701.
https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wcms.1701

Q-*CTRL*. (2023). Q-CTRL Adds Morpheus Ventures to Record-Setting Series B Funding Round.
https://q-ctrl.com/blog/q-ctrl-adds-morpheus-ventures-to-record-setting-series-b-funding-round-with-total-of-54-million-usd-raised.

QCI Hungary. (n.d.). Quantum Technology in Hungary.
https://qcihungary.hu/en/home/

QED-C, Quantum Economic Development Consortium, (2025). State of the Global Quantum Industry.
https://quantumconsortium.org/quantum-marketplace/

Qi, H., Wang, L., Gong, C., & Gani, A. (2024). A survey on quantum data mining algorithms: challenges, advances and future directions. Quantum Information Processing, 23(3), 74.
https://link.springer.com/article/10.1007/s11128-024-04279-z

Qpic1550. (n.d). About.
https://www.qpic1550-project.eu/about/.

Quandela. (n.d.). Quandela Applications in Pharmaceuticals.
https://www.quandela.com/applications/4-pharmaceuticals/.

Quantera. (2023). Quantum Technologies. Public Policies in Europe.
https://quantera.eu/quantum-technologies-public-policies-2023/

Quantum Computing Lab. (2023). Germany's Action Plan for Quantum Technologies.
https://www.quantumcomputinglab.cineca.it/en/2023/05/09/germanys-action-plan-for-quantum-technologies/

Quantum Delta NL. (2024). Quantum Technologies and their Global Impact. Discussion Paper, Digital Transformation Dialogue, Pieter Vermaas and Ulrich Mans.

Quantum Delta NL. (2023). White Paper. Mapping Quantum Supply Chains. Towards European technology sovereignty in an emerging industry.
https://quantumdelta.nl/news/white-paper-mapping-the-supply-chains-for-quantum-communication

Quantum Delta NL. (2023). White Paper. Mapping the Supply Chain for Quantum Communications.
https://quantumdelta.nl/news/white-paper-mapping-the-supply-chains-for-quantum-communication

Quantum Delta NL. (n.d.). Delft Hub.
https://quantumdelta.nl/delft-hub

Quantum Flagship. (2020). Strategic Research Agenda.
https://qt.eu/publications

Quantum Flagship. (2022). Research and Industry Agenda.
https://qt.eu/publications

Quantum Flagship. (2024). Strategic Research and Industry Agenda 2030.
https://qt.eu/publications

Quantum Flagship. (n.d.). About Quantum Flagship.
https://qt.eu/about-quantum-flagship/

Quantum Flagship. (n.d.). QuCats Project.
https://qt.eu/projects/csa-projects/qucats

Quantum Life Science. (n.d.). About Quantum Life Science.
https://quantumlifescience.se/about/

Quantum Telecommunications Italy. (2024). I sistemi QKD di QTI per proteggere le comunicazioni al vertice del G7 2024.
https://www.qticompany.com/qtis-qkd-systems-to-secure-communications-at-the-g7-summit-2024/.

Quantum Telecommunications Italy. (2024). I sistemi QKD di QTI per proteggere le comunicazioni al vertice del G7 2024.
https://www.qticompany.com/qtis-qkd-systems-to-secure-communications-at-the-g7-summit-2024/.

Quantum Telecommunications Italy. (n.d). Products.
https://www.qticompany.com/products/.

Quantum Telecommunications Italy. (n.d). Who we are.
https://www.qticompany.com/who-we-are-qti/.

Quantum Telecommunications Italy. (n.d). Who we are.
https://www.qticompany.com/who-we-are-qti/.

Quantumnet. (2023). Home.
https://www.quantum-net.it/it/

Quantumnet. (2023). QuantumNet al Quantum Business Europe 2023.
https://www.quantum-net.it/it/quantumnet-al-quantum-business-europe-2023/

QUIC (European Quantum Industry Consortium) 2024, Report, "A Portrait of the Global Patent Landscape in Quantum Technologies"
:https://www.euroquic.org/new-white-paper-release-insights-from-quic-on-the-global-patent-landscape-in-quantum-technologies/

QURECA. (2023). Making European Industry Quantum Ready.
https://www.qureca.com/qtindu-making-european-industry-quantum-ready/

QuTech. (2015). Investment in Quantum Technology. https://qutech.nl/2015/06/01/investmentquantumtechnology

Rappert B., Webster A., Charles D. (1999), Making sense of diversity and reluctance: academic-industrial relations and intellectual property, *Research Policy*, n. 28, 873-890.
https://www.sciencedirect.com/science/article/abs/pii/S0048733399000281

Reuters. (2023). French Quantum Computer Startup PASQAL Raises 100 Million Euros. https://www.reuters.com/technology/french-quantum-computer-startup-pasqal-raises-100-million-euros-2023-01-24/.

Rigetti Computing. (2024a). Quantum-Enhanced Machine Learning with Moody's Analytics. https://medium.com/rigetti/quantum-enhanced-machine-learning-with-moodys-analytics-543d37df0549

Rigetti Computing. (2024b). Rigetti Expands QCS™ Availability on Microsoft's Azure Quantum. https://investors.rigetti.com/news-releases/news-release-details/rigetti-expands-qcstm-availability-microsofts-azure-quantum

Safari, A., & Ghavifekr, A. A. (2022). Quantum technology & quantum neural networks in Smart Grids control: premier perspectives. In 2022 8th International Conference on Control, Instrumentation and Automation (ICCIA) (pp. 1-6). IEEE.
https://ieeexplore.ieee.org/document/9737203

Roland Berger. (2024). Quantum Technologies – Ready for take-off at last?. https://www.rolandberger.com/en/Insights/Publications/Quantum-Technologies-Ready-for-take-off-at-last.html

Singh, J., & Bhangu, K. S. (2023). Contemporary quantum computing use cases: taxonomy, review and challenges. Archives of Computational Methods in Engineering, 30(1), 615-638.
https://link.springer.com/article/10.1007/s11831-022-09809-5

SIPRI (*Stockholm International Peace Research Institute,* 2025), "Military and Security Dimensions of Quantum Technologies: a Primer", M. Krelina.
https://www.sipri.org/publications/2025/other-publications/military-and-security-dimensions-quantum-technologies-primer

State Secretariat for Education, Research and Innovation (SERI). (n.d.). Swiss Quantum Initiative. https://www.sbfi.admin.ch/sbfi/it/home/ricerca-e-innovazione/ricerca-e-innovazione-in-svizzera/sqi.html

Swiss Quantum Initiative (n.d.). The Swiss Quantum Initiative (SQI).
https://quantum.scnat.ch/en

Swissnex. (2024). Switzerland: A Hub for Quantum.
https://portal-cdn.scnat.ch/asset/d33dfe3b-49c9-5130-8f8a-029d6b4b36cd/Switzerland-A-Hub-for-Quantum.pdf?b=ac850fa6-0455-5469-9aa3-91293eb64c0a&v=e72fc8c7-e298-55e8-b5d0-28e4a670fbe4_0&s=fkgIXnriYG4yo-ch4Gzp0amwqdQZB_ZtPBjCAylehiQRpiJUZHFHTU6jgjiqQinSAMy0czVvoGqh2Zjy8rfamYA7xeC6CvMmEkG4S_8WNu8QzWfLkdDfAlZWjjqz9FjR3IyjyRFdCGoPqmF1pTjlweOr9eTs3jU1g0gqKMXCXwY

TechHQ. (2022). IBM Just Unveiled Its Most Powerful Quantum Computer Yet—A 433-Qubit Machine.
https://techhq.com/2022/11/ibm-just-unveiled-its-most-powerful-quantum-computer-yet-a-433-qubit-machine/#:~:text=IBM%20just%20unveiled%20its%20most%20powerful%20quantum%20computer%20yet%20%E2%80%94%20a,Eagle%20processor%20unveiled%20in%202021.&text=IBM%20intends%20to%20scale%20up,qubits%20by%202025%20and%20beyond.

Terra Quantum. (2023). Terra Quantum Breaks Records in Quantum Key Distribution.
https://terraquantum.swiss/news/terra-quantum-breaks-records-in-quantum-key-distribution-paving-way-to-offering-unprecedented-security-over-existing-fiber-optic-networks-globally#:~:text=Terra%20Quantum%20successfully%20sent%20quantum,second)%20(arXiv%20Paper.

The Quantum Insider. (2024). French National Quantum Update.
https://thequantuminsider.com/2024/03/29/french-national-quantum-update-march-2024/#:~:text=The%20French%20Quantum%20Strategy%20is,million%20comes%20from%20private%20investors

The Quantum Insider. (2024). PASQAL Announces New Roadmap Focused On Business Utility And Scaling Beyond 1,000 Qubits Towards Fault Tolerance Era.

https://thequantuminsider.com/2024/03/12/pasqal-announces-new-roadmap-focused-on-business-utility-and-scaling-beyond-1000-qubits-towards-fault-tolerance-era/

The Quantum Insider. (2024). South Korea Sets Stage for Technological Revolution with Quantum Computing Initiatives.
https://thequantuminsider.com/2024/02/19/south-korea-sets-stage-for-technological-revolution-with-quantum-computing-initiatives/.

Times of Israel. (2022). Defense Ministry Innovation Authority to Fund Israel's First Quantum Computer.
https://www.timesofisrael.com/defense-ministry-innovation-authority-to-fund-israels-first-quantum-computer/.

TU/e. (2021). Quantum Delta NL Awarded 615 Million Euro from Netherlands National Growth Fund to Accelerate Quantum Technology.
https://www.tue.nl/nieuws-en-evenementen/nieuwsoverzicht/09-04-2021-quantum-delta-nl-awarded-615-million-euro-from-netherlands-national-growth-fund-to-accelerate-quantum-technology

U.S Department of State. (2023). Joint Statement of the United States of America and France on Cooperation in Quantum Information Science and Technology.
https://www.state.gov/joint-statement-of-the-united-states-of-america-and-france-on-cooperation-in-quantum-information-science-and-technology/

UFM. (2023). Government's Billion Investment Strategy for Quantum Technology.
https://ufm.dk/aktuelt/pressemeddelelser/2023/regeringen-klar-til-milliardinvestering-som-led-i-ny-strategi-for-kvanteteknologi

UK National Quantum Technologies Programme. (n.d.). UK Quantum Technology Sensors.
https://uknqt.ukri.org/our-programme/#:~:text=The%20UK%20Quantum%20Technology%20Sensors,the%20UK%20quantum%20technology%20community.

UKRI, National Quantum Computing Centre, 2025. The convergence of healthcare and pharmaceuticals with quantum computing: A new frontier in medicine. Insights papers.
https://www.nqcc.ac.uk/quantum-computing-for-healthcare-and-pharmaceuticals/

United Nations (*UN*). (2024). The Pact for the Future, Global Digital Compact, and Declaration on Future Generations.
https://www.un.org/sites/un2.un.org/files/sotf-the-pact-for-the-future.pdf

United Nations Educational, Scientific and Cultural Organization (*UNESCO*). (2024). Quantum technologies and their global impact: A Discussion Paper.
https://unesdoc.unesco.org/ark:/48223/pf0000388955

United Nations Educational, Scientific and Cultural Organization (*UNESCO*). (2023). "Your opinion doesn't matter, anyway: Exposing Technology-Facilitated Gender-Based Violence in an Era of Generative AI".
https://unesdoc.unesco.org/ark:/48223/pf0000387483/PDF/387483eng.pdf.multi

United Nations Conference on Trade and Development (*UNCTAD*). (2021). Technology and Innovation Report 2021.
https://unctad.org/page/technology-and-innovation-report-2021

United Nations University (*UNU*) (2023). The High-Level Advisory Board on Effective Multilateralism (HLAB). A Breakthrough for People and Planet: Effective and Inclusive Global Governance for Today and the Future.
https://highleveladvisoryboard.org/breakthrough/pdf/highleveladvisoryboard_breakthrough_Shift1.pdf

University of Copenhagen. (2016). Massive Investment from Theoretical Quantum Physics to Usable Quantum Technology.
https://nbi.ku.dk/english/news/news16/massive-investment-from-theoretical-quantum-physics-to-usable-quantum-technology/.

University of Copenhagen. (2020). Tomorrow's Pharmaceuticals Could Be Discovered by Quantum Simulators. https://science.ku.dk/english/press/news/2020/tomorrows-pharmaceuticals-could-be-discovered-by-quantum-simulators/

University of Copenhagen. (n.d.). Field-Ready Single-Photon Quantum Technology. https://nbi.ku.dk/english/industrial-collaboration-at-nbi/cases/fire-q-field-ready-single-photon-quantum-technology/

van Daalen, O. (2024). Developing a human rights compatible governance framework for quantum computing. Research Directions: Quantum Technologies, 2, e1. doi:10.1017/qut.2024.2

van Deventer, O., Spethmann, N., Loeffler, M. *et al.* Towards European standards for quantum technologies. *EPJ Quantum Technol.* 9, 33 (2022).
https://doi.org/10.1140/epjqt/s40507-022-00150-1

Vermaas, P., & Mans, U.(2024). Quantum technologies and their global impact: discussion paper. UNESCO, Quantum Delta (Netherlands), & Centre for Quantum and Society. Digital transformation dialogue, Paris,https://unesdoc.unesco.org/ark:/48223/pf0000388955

Vinnova. (2023). The Swedish Quantum Agenda. https://www.vinnova.se/globalassets/bilder/publikationer/the-swedish-quantum-agenda.pdf?cb=20230328130156.

VTT Technical Research Centre of Finland. (2023). Finland Launches 20-Qubit Quantum Computer Development. https://www.vttresearch.com/en/news-and-ideas/finland-launches-20-qubit-quantum-computer-development-towards-more-powerful-quantum.

Warren, R. H. (2020). Solving the traveling salesman problem on a quantum annealer. SN Applied Sciences, 2(1), 75. *https://link.springer.com/article/10.1007/s42452-019-1829-x*

Webwire. (2024). Post-quantum cryptography: six French cyber players join forces to design the secure communication networks of tomorrow.
https://www.webwire.com/ViewPressRel.asp?aId=319363.

Wired. (2024). 10 startup italiane da seguire nel 2024.
https://www.wired.it/gallery/startup-italia-10-2024-intelligenza-artificiale/

Wu, Y., Wang, Y., Ye, X., Liu, W., Niu, Z., Duan, C. K., ... & Du, J. (2024). Third-order exceptional line in a nitrogen-vacancy spin system. Nature Nanotechnology, 19(2), 160-165.
https://www.nature.com/articles/s41565-023-01583-0

Yan, R., Wang, Y., Dai, J., Xu, Y., & Liu, A. Q. (2022). Quantum-key-distribution-based microgrid control for cybersecurity enhancement. IEEE Transactions on Industry Applications, 58(3), 3076-3086.
https://ieeexplore.ieee.org/document/9735409

Ye, J., & Zoller, P. (2024). Essay: Quantum Sensing with Atomic, Molecular, and Optical Platforms for Fundamental Physics. Physical Review Letters, 132(19), 190001.
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.132.190001

YoleGroup (2021). Industrial interest in quantum technologies continues, leading to major investments and a large market in 5-10 years.
https://medias.yolegroup.com/uploads/2021/06/YINTR21211-Quantum-Technologies-2021-Flyer.pdf

YoleGroup. (2024). Quantum winter? Not so sure. Each year continues to see newcomers emerging, but everyone hopes to see a commercial use case soon, leveraging the $2.3B opportunity by 2030.
https://www.yolegroup.com/product/report/quantum-technologies-2024/

World Economic Forum (WEF). (2022). Quantum Computing Governance Principles. https://www3.weforum.org/docs/WEF_Quantum_Computing_2022.pdfWEF (2024). Quantum Economy Blueprint 2024. https://www3.weforum.org/docs/WEF_Quantum_Economy_Blueprint_2024.pdf

World Economic Forum (2024), Report, “Quantum for Society: Meeting the Ambition of the SDGs”. https://www3.weforum.org/docs/WEF_Quantum_for_Society_2024.pdf

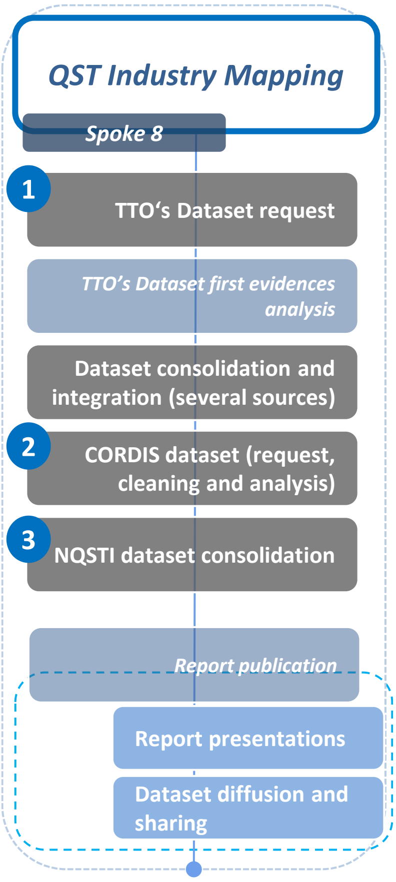
World Economic Forum (2025), Report, “Embracing the Quantum Economy: A Pathway for Business Leaders”. https://reports.weforum.org/docs/WEF_Embracing_the_Quantum_Economy_2024.pdf

Zhao, R. X., Shi, J., & Li, X. (2024). QKSAN: A quantum kernel self-attention network. IEEE Transactions on Pattern Analysis and Machine Intelligence.
https://ieeexplore.ieee.org/document/10613453

APPENDIX 1 - METHODOLOGICAL NOTE

Several purposes drove creation of the database of firms that operate inside QST. In particular:

1. *to investigate firms that effectively conduct research and production projects, utilizing QST properties;*
2. *to draw up a list of firms representative of the national QST business world;*
3. *to enlarge as much as possible the sample of organizations considered (as for geographical scope, as for sectors involved);*
4. *to gather up-to-date information about the organizations considered;*
5. *to have a set of variables on which to draw some first considerations.*



It is possible to recognize several different steps in sampling. At the beginning of the *NQSTI* project, the author tried to define first reliable sources for the extraction of the firms interested in the research (TTOs' partnerships, scientific literature, economic and consulting reports, newspapers' articles, participation in Conferences and Technological Fairs).

Then the main activity was the definition of the QST activity of the organizations (product and services offered, or research project conducted). The third stage of the investigation was the collection and consolidation of the data and variables for all the firms of the sample and, finally, the elaboration of the first results. All the research activities have been developed between January 2023 and March 2025. In particular, it is possible to identify three specific phases in the collection of information on the QST companies.

Phase 1— the Technology Transfer Organizations panel

To start Quantum Science and Technology analyses in the Italian context, we begin collecting Information on the research collaborations put in place by all the partners participating in *Spoke 8* (15 TTOs)[129]. We started investigating companies that already cooperate or are about to start joint research and development projects with universities, EPRs, and foundations that are part of the *NQSTI* Extended Partnership. Obviously, we considered only companies that consider fields of applied research within the QST sectors and wanted to collaborate in these specific

[129] 15 are the organizations participating to *NQSTI* Spoke 8 "TT" are: *CNR- National Research Council, University of Naples – Federico II, Bruno Kessler Foundation, IIT - Italian Institute of Technology, Scuola Superiore Sant'Anna, Scuola Normale Superiore, University of Catania, University of Pavia, University of Padova, INFN – National Institute of Nuclear Physics, University Milano-Bicocca, University of Firenze, Sapienza University, University of Trieste, University of Camerino*.

scientific domains. The main questions were about the industrial sectors, the mechanism of cooperation, and the existence of shared IPRs.

First evidence of the elaboration of the dataset has been presented to the *First NQSTI Annual Meeting* (Rome, 15-16 January 2024). The dataset has been sent to the *Steering Committee* and to *Spoke 8* groups' coordinators to allow a discussion on the next steps to follow.[130]

Phase 2—the Cordis dataset

The *Cordis'* dataset[131] allows the investigation of information about EU research and development projects. Established in 1994, it gives free access to EU-funded research and innovation, where you can find data on projects, topics, and publications funded by the EU's research programs. *Cordis* belongs to the *Research and Innovation community platform of the European Commission*.

Science-based firms form public-private partnerships to join EU projects with the aim of addressing the most pressing challenges through concerted research and innovation initiatives. European Partnerships are a key implementation tool of *Horizon Europe* and significantly contribute to achieving the Union's political priorities, reducing the fragmentation of the research and innovation landscape[132].

It has special meaning, consequently, to analyze the private partners that participated in the European research programs.

Dataset - HORIZON EUROPE - Projects with at least an Italian organization (Public or private)
Extraction date: 14th May 2024 (from the beginning of 2021 to)
Keyword: Quantum
Total number of projects extracted: 197
Total number of projects analyzed for the discussion: 183[133]
Main Information: abstract, financial measure, research fields, typology of the organization, dimension of the firm, dimension of the investment, network of organizations (participating institutions), beginning and end of the project.

The cleaning of the dataset has been realized through reading the project abstracts. Particularly, several research projects contained the words "quantum leap" in the description. Some projects have as core research activities directly linked to QST, other research programs investigate, on the contrary, specific problems through the QST lens (partially, not as core research activity).

Phase 3—the NQSTI dataset consolidation

After completing the dataset with information available in institutional reports, in consulting and technological literature, specialized magazines, and the companies participating in TT and technological events, the scientific literature on QST was collected (see Bibliography). The reports describing QST sector structure in a general way or presenting specific industrial fields (sensing, computing, imaging) were then investigated. Still, to have an idea of the companies

[130] From the first meetings of the participants emerged clearly that there were Disclosure Agreements between PROs and companies that limited the complete gaining of the Information on Technology Transfer Mechanisms and partnerships.

[131] https://cordis.europa.eu. Accessed May 2024.

[132] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/european-partnerships-horizon-europe_en. Accessed September 2024.

[133] Consequently, 14 projects are not considered for this analysis, specifically: *ANDREAH* (101046846), *ARCHIMEDES* (101057527), *CUE-GO* (101058349), *ELOQUENCE* (101094065), *ETTS* (101096405), *EVAI* (101104404), *IMPACT4MECH* (101112118), *ISPLASH* (101112295), *MAPWORMS* (101114050), *MEETWEEN* (101116257), *NEXTGEM* (101135916), *OLAMUR* (101135916), *PRESTO* (190181809), and *QUANTUM* (190190195).

directly involved in the QST research, the datasets belonging to *Quantum Flagship* (*Quantera*[134]), *QUIC* (*Quantum Industry Consortium*[135]) and *EPO* (*European Patent Office*) reports (*EPO*, 2023a; *EPO,* 2023b) have been analyzed.
Participants in international trade fairs and conferences are another meaningful source of QST firms. Trade fairs always show companies active in different markets, looking for new clients, new partnerships, and new collaborations. Firms participating in several workshops, summer schools, and public-private meetings were considered.[136]
The various sources gave birth to a first list of private organizations that exploit QST. Many firms, of course, were cited several times in the papers, in the economic reports and on the websites. For every single company, the authors preliminarily verified whether the firm belonged to the QST sector (in the case of non-specific events). They gathered this information through the official website that describes the products, or the services offered, the markets served and the research processes they are conducting. In the case of companies' websites that resulted poor in the description of the activities or, on the contrary, too big to understand if there exists a direct link to QST, they made use of other references, particularly of newspapers and magazines' articles (interviews and business case studies presented on the firms' websites on the page "Press releases or media").

The variables and limits

The information gathered for all the companies in the sample is:

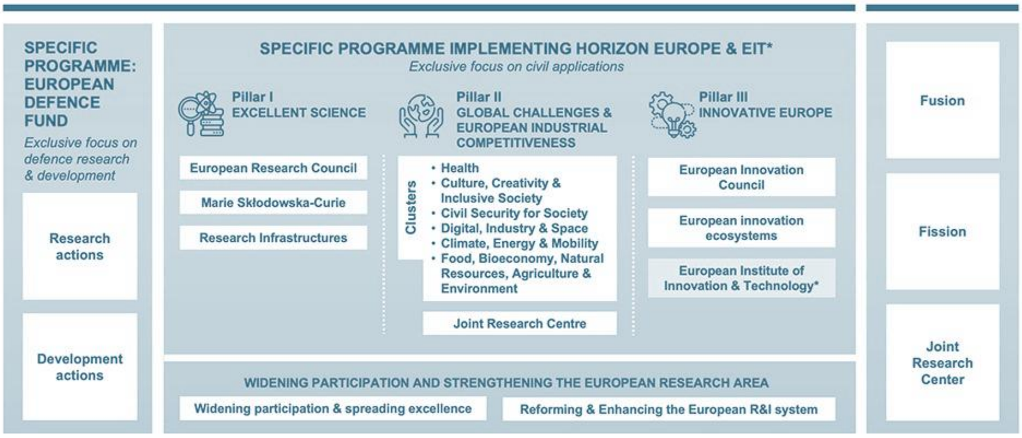
- *Business name;*
- *Head Office (city, state);*
- *Websites URL;*
- *Dimension: spinoff, SMEs, other;*
- *Year of establishment;*
- *Short description of the products or services offered (mission);*
- *ATECO codes;*
- *Markets served;*
- *QST sectors;*
- *Others (general notes).*

To have a clear classification of the QST fields, the author followed the taxonomy realized by *CEN-CENELEC* exposed in van Deventer *et al.* (2022)**.** The representation of the QST pillars made to orient standardization actions at European levels illustrates a simple and shared description of the main quantum sectors (a schematization of the model is offered in the first Chapter, *figure 5*). It has been decided, nevertheless, to consider only the platforms and systems classification.
The dataset aims to represent a first step through the gathering and analysis of the QST Italian Industrial System. Authors hope in the next editions to add other relevant sources of information, such as VCs' investments in the national territory or specific IPRs analysis.

[134] Quantera, Quantum Landscapes Database. Accessed July 2024. https://quantera.eu/wp-content/uploads/D6.1_Database_updated-version-_Feb2021_no_contacts-1.pdf
[135] European Quantum Industry Consortium, QUIC Member List. Accessed September 2024. https://www.euroquic.org/members-list/
[136] All the Knowledge Transfer events participated by *NQSTI* members are cited here: https://nqsti.it/activities/knowledge-transfer

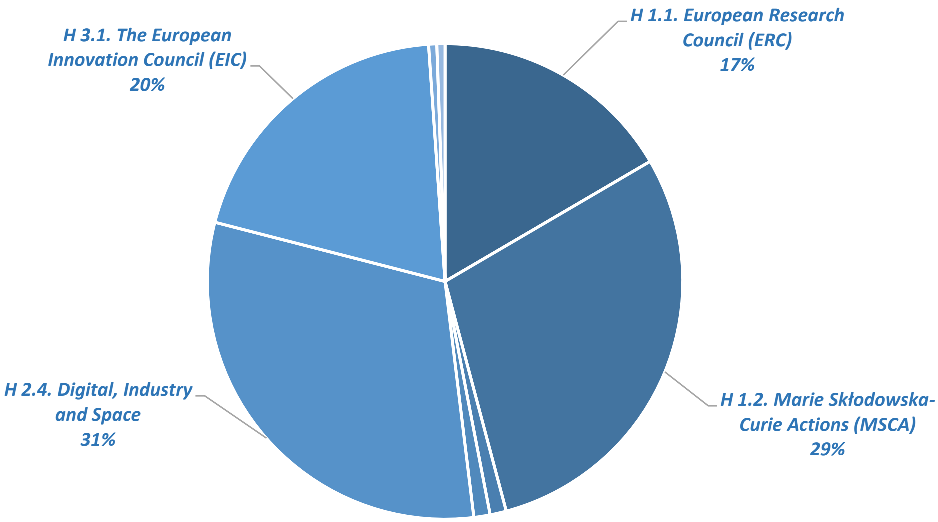
APPENDIX 2 – Italian Participation in *Horizon Europe*: the *CORDIS* analysis[137]

Figure 43. The Horizon Europe Framework



The *CORDIS dataset* allows us to discuss and evidence ulterior issues, providing a way to understand deeply public-private dynamics in Quantum Science and Technology. *Figure 43* recognizes *Horizon Europe*'s structure, through the three main pillars: *Excellent Science*, Global Challenges & European Industrial Competitiveness, *Innovative Europe*, and other specific programs. *Figure 44* represents the distribution of the 181 *Horizon Europe* projects investigated on the specific financial measure.

Figure 44. The legal basis



[137] The authors wish to thank *Cordis Helpdesk Service* for the support, particularly in the person of *Nuno Teixeira*.

As evidenced, participation concerns primarily *Pillar II i*n the cluster "Digital, Industry & Space", with 56 projects representing 31% of the total sample; secondly, *Marie Sklodowska-Curie Actions* have a similar percentage, with 53 Italian participations.

European Research Council initiatives (30) and *European Innovation Council* (36) offer a significant number of projects, with 20% and 17%, respectively.

To better understand the research theme, *H2.4 Digital, Industry and Space* has been divided into sub-fields (see *figure 45*). The main research area, "Key Digital Technologies", represents 45% of all the projects participated in (26), followed by the voice "Advanced Computing and Big Data", with 14 projects. Emerging enabling technologies have, indeed, only six participations.

Figure 45. The Digital, Industry, and Space are the main research areas

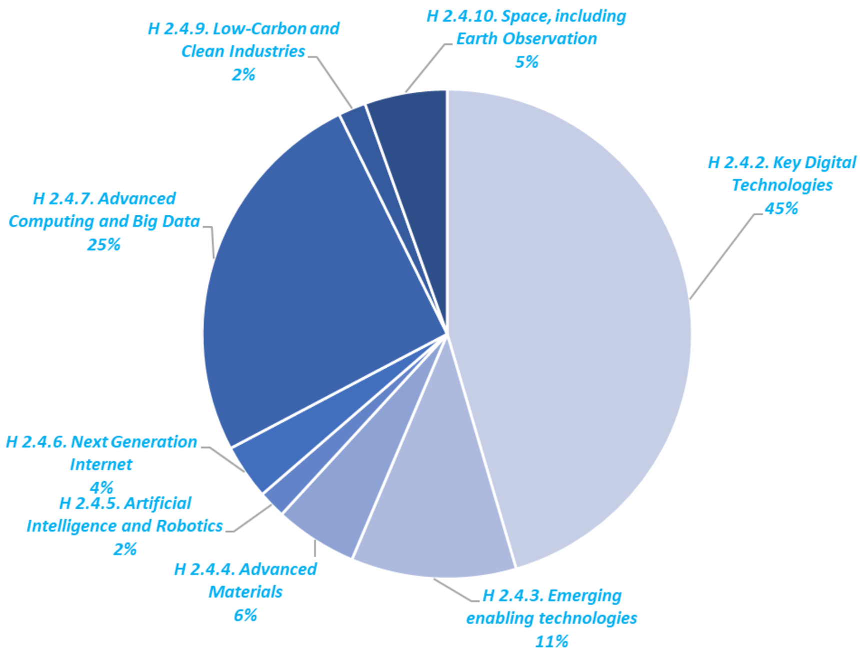


Table 11. The total number of Horizon Europe Projects per Italian Research Organization (public or "others" with more than one project funded)

Research Organization	*Number of projects*
CONSIGLIO NAZIONALE DELLE RICERCHE	**36**
FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA	**14**
UNIVERSITA DEGLI STUDI DI PADOVA	**14**
POLITECNICO DI MILANO	**12**
UNIVERSITA DEGLI STUDI DI FIRENZE	**11**
ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA	9
UNIVERSITA DEGLI STUDI DI MILANO	9
SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI DI TRIESTE	8
ISTITUTO NAZIONALE DI RICERCA METROLOGICA	6
UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA	6
UNIVERSITA DI PISA	6

CINECA CONSORZIO INTERUNIVERSITARIO	5
FONDAZIONE BRUNO KESSLER	5
POLITECNICO DI TORINO	5
UNIVERSITA DEGLI STUDI DI NAPOLI FEDERICO II	5
UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA	5
UNIVERSITA DEGLI STUDI DI TRENTO	5
SCUOLA SUPERIORE DI STUDI UNIVERSITARI E DI PERFEZIONAMENTO S ANNA	4
UNIVERSITA DEGLI STUDI DELL'AQUILA	4
UNIVERSITA' DEGLI STUDI DI MILANO-BICOCCA	4
UNIVERSITA DEGLI STUDI DI TORINO	4
UNIVERSITA DEGLI STUDI DI TRIESTE	4
FONDAZIONE LINKS - LEADING INNOVATION & KNOWLEDGE FOR SOCIETY	3
LABORATORIO EUROPEO DI SPETTROSCOPIE NON LINEARI	3
POLITECNICO DI BARI	3
UNIVERSITA DEGLI STUDI DI GENOVA	3
UNIVERSITA DEGLI STUDI DI PARMA	3
UNIVERSITA DEGLI STUDI DI PAVIA	3
UNIVERSITA DEGLI STUDI DI ROMA TOR VERGATA	3
UNIVERSITA DEGLI STUDI DI SALERNO	3
ISTITUTO DI RICERCHE FARMACOLOGICHE MARIO NEGRI	2
SCUOLA NORMALE SUPERIORE	2
ISTITUTO NAZIONALE DI FISICA NUCLEARE	2
ISTITUTO SUPERIORE DI SANITA	2
SCUOLA UNIVERSITARIA PROFESSIONALE DELLA SVIZZERA ITALIANA	2
UNIVERSITA DEGLI STUDI DI CAMERINO	2
UNIVERSITA DEGLI STUDI DI PALERMO	2
UNIVERSITA DEGLI STUDI DI PERUGIA	2

Table 11 lists Italian Research Organizations with the largest Horizon EU Quantum participation. The *National Research Council*'s involvement with 36 projects is relevant. It is worth noting that, beyond *Consiglio Nazionale delle Ricerche* and *Università degli Studi di Napoli Federico II,* South Research entities are not adequately represented in this classification.

The following *table* presents the classification of *Horizon Europe* participation, from largest to smallest, per financial dimension within the Italian sample of funded projects. It describes the project titles and the acronyms, the start and the end dates, the abstract, and the total amount financed.

Table 12. The main QST Horizon Europe projects for the financial dimension

acronym	title	startDate/endDate	totalCost
photonixFAB	*Building a European industrial supply chain for SOI- and SiN-based silicon photonics, including heterogeneous integration to support emerging markets*	*01/05/2023 - 31/10/2026*	*41.893.419,11*
		Coordinator: ***X-FAB FRANCE***	*Italian participant:* ***NOKIA SOLUTIONS AND NETWORKS ITALIA SPA***

photonixFAB brings together key European photonics and semiconductor players, to establish a strong and sovereign European supply chain for silicon photonics. The consortium leverages the volume capacity of X-FAB, the European More-than-Moore foundry, and addresses the work program with six key objectives: (1) Transferring IMEC's world-renowned silicon-on-insulator (SOI) platform to X-FAB, to achieve industrial manufacturing capacity. The SOI platform addresses a variety of high-speed and sensing applications. (2) Extending the industrial manufacturing capability of LIGENTEC's silicon nitride (SiN) technology at X-FAB, to become the industry standard for SiN photonics. The low-loss, and broad transparency of SiN are perfect for sensing, quantum computing, amongst others. (3) Increasing maturity of heterogeneous integration with SMART Photonics' Indium Phosphide (InP) active components such as lasers, modulators and detectors. These components are integrated on top of the SOI and SiN platforms by transfer-printing. This is an X-FAB associated technology, forming a key innovation differentiator for photonixFAB. The leading European RTOs, IMEC and CEA, are supporting photonixFAB with various technologies, developed in Horizon Europe activities, such as prototype transfer-printing, LiNbO3 modulators and Ge detectors on SiN. (4) Strengthening the European ecosystem with design automation (Luceda), innovative packaging solutions (PHIX), and increased testing capabilities. (5) Demonstrating the viability of the new supply chain and technologies through six application-oriented demonstrators in a wide array of markets. (6) Setting up pilot line and multi-project wafer access to serve innovation by startups, SMEs and large entities, and opening photonixFAB for direct feedback on competitiveness and capabilities. Thereby the relationships between the supply chain partners and prospective end-users, as well as between the photonics and the ECS worlds will be strengthened.

A-IQ Ready	*Artificial Intelligence using Quantum measured Information for realtime distributed systems at the edge*	*01/01/2023 - 31/12/2025*	*35.064.255,00*
		Coordinator: ***AVL LIST GMBH***	*Italian participants:* ***IDEAS & MOTION SRL, POLITECNICO DI TORINO, SLEEP ADVICE TECHNOLOGIES SRL, TEKNE SRL***

Global environmental issues, social inequality and geopolitical changes will pose numerous problems for our society in the future. To face these new challenges and deal with them, there is a need to understand and appropriately utilize new digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics and biotechnologies. A-IQ Ready proposes cutting-edge quantum sensing, edge continuum orchestration of AI and distributed collaborative intelligence technologies to implement the vision of intelligent and autonomous ECS for the digital age. Quantum magnetic flux and gyro sensors enable the highest sensitivity and accuracy without any need for calibration, offer unmatched properties when used in combination with a magnetic field map. Such a localization system will enhance the timing and accuracy of the autonomous agents and will reduce false alarms or misinformation by means of AI and multi-agent system concepts. As a priority, the communication guidance and decision making of groups of agents need to be based on cutting-edge technologies. Edge continuum orchestration of AI will allow decentralizing the development of applications, while ensuring an optimal use of the available resources. Combined with the quantum sensors, the edge continuum will be equipped with innovative, multi-physical capabilities to sense the environment, generating “slim” but accurate measurements. Distributed intelligence will enable emergent behavior and massive collaboration of multiple agents towards a common goal. By exploring the synergies of these cutting-edge technologies through civil safety and security, digital health, smart logistics for supply chains and propulsion use cases, A-IQ Ready will provide the basis for the digital society in Europe based on values, moving towards the ideal of Society 5.0.

QSNP	*Quantum Secure Networks Partnership*	*01/03/2023 - 31/08/2026*	*24.999.999,75*
		Coordinator: ***FUNDACIO INSTITUT DE CIENCIES FOTONIQUES***	*Italian participants:* ***UNIVERSITA DEGLI STUDI DI PADOVA, NEXTWORKS SRL, THINKQUANTUM SRL, MICRO PHOTON DEVICES SRL, TELECOM ITALIA SPA, POLITECNICO DI BARI***

The Quantum Secure Networks Partnership (QSNP) project aims at creating a sustainable European ecosystem in quantum cryptography and communication. A majority of its partners, which include world-leading academic groups, research and technology organizations (RTOs), quantum component and system spinoffs, cybersecurity providers, integrators, and telecommunication operators, were members of the European Quantum Flagship projects CIVIQ, UNIQORN and QRANGE. QSNP thus gathers the know-how and expertise from all technology development phases, ranging from innovative designs to development of prototypes for field trials. QSNP is structured around three main Science and Technology (ST) pillars. The first two pillars, “Next Generation Protocols” and “Integration”, focus on frontier research and innovation, led mostly by academic partners and RTOs. The third

ST pillar “Use cases and Applications” aims at expanding the industrial and economic impact of QSN technologies and is mostly driven by companies. In order to achieve the specific objectives within each pillar and ensure that know-how transfer and synergy between them are coherent and effective, QSNP has established ST activities corresponding to the three main layers of the technology value chain, “Components and Systems”, “Networks” and “Cryptography and Security”. This framework will allow achieving the ultimate objective of developing quantum communication technology for critical European infrastructures, such as EuroQCI, as well as for the private information and communication technology (ICT) sectors. QSNP will contribute to the European sovereignty in quantum technology for cybersecurity. Additionally, it will generate significant economic benefits to the whole society, including training new generations of scientists and engineers, as well as creating high-tech jobs in the rapidly growing quantum industry.

QIA-Phase1	*Quantum Internet Alliance - Phase1*	*01/10/2022 - 31/03/2026*	*24.000.000,00*
		Coordinator: ***TECHNISCHE UNIVERSITEIT DELFT***	*Italian participant:* ***UNIVERSITA DEGLI STUDI DI PARMA***

The mission of the Quantum Internet Alliance (QIA) is to build a global Quantum Internet made in Europe – by developing a full-stack prototype network, and by driving an innovative European Quantum Internet ecosystem capable of scaling the network to world leading European technology. Building on its proven track record in teamwork, which has already resulted in world first Quantum Internet technology, QIA advances this mission in two complementary objectives: The first is the realization of a full-stack prototype network able to distribute entanglement between two metropolitan-scale networks via a long-distance backbone (>500 km) using quantum repeaters. The second is the establishment of a European platform for Quantum Internet development, which will act as a catalyst for a European Quantum Internet Ecosystem including actors all along the value chain. QIA’s network will enable advanced quantum-network applications and prepare the ground for secure quantum computing in the cloud, thanks to our new generation of end nodes including both processing nodes and low-cost photonic client devices. Nodes in the metropolitan network will be interconnected via hubs that allow the scalable connection of hundreds of end nodes, paving the way for early adopters. The long-distance backbone will be realized using fully functional quantum repeaters unlocking Pan-European end-to-end quantum communication. QIA’s prototype network will operate on standard optical fibers and serves to validate all key sub-systems, ready to be scaled by European industry.In this first SGA we will advance towards the long-term objectives set up in the FPA project. Here we present in detail how work will be implemented during this first phase of the SGA.

Qu-Pilot	*Experimental production capabilities for quantum technologies in Europe*	*01/04/2023 - 30/09/2026*	*18.999.992,00*
		Coordinator: ***TEKNOLOGIAN TUTKIMUSKESKUS VTT OY***	*Italian participants:* ***FONDAZIONE BRUNO KESSLER, THALES ALENIA SPACE ITALIA SPA, THINKQUANTUM SRL***

The Qu-Pilot SGA proposal consists of 21 partners from 9 different countries aiming to develop and provide access to the first, federated European fabrication (production) capabilities for quantum technologies, building on and linking together existing infrastructures in Europe. Qu-Pilot will implement the first stage of the capability innovation roadmap for providing experimental (pilot) production capabilities and a roadmap for transferring such capabilities to an industrial production environment, as was proposed in the awarded FPA. It will provide experimental production capabilities for quantum technologies in computing, communication and /or sensing through 13 service-provider organizations available to users, including industry, in particular SMEs and contribute to developing European standards in the field. Qu-Pilot will provide services for the development of a European supply chain of quantum technologies, provide European industry, especially startups and SMEs, with the necessary innovation capacity, and make sure that critical IP remains within the EU. The initial service offering will be validated through use cases with companies within the SGA. A minimum of 20 such use cases are expected and of those 11 are already part of this Qu-Pilot SGA proposal. The competence development, industrial use cases and ecosystem building – all the activities identified and set out in the FPA will have first set of implementation through this first SGA.

Qu-Test	*Qu-Test*	*01/04/2023 - 30/09/2026*	*18.934.689,50*
		Coordinator: ***NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO***	*Italian participant:* ***ISTITUTO NAZIONALE DI RICERCA METROLOGICA***

Qu-Test brings together 13 service providers for a federated network of testbeds and 11 industrial users from the European quantum community. The network brings together competences and infrastructures across Europe to offer testing and validation services. A first goal of this cooperation is to support the creation of a trusted supply chain through the validation of quantum devices, chips, components and systems by the testbed network as an independent third party. A second goal is to discuss and agree on unified sets of parameters to characterize quantum devices. Methodologies and procedures will be harmonized among the partners of the testbed network in a step towards establishing standards for quantum technologies. Qu-Test is aligned along three testbeds: quantum computing, quantum communication, quantum sensing. In more detail, the Quantum Computing Testbed will measure, characterise and validate cryogenic quantum devices, cryogenic qubits such as superconducting and semiconducting qubits, photonics qubits and ion traps. The Quantum Communication Testbed will characterize devices for Quantum Key Distribution (QKD) and Quantum Random Number Generation (QRNG) and provide design and prototyping services to support innovation in the supply chain of quantum communication technologies. Finally, the Quantum Sensing Testbed will benchmark sensing and metrology instruments provided by industry and use a large suite of quantum sensors (clocks, gravimeters, magnetometers, imagers) to validate industrial use cases aiming at generating new business cases for quantum sensing and metrology devices. With additional services of IPR support, business coaching and innovation management, Qu-Test supports the European quantum industry with a holistic one-stop-shop to move the full ecosystem forward.

CARIOQA-PMP	*Cold Atom Rubidium Interferometer in Orbit for Quantum Accelerometry – Pathfinder Mission Preparation*	*01/12/2022 - 31/03/2026*	*16.995.469,75*
		Coordinator: ***CENTRE NATIONAL D'ETUDES SPATIALES - CNES***	*Italian participants:* ***POLITECNICO DI MILANO, LEONARDO SPA***

The overarching goal of CARIOQA-PMP is to prepare the deployment of quantum gravimeters/accelerometers in space, within the decade, through a Quantum Pathfinder Mission. Indeed, the emergence of quantum sensors offers an opportunity to provide new applications for climate sciences through the improvement of space gravimetry performance. Hence, the mastery of this technology in space is one of the major environmental, technological and strategic challenges of the decade. Three main objectives have been set for the scope and duration of CARIOQA-PMP:1. To develop an Engineering Model (EM) of the mission's instrument and to increase the TRL of the critical subsystems up to 5. Complementary EU industrial partners develop the subsystems of the instrument (i.e. Physics Package, Laser System, Microwave Source and Ground Support Equipment) and increase its TRL by assessing the critical technologies in relevant environments. Excellent institutes bring their quantum expertise for the definition of the EM and the mastering of its performance2. To guarantee the adequacy of the hardware development with the future scientific needs. Through their knowledge of scientific applications, leading institutes in geodesy analyse and simulate potential mission scenarios for the Quantum Pathfinder Mission and future Post-Pathfinder scientific missions3. To establish a technical and programmatic roadmap for Quantum Space Gravimetry Missions. This roadmap will be shared and validated by European stakeholders. It ensures the impact maximisation of the project's results through its harmonisation with the European programmatic frameworkCARIOQA-PMP brings together the main players of quantum sensors in Europe. It gathers unique skills among 16 partners from 5 EU Member States including 2 space agencies, 8 research organisations and 6 industries. As a result, CARIOQA-PMP will secure the capacities for implementing quantum gravimeters/accelerometers in space within the EU, contributing to the EU's strategic goal of non-dependence and autonomy.

PASQuanS2.1	*Programmable Atomic Large-scale Quantum Simulation 2 - SGA1*	*01/04/2023 - 30/09/2026*	*16.594.068,75*
		Coordinator: ***MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV***	*Italian participants:* ***CONSIGLIO NAZIONALE DELLE RICERCHE, UNIVERSITA DEGLI STUDI DI PADOVA, THALES ALENIA SPACE ITALIA SPA***

The project Programmable Atomic Large-scale Quantum Simulation (PASQuanS2.1) is the first decisive step toward the transformation of the European landscape for programmable quantum simulators, finally delivering internationally leading platforms involving over 1000 neutral atoms in optical tweezer arrays and also in optical lattices. In the context of this Specific Grant Agreement, we will bring together partners from academia and industry (including technology enablers, platform developers, and end-users) to address central technological challenges. We will connect technologies across national borders and use our combined expertise and technologies to scale up the system size, reduce noise and temperature, and improve stability. We will test and transfer know-how between trapped ion and neutral atom platforms and integrate the hardware with application-specific software stacks for analogue solutions of relevant real-world problems, including verification and optimal control techniques. We will facilitate the expansion and networking of the supply chain and startup companies delivering platforms, en-route to the delivery of technology readiness level (TRL) 6-7 quantum simulators, including both cloud-based platforms, and quantum simulators linked with existing high-performance computing infrastructure. We will work with the end-user community across academia and industry to identify new specific applications where quantum simulators provide a practical quantum advantage over traditional high-performance computing. We will particularly address potential applications in materials science, quantum chemistry and in optimisation. We deliver a clear plan for dissemination, exploitation, and communication. This includes developing and protecting intellectual property, and to expand awareness of quantum simulators and their capability and applications amongst policy makers, industry, and the general public.

Resilient Trust	*Resilient Trust- Trusted SMEs for Sustainable Growth of Europeans Economical Backbone to Strengthen the Digital Sovereignty*	*01/10/2023 - 30/09/2026*	*16.470.803,05*
		Coordinator: ***UNIVERSITE GUSTAVE EIFFEL***	*Italian participants:* ***DGS SPA, AKKODIS ITALY SRL, CENTRO NAUTICO PERMARE S.R.L., RO TECHNOLOGY SRL, RULEX INNOVATION LABS SRL, UNIVERSITA DEGLI STUDI DI GENOVA, LINK CAMPUS UNIVERSITY, UNIVERSITA DEGLI STUDI DELL'AQUILA***

The internet of things (IoT) is promising as it drives the datafication of our everyday life and thus, leverages synergies between originally considered "dead" things and enables them to proactively serve humans. IoT leads to a high automation potential with which we improve the life of billions of people and compensate for societal problems such as a growingly old population, missing high-skilled labour across Europe or the efficiency limits in current production capabilities. IoT5.0, an Artificial Intelligence (AI) -assisted Internet of Things, could even more benefit society, as the devices could even learn how to provide more value. But the ubiquitous connectivity comes at a cost. Security levels have to rise tremendously to ensure a network stays secure and safe for humans. This additional effort often is a burden for small and medium sized enterprises as the complexity and security demands of such systems rise faster than available resources. This is especially dangerous as a single corrupted, malicious device can result in the exploitation of the entire network of connected devices by an attacker. Consequently, RESILIENT TRUST focuses on end-to-end security of IoT processing chains with a focus on strong exploitation for SMEs. This vision will be realized by developing specialized hardware to establish TRUST in-between a network and a wall of RESILIENCE even against new attack methods such as post quantum attacks and AI based attacks. The architecture of the secure processing chain will be carefully built after threat modelling, asset identification, risk analysis, security objectives and requirements definition. Consequently, RESILIENT TRUST will address and significantly mitigate these major risks to enable IoT5.0. That way this project will be a driver for sustainable development and the generation of convenience and wealth. A solution is proposed to ensure end-to-end security by boosting RESILIENCE and TRUST along different key supply chains of IoT device

ALLEGRO	Agile uLtra Low EnerGy secuRe netwOrks	01/01/2023 - 30/06/2026	11.829.201,25
		Coordinator: **FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV**	*Italian participants:* **ERICSSON TELECOMUNICAZIONI SPA, TELECOM ITALIA SPA, CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI, FONDAZIONE LINKS, POLITECNICO DI TORINO**

ALLEGRO aims at designing and validating a novel end-to-end sliceable, reliable, and secure architecture for next-generation optical networks, achieving high transmission/switching capacity -- with 10 Tb/s for optoelectronic devices and 1 Pbt/s for optical fiber systems --; low power consumption/cost -- with > 25% savings -- and secure infrastructures and data transfers. The architecture relies on key enabling innovations: i) smart, coherent transceivers exploiting multi-band & multi-fiber technologies for P2P and P2MP applications, based on e.g., high-speed plasmonic modulators/photodetectors and programmable silicon photonic integrated waveguide meshes; ii) loss-less, energy-efficient transparent photonic integrated optical switches, eliminating OEO conversions, e.g., with on-chip amplification in the O-band for datacom applications; iii) a consistent approach to security, in terms of functional/protocol architectures and communications, further improving QKD systems, enabling optical channel co-existence and researching on quantum-resistant (post-quantum) cryptography, developing systems based on physically unclonable functions; and iv) a scalable AI/ML assisted control and orchestration system, responsible for autonomous networking, dynamic and constrained service provisioning, function placement and resource allocation, leveraging devices increasing programmability and overall network softwarization.To achieve the target objectives and KPIs, ALLEGRO has defined a clear methodology ending in ambitious demonstrators. The consortium includes a good balance of industry and research/academia with know-how in complementary fields. The results of ALLEGRO will be disseminated in leading conferences, events, and high-impact journals. They will have a concrete and measurable economic and social impact, contributing towards achieving key European objectives, reinforcing European leadership and digital sovereignty in the ongoing digital and green transition.

EPIQUE	*European Photonic Quantum Computer*	*01/01/2024 - 31/12/2026*	*10.340.741,50*
		Coordinator: ***UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA***	*Italian participants:* ***CONSIGLIO NAZIONALE DELLE RICERCHE, UNIVERSITA DEGLI STUDI DI FIRENZE***

Photonics is one of the first platforms explored for quantum computing (QC), bringing the advantage of low decoherence and natural connectivity for distributed and blind QC. Recent years have witnessed a step-change in the scale, complexity, and scope of QC with photons which recently led to 3 out of the 4 demonstrations of quantum advantage from Canadian and Chinese groups. These impressive achievements were obtained with squeezed light in bulky apparatus that are not fit for scalability. Europe shows strong leadership in development of integrated optical QC platforms, with breakthroughs in the development of high transmission dense photonic chips, record efficiency detectors and deterministic single photon sources. Photonic QC also benefits from a clear roadmap toward fault tolerant architectures proposed by leading EU quantum algorithm teams. EPIQUE gathers world leaders in photonics QC with expertise in both technology and algorithms from academia and SMEs who work together to deliver the technological breakthroughs required to push the platform toward general purpose QC. This will be achieved via new nanofabrication that combines novel switching with mature silicon compatible circuitry, via optimising both single photon sources and detectors, via new interfacing possibilities in silicon nitride and direct write modular chips, via fast low loss switching in lithium niobate, and via quantum architectures that leverage all of these advances. EPIQUE will develop three QC prototypes that will demonstrate essential building blocks of generating and fusing quantum states to entangle >10 qubits, and critical measurement and feedforward capabilities required to scale the platform to >1000 qubits. At the end of this project, we will have proven a route to general purpose quantum computing that will strengthen private investment in EU based optical QC companies.

SPINUS	*Spin based quantum computer and simulator (SPINUS)*	*01/01/2024 - 31/12/2027*	*10.166.376,25*
		Coordinator: ***FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV***	*Italian participant:* ***FONDAZIONE BRUNO KESSLER***

The SPINUS project aims to establish experimental platforms for both quantum simulation (with >50 quantum units) and quantum computation (with >10 qubits). Despite rapid advancements, scaling and implementing quantum simulators and computers towards a regime surpassing available classical methods remains difficult due to the demanding constraints of existing architectures. By utilizing the exceptional qualities of silicon carbide (SiC) and diamond materials, the SPINUS project suggests a novel strategy for scalable solid-state quantum simulation and computation hardware based on nuclear spin networks and dipole-dipole entangled electron spin qubits. Our first goal is to create a quantum simulation platform that uses optically polarized NV centers and color centers along with nuclear spin networks in diamond or SiC. This technology allows for the investigation of a wide range of strongly correlated models without being constrained by the capabilities of the available quantum simulators. Second, we aim at scaling up platforms for solid-state quantum computing to more than 10 fully programmable qubits at ambient temperatures. For these purposes, the consortium will investigate various architectures and techniques for initializing, controlling, and reading out the spin qubits with the goal of achieving large-scale quantum simulation and computation capabilities. This will take advantage of the excellent coherence properties and robustness against environmental noise of these materials.SPINUS has great potential to advance the field of quantum computing and simulation and open new possibilities for the investigation of intricate quantum systems by fostering and contributing to a European quantum and a European diamond ecosystem by working closely with startup businesses affiliated with the project team and cooperation with the related Flagship initiatives.

IMPRESS	*Interoperable electron Microscopy Platform for advanced RESearch and Services*	*01/02/2023 - 31/01/2027*	*9.633.919,26*
		Coordinator: ***CONSIGLIO NAZIONALE DELLE RICERCHE***	*Italian participants:* ***AREA DI RICERCA SCIENTIFICA E TECNOLOGICA DI TRIESTE, CENTRAL EUROPEAN RESEARCH INFRASTRUCTURE, PROMOSCIENCE SRL***

IMPRESS (Interoperable electron Microscopy Platform for advanced RESearch and Services) aims to co-develop and deliver advanced transmission electron microscopy (TEM) instrumentation, methods and tools that will revolutionize the way in which TEMs are used by all new and well-established scientific communities, integrate them with other instrumentation at analytical research infrastructures (RIs) and create new business opportunities for small and medium-sized enterprises. The core of the project is the development of a standardized cartridge-based interoperable platform for TEM that is based on common interfaces and data formats, is flexible and adaptable and allows users to perform advanced correlative experiments using different instruments and to co-develop methodological options that are not yet satisfied by commercially available electron microscopes. The solutions will be delivered at technology readiness level 8 through a pre-commercial procurement. The project also involves the co-development of new electron sources, techniques based on adaptive optics and event-driven detectors, application-relevant in situ/operando sample environments and software for simulation of experiments and remote access based on artificial intelligence. By the end of the project, these developments will be integrated with the new cartridge-based platform, in order to make them available to all users of RIs and other TEMs owners. An open knowledge and innovation hub for TEM will be created and a training programme will promote the new solution, to initiate RI staff in their use and to provide both materials and life science communities with optimized tools for tackling societal challenges, especially in the energy and health sectors. The project will exploit synergies and collaboration with five RIs of European dimension for the benefit of users from diverse scientific communities and will pave the way towards a new cooperative model for the development and operation of RIs for TEM

CASTLE	*Chirality and spin selectivity in electron transfer processes: from quantum detection to quantum enabled technologies*	*01/01/2023 - 31/12/2028*	*8.976.957,00*
		Coordinator: ***UNIVERSITA DEGLI STUDI DI FIRENZE***	*Italian participants:* ***UNIVERSITA DEGLI STUDI DI PARMA, UNIVERSITA DEGLI STUDI DI TORINO, CONSORZIO INTERUNIVERSITARIO NAZIONALE PER LA SCIENZA E TECNOLOGIA DEI MATERIALI***

Chirality is a key property of molecules important in many chemical and nearly all biological processes. Recent observations have shown that electron transport through chiral molecules attached to solid electrodes can induce high spin polarization even at room temperature. Electrons with their spin aligned parallel or antiparallel to the electron transfer displacement vector are preferentially transmitted depending on the chirality of the molecular system resulting in Chirality-Induced Spin Selectivity (CISS). The long-term vision of the CASTLE project is to transform the CISS effect into an enabling technology for quantum applications. This will be accomplished by achieving four key objectives. 1) The occurrence of CISS will be studied at the intramolecular level by photo-inducing rapid electron transfer within covalent donor-chiral spacer-acceptor molecules to generate long-lived radical pairs (RPs). 2) Direct detection of RP spin polarization will be performed using time-resolved and pulsed electron and nuclear magnetic resonance techniques. In addition, polarization transfer from one of the radicals comprising the spin-polarized RP to a stable molecular spin (Q) will be used to initialize the quantum state of Q, making it a good qubit for quantum applications, particularly sensing. 3) Quantum mechanical studies of the CISS effect will provide predictive models for molecular qubit design. 4) The CISS effect will be used to control, readout, and transfer information in prototypical devices embedding hybrid interfaces based on semiconducting or conducting substrates, thus dramatically advancing the use of molecular spins in quantum information technologies targeting high-temperature operation. These devices will be used also to prove molecule-based Quantum Error Correction. The knowledge acquired with CASTLE will impact a wide range of fields, including magnetless spintronics, dynamic nuclear polarization for NMR signal enhancement, catalysis, and light harvesting.

MaX	*MAterials design at the eXascale*	*01/01/2023 - 31/12/2026*	*8.496.392,50*
		Coordinator: ***CONSIGLIO NAZIONALE DELLE RICERCHE***	*Italian participants:* ***SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI DI TRIESTE, CINECA CONSORZIO INTERUNIVERSITARIO, E 4 COMPUTER ENGINEERING SPA, TRUST-IT SERVICES SRL***

Understanding, predicting, and discovering the properties and performance of materials is key to delivering the technologies that power our economy and provide a sustainable development to our society. For this reason, materials simulations have become one of the most intensive and fast growing domains for high-performance computing worldwide, with a recognized European leadership in developing and innovating the ecosystem of quantum simulation codes. MaX will target these lighthouse codes to address the challenges and leverage the opportunities arising from future exascale and post-exascale architectures, and to offer powerful paths to discovery and innovation serving both scientific and industrial applications.MaX includes (1) the core developing teams of the European lighthouse codes; (2) the HPC centres designing and hosting pre-exascale and exascale systems; (3) the main European companies engaged in the development of exascale technologies; and it brings (4) a sustained record in training and educating the community, and (5) in disseminating its resources under an extensive open-source model that includescodes, workflows, and FAIR data.These synergies will underpin the objectives of the present proposal, that aims to upscale the MaX codes and their performance to multiple heterogeneous exascale architectures; to endow these codes with innovative capabilities enabled by such architectures; to co-design the hardware and software in collaboration with the relevant European stakeholders; to enable turn-key simulation capabilities that meet the power of exascale resources and deliver the resilience needed; to disseminate the entire ecosystem of codes, workflows, and data; and to train and engage developers and users in fully leveraging such powerful instruments for discovery and innovation.

NOUS	*A catalyst for EuropeaN ClOUd Services in the era of data spaces, high-performance and edge computing*	*01/01/2024 - 31/12/2026*	*8.428.875,00*
		Coordinator: ***FUNDACION INSTITUTO INTERNACIONAL DE INVESTIGACION EN INTELIGENCIA ARTIFICIAL Y CIENCIAS DE LA COMPUTACION***	*Italian participants:* ***CONSORZIO INTERUNIVERSITARIO PER L'OTTIMIZZAZIONE E LA RICERCA OPERATIVA, POLITECNICO DI TORINO, TELECOM ITALIA SPA, UNIVERSITA DI PISA, UNIVERSITA DEGLI STUDI DI MODENA E REGGIO EMILIA***

NOUS will develop the architecture of a European Cloud Service that allows computational and data storage resources to be used from edge devices as well as supercomputers, through the HPC network, and Quantum Computers. NOUS will be an Infrastructure-as-a-Service (IaaS)/Platform-as-a-Service (PaaS) cloud provider, harnessing edge computing and decentralisation paradigms to incorporate a wide array of devices and machines in its computational flow to provide leaps in Europe’s capability to process vast amounts of data.The pipeline of the NOUS in the project will include three types of components: i) computational components that are responsible for executing computations, ii) edge components that are responsible for communicating with edge devices (such as IoT sensors/ actuators/ devices), iii) data storage components that are responsible for data storage and storage management. Components are researched individually, expecting to yield breakthroughs, and jointly, to create the architecture and cloud-level services such as syndication with other platforms and virtual labs. The project has defined 4 use cases that will allow the testing of the developed technologies in real-world scenarios that industry leaders face.The NOUS architecture will be made open source to allow the capitalization by companies and organisations. Furthermore, a set of workshops and collaboration activities is envisioned with Data Spaces Support Centre, Gaia-X, FIWARE and EOSC powered by a strong consortium of 21 partners from 11 European countries.

OASEES	*Open Autonomous programmable cloud appS & smart EdgE Sensors*	*01/01/2023 - 31/12/2025*	*7.987.425,00*
		Coordinator: ***NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"***	*Italian participants:* ***ENGINEERING - INGEGNERIA INFORMATICA SPA, EMOTION SRL, ASM TERNI SPA, SCM GROUP SPA, CSR CONSORZIO STUDI E RICERCHE SRL, DS TECH SRL***

The massive increase in device connectivity and generated data has resulted in the proliferation of intelligent processing services to create insights and exploit data in a multi-modal manner. Currently, the most powerful data processing operates in a centralized manner at the cloud, which provides the ability to scale and allocate resources on demand and efficiently. Centralized processing and cloud hosting, bound and limit their services and applications to operate in a resource restricted manner, relying usually on large single entities to provide, i) Authentication, ii) Data storage, iii) Data processing, iv) Connectivity, v) Vendor-locked environments for development and orchestration. This significantly limits the user from its data governance and even identity management. Similarly, existing solutions for edge device authentication require a centralized entity to trust them and authenticate them, rendering a non-portable identification paradigm. OASEES aims to create an open, decentralized, intelligent, programmable edge framework for Swarm architectures and applications, leveraging the Decentralized Autonomous Organization (DAO) paradigm and integrating Human-in-the-Loop (HITL) processes for efficient decision making. The OASEES vision is to provide the open tools and secure environments for swarm programming and orchestration for numerous fields, in a completely decentralized manner. An important aspect in this process is identification and identity management, in which OASEES targets the implementation of a portable and privacy preserving ID federation system, for edge devices and services, with full compliance and compatibility to GAIA-X federation and IDSA trust directives and specifications. This situation solidifies the need for an integrated enabler framework tailored to the edge's extreme data processing demands, using different edge accelerators, i.e. GPU, NPU, SNN and Quantum.

FIQUgS	*Field Quantum Gravity Sensors*	*01/10/2022 - 30/09/2025*	*6.810.870,00*
		Coordinator: ***EXAIL***	*Italian participant:* ***GEOMATICS RESEARCH & DEVELOPMENT SRL***

Gravimetry aims at unveiling the density structure of the undergrounds by measuring subtle changes of the local gravity acceleration. The first-generation of quantum gravity sensors (QGs) has received a strong interest from many customers, and the market is still growing. But the commercial potential and the positive-impact of the technology are not yet fully exploited because of several limitations such as transportability, robustness, user-friendless or high operation costs. To overcome the barriers that limit the operational utilization of field gravimetry and develop the solutions that will allow us to fully address the exploitable market, we propose to conduct in FIQUgS the development of several innovations, either at the technological level with improved QGs built upon a reliable and efficient supply chain, or in terms of operational methodology.The development of a next generation QGs product line, and the services associated for the conduction of field surveys, data acquisition and data inversion will allow to considerably develop our capability to address the market of advanced geophysics. The unique industrial and technological capabilities that will result from FIQUgS will positively contribute to several important societal objectives, especially the European Green Deal:- the new field QGs will allow for a reduction of the environmental impact associated to mining activities thanks to a reduction of drilling operations, and civil engineering where it will contribute to more efficient and resilient constructions.- they will contribute to an improved utilization of geothermal energies through the development of non-invasive monitoring capabilities of the energy reservoir.- they will be involved in CO2 storage operations and will contribute to the fight against global warming thanks to these advanced monitoring capabilities.FIQUgS will also have an impact in quantum technologies markets, such as high-performance navigation or advanced photonics.

MUQUABIS	*Multiscale quantum bio-imaging and spectroscopy*	*01/07/2022 - 30/06/2026*	*6.664.541,25*

		Coordinator: ***CONSIGLIO NAZIONALE DELLE RICERCHE***	*Italian participants:* ***UNIVERSITA CAMPUS BIO MEDICO DI ROMA, LEONARDO SPA, PPQSENSE SRL***

Understanding and controlling complex systems at different scales is a major challenge in biology and medicine. Quantum sensing technologies hold much promise for disruptive approaches to imaging and spectroscopy of biological matter. MUQUABIS aims at developing synergetic tools of quantum bio-sensing and bio-imaging. Such sensors will offer biology a distinctive host of powerful features – non-invasiveness, sensitivity, spatial and temporal resolutions, likely to conquer new frontiers in imaging and spectroscopy, out-of-reach of their classical counterparts. A focus is a global structural and functional understanding of cardiac cell layers from molecules to cells to tissues. ¬Their study in healthy and diseased conditions will shed light on cardiac arrhythmias, largely responsible for morbidity and sudden cardiac death. Advancing beyond modern tools of photonics and quantum measurements, new concepts for quantum frequency combs and infrared lasers will be explored. Low-light-level spectro-imaging will detect cell-membrane proteins and gaseous metabolites nearby cell tissues, below the quantum noise limit. Concurrently, a quantum magneto-microscope based on diamond nitrogen-vacancy centers will be combined to optical imaging for electrophysiology. Such a hybrid sensor will simultaneously and locally reveal the magnetic and electric fields in cardiac-cell activity. MUQUABIS proposes a unique synergic effort, gathering complementary expertise, technologies and infrastructures. Leading research institutions in quantum sensing, quantum optics and biophysics, together with four high-tech companies will rapidly move the project from fundamental quantum sensing components and protocols to technology validation on biological samples to a roadmap for industrial exploitation. MUQUABIS will pave the way to ground-breaking quantum-based tools and protocols for medical diagnostics and treatments, a strategic objective for the European Quantum Technology flagship.

QUCATS	*Quantum Flagship Coordination Action and Support*	*01/05/2022 - 30/04/2025*	*6.636.973,75*
		Coordinator: ***CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS***	*Italian participant:* ***CONSIGLIO NAZIONALE DELLE RICERCHE***

Quantum Technologies (QT) are now developing quickly and broadly in Europe, and the QT Flagship launched 3 years ago is part of a larger Quantum Fleet. This evolution goes together with a reinforcement of the move from the lab to real-world applications, and to industry involvement towards potential markets. The QUCATS CSA is designed to accompany this transition, with the main goals to foster an open and inclusive ecosystem at the European and international levels, to contribute to the development of QT benchmarks and standards, and to step-up training and education of a quantum aware workforce. These outcomes will be reached through the execution of five Work Packages, and their expected impacts will be to preserve the ownership sense built by the previous QT initiatives, now enlarged from labs to the European quantum industry; to make sure that a plurality of voices is consulted and heard, delivering a consistent scientific and political message on critical QT-related issues; and to guarantee that the new phase of the QT Flagship will be validated and supported by the largest possible scientific and industry community. A crucial issue is to allow researchers and policy makers to strike a balance between protectionism and full free trade, in order to keep going the worldwide exchange of ideas, ultimately leading to the conceptual and technological breakthroughs required for the full realization of the QT potential. This smart openness will make Europe more attractive for foreign companies, avoiding at the same time the move of QT companies to countries outside it. Particular attention will be brought to the coordination and development of international QT standards and regulations, and to new educational programs on a European scale, able to train QT specialists, well skilled to make progress in the current Flagship phase and beyond it. Ultimately, the goal of QUCATS is to keep the whole European QT initiative on the path towards a full success on a global scale.

Figure 46. The start date and end date of Horizon Europe projects

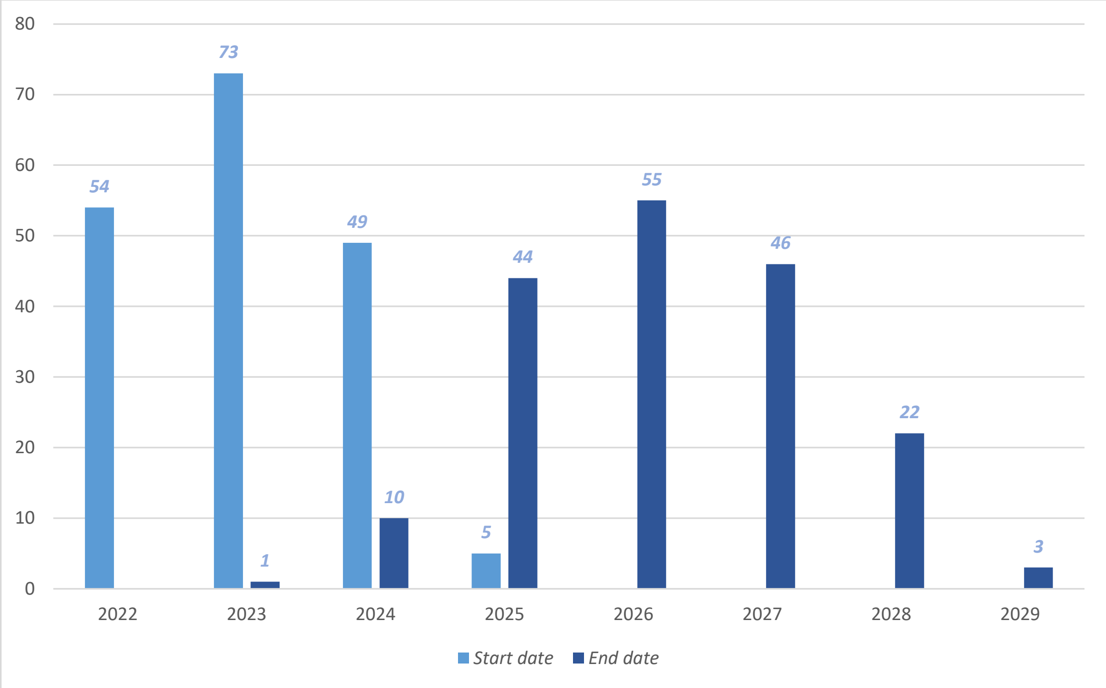


Figure 46 illustrates the start and end dates for every Horizon Europe project considered in this analysis. In 2023, it is possible to appreciate the substantial number of projects awarded overall to Italian organizations as coordinators or participants (73). It was too early to comment on the 2024 results (as the data extraction was developed in May 2024), but the amount seems interesting nonetheless. As a consequence of the PNRR funding, it is expected that there will be a significant reduction in Horizon EU Italian participation in the coming years.

Table 13 classifies the public and private organizations. The European Union recognizes five typologies that span from public research and education to public bodies to private for-profit companies. The table describes all the organizations participating in the Horizon EU projects considered (not only the Italian ones).

Table 13. The organizations typology

Organizations typologies (public or private)	
HES - Higher or Secondary Education	**670**
OTH - Others	**45**
PRC - Private for profit (excluding education)	**567**
PUB - Public body (excluding research and education)	**20**
REC - Research organizations	**365**
Total	**1667**

As emerged earlier in the description of the main European projects, each organization could cover a specific role within the research and development networks. Universities, public research entities, or companies could be coordinators of the entire project, participants, or still a “third party”. The last term means that the firm or the public institution develops a phase of the research project, but it is not directly involved in the network activity.

Figure 47. The companies’ participation in total per country of origin

Figure 47 describes the participation of Italian and European companies in the projects. The relevant number of private firms participating (averaging 30-35% for each single country) is clearly evident.

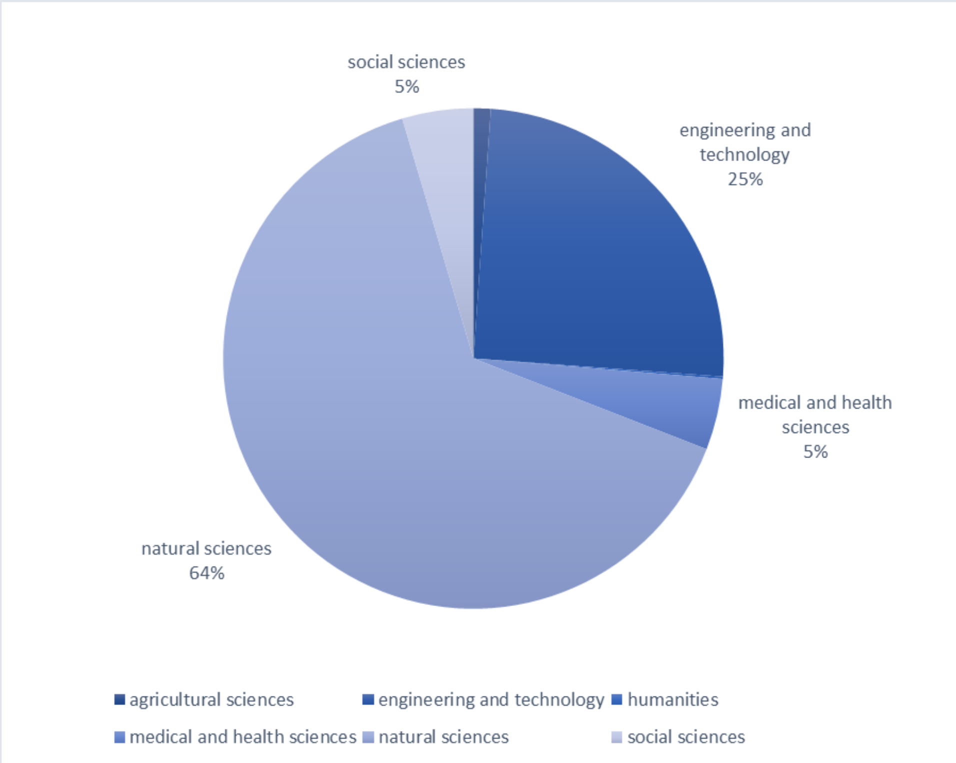
EuroSciVoc Path1	
agricultural sciences	*7*
engineering and technology	*157*
humanities	*1*
medical and health sciences	*29*
natural sciences	*406*
social sciences	*29*
Total	*629*

The *European Science Vocabulary* (EuroSciVoc) is a multilingual taxonomy that represents all the main fields of science, as identified from *CORDIS* content, and is organized through a semi-automatic process based on NLP (Neuro-Linguistic Programming) techniques. Each category is enriched with relevant keywords extracted from the textual descriptions of *CORDIS* projects[138].

[138] More Information on: https://op.europa.eu/en/web/eu-vocabularies/euroscivoc

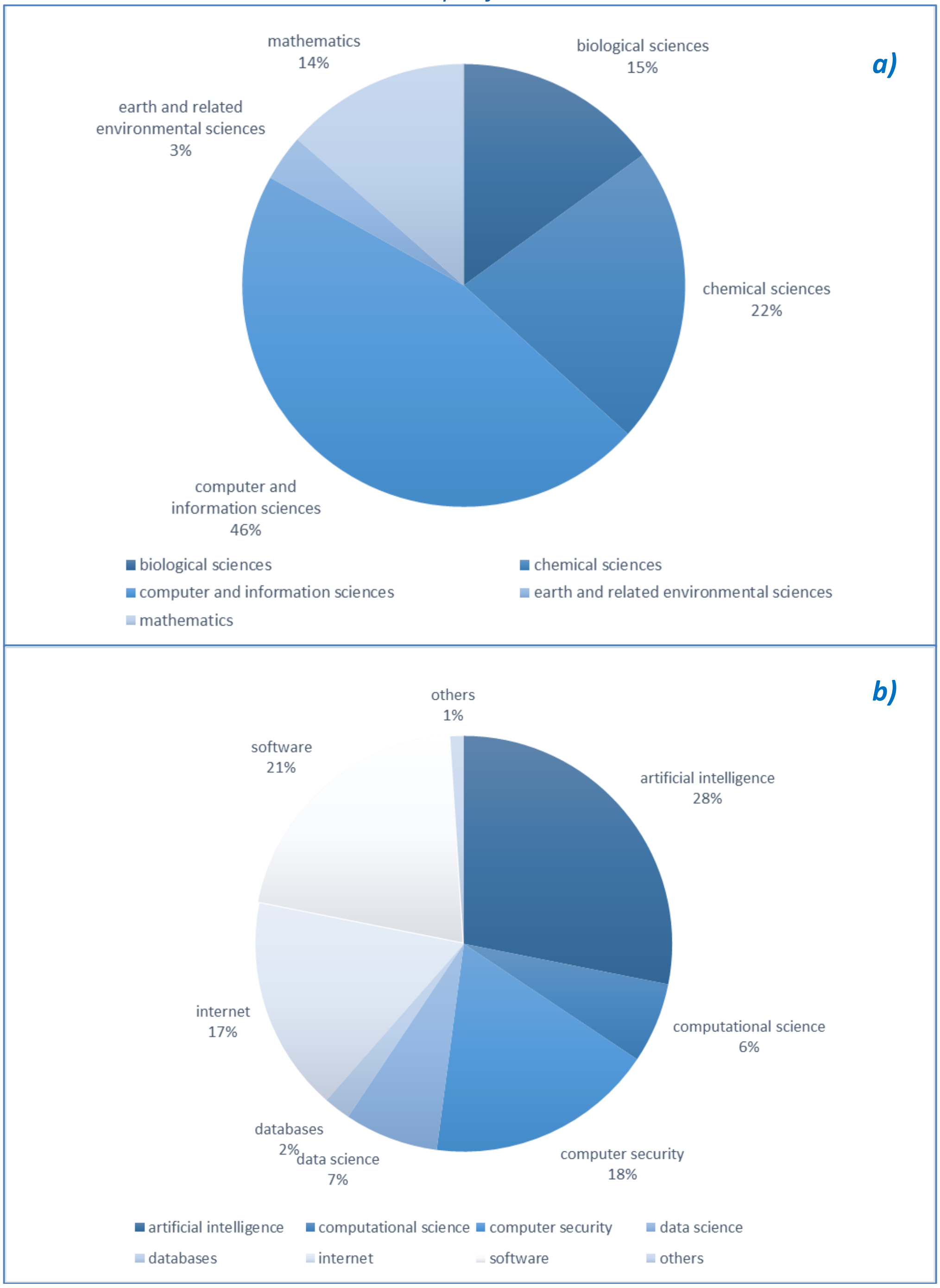
At the first level of analysis of the selected projects, it is noticeable that the Natural Sciences represent 64% (406) of all the fields of science. Engineering and technology also exhibit a significant global presence, accounting for 25% (see *figure 48*).

Figure 48. The EuroSciVoc taxonomy in the projects



Investigating the second level of description of research fields in natural sciences, the importance of *Computer and Information Sciences* emerges, representing 46% of the total. In *figure 49a*, the main application areas are readily identifiable. In *figure 49b*, *Computer and Information Sciences* have been further divided into scientific and technological areas.

Figure 49. The EuroSciVoc "Natural Science" specification



NQSTI National Quantum Science and Technology Institute S.c.a.r.l.

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