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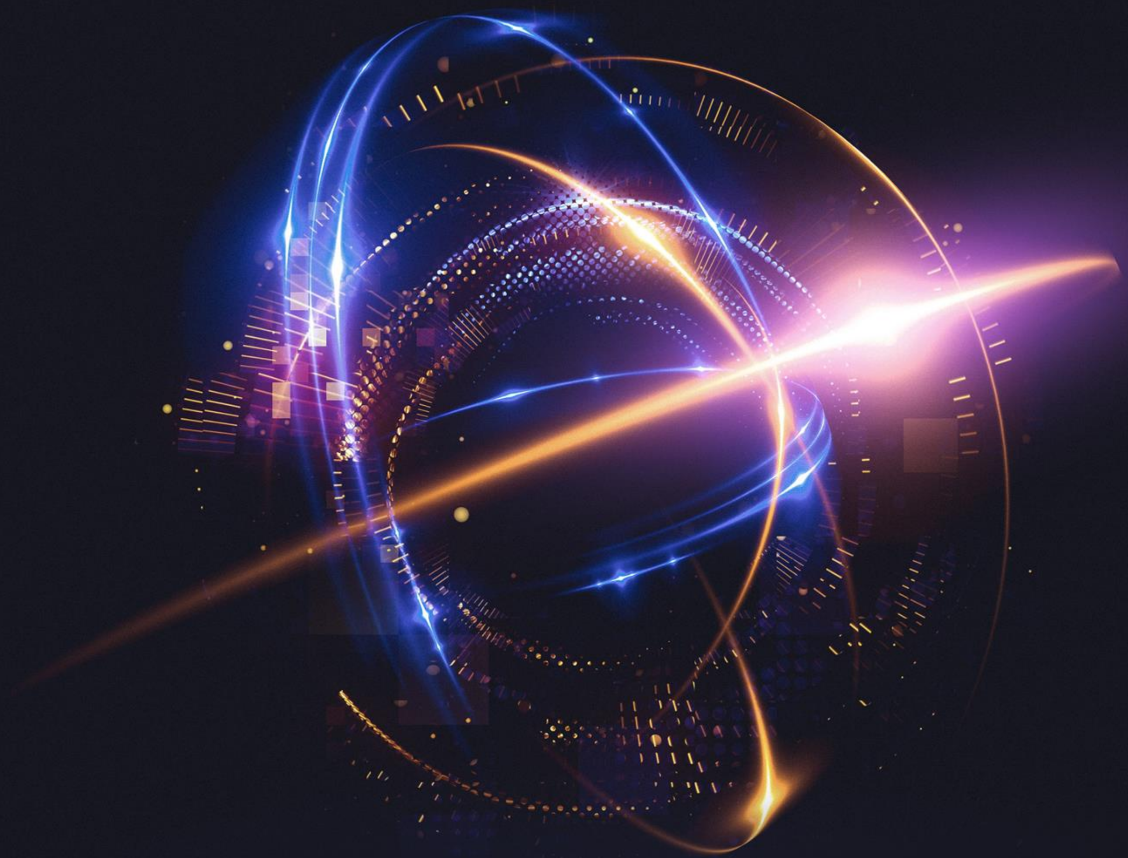

Quantum Computing

Get ready for next gen computation

July 2022

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Executive Summary

Quantum computing is one of the most promising technology that highlights revolutionary applications starting from today. Such technology is enabling individuals and companies to solve computational problems that were previously considered intractable. While quantum computers aren't going to replace classical computers, quantum technology is significantly changing the way the world operates.

Quantum Computing is a new paradigm of processing information that uses quantum phenomena such as superposition and *entanglement* to perform calculations by using new machines called Quantum Computers. These machines process information on quantum bits, or qubits, using unique properties not available with today's computers. Nowadays traditional computers cannot tackle the most demanding challenges coming from scientific research field and business industry as well. Quantum Computing, leveraging on quantum mechanics, can surprisingly scale its computational power by increasing the number of quantum bits, or qubits.

To become a scalable and reliable technology QC needs to face some challenges: first, Q-computers are extremely sensible on external factors (e.g., fabrication, working temperature); second, a qubit complete state may not be measured precisely, so verification is difficult; and third, errors occur much more often than with classical computing. Improving the fidelity of qubit operations is key to increasing the usefulness of quantum algorithms, as well as for implementing error correction schemes with reasonable qubit overhead.

Quantum Computer market is expected to grow from USD 472 million in 2021 to USD 1,765 million by 2026, at a CAGR of 30.2%. The early adoption of quantum computing in banking and finance sector is expected to fuel the growth of the market globally as far as the rising investments by governments of different countries to carry out research and development activities related to quantum computing technology. Such government agencies are investing increasingly in the development of quantum computing technology so that different optimization and simulation strategies can be implemented with quantum computers, supporting their research institutes for the development of quantum computers.

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What is Quantum Computing

Quantum mechanics, the subfield of physics that describes the behavior of very small particles, provides the basis for a new paradigm of computing. Quantum computing (QC) was first proposed in the 1980s as a way to improve computational modeling of the behavior of very small ("quantum") physical systems. Interest in the field grew in the 1990s with the introduction of Shor's algorithm, which, if implemented on a quantum computer, would exponentially speed up an important class of cryptanalysis and potentially threaten some of the cryptographic methods used to protect government and civilian communications and stored data. In fact, quantum computers are the only known model for computing that could offer exponential speedup over today's computers.

While a classical computer uses bits to represent the values it is operating on, a quantum computer uses quantum bits, or qubits. A bit can either be 0 or 1, while a qubit can represent the values 0 or 1, or some combination of both at the same time (known as a "superposition"). While the state of a classical computer is determined by the binary values of a collection of bits, at any single point in time the state of a quantum computer with the same number of quantum bits can span all possible states of the corresponding classical computer, and thus works in an exponentially larger problem space.

Although quantum computers have a significant performance advantage, system fidelity remains a weak point. Qubits are highly susceptible to disturbances in their environment, making them prone to error. Correcting these errors requires redundant qubits for error correction and extensive correction codes, however useful applications of so-called Noisy Intermediate Scale Quantum devices, or "NISQ's" is proceeding very rapidly.

Why Quantum Computing

1. Relevance

In an increasingly dynamic and global context, technology and the ability to process complex information have become a differentiating factor on the market. Big data represents the starting point for analyzing and predicting future behaviors. The challenges, arising above all from the field of scientific research and industry, require a computing capacity that is difficult to achieve by traditional computers.
Quantum computers, exploiting quantum mechanics, can scale the computing power by transforming normal bits into quantum bits according to an iterative model. The ability to process a large amount of data and the speed of calculation allow Quantum Computers to be used in a multitude of sectors. The following cases highlight possible uses of the QC to a series of activities that can be considered cross industries.

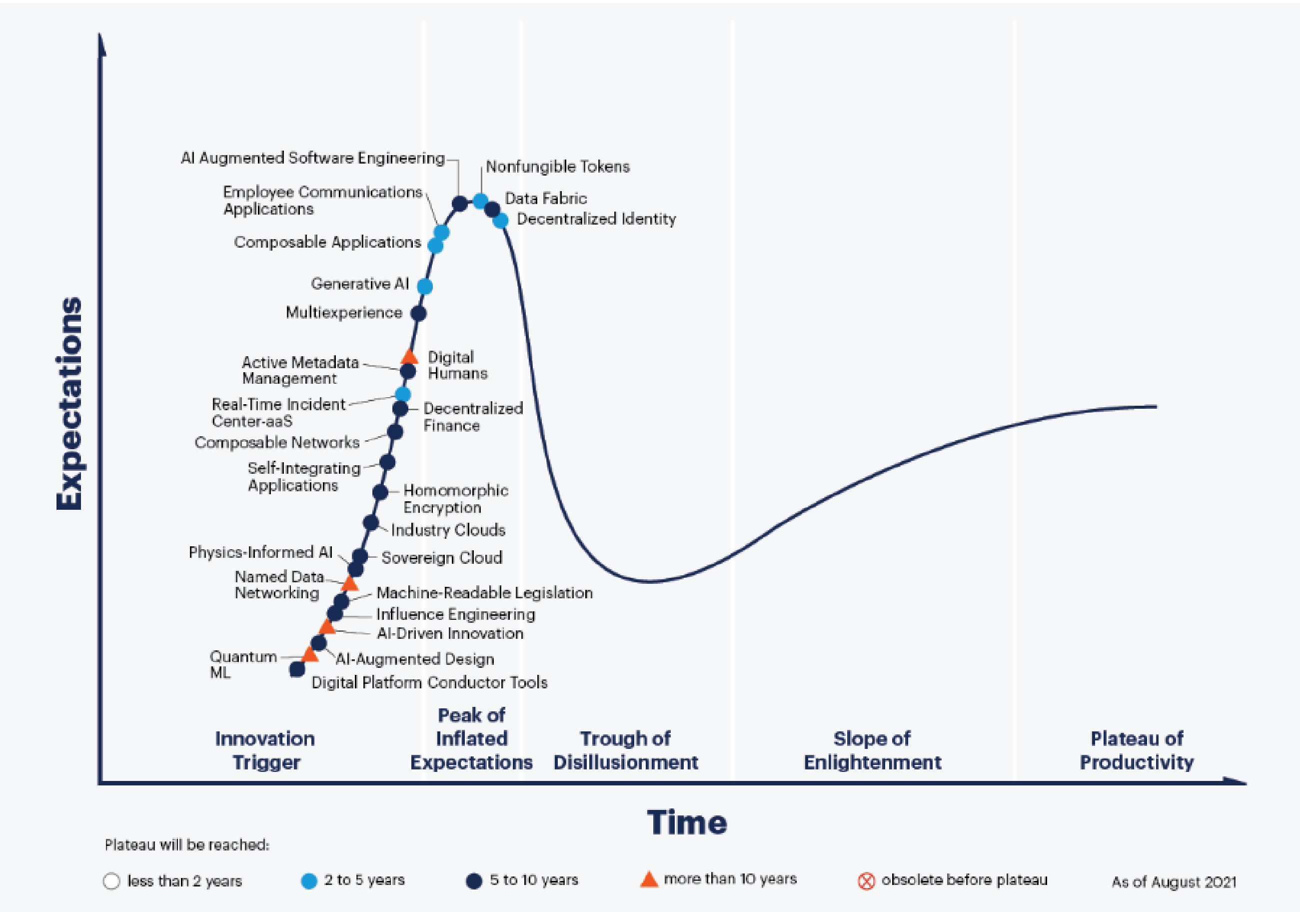
- Material design - the use of quantum computers in industrial sectors can favor the design and development of new materials through statistical simulations and combinatorial analysis of several variables.
- Supply chain optimization - the quantum computer will be able to optimize procurement processes by processing a large amount of data collected from Internet-of-Things (IoT) devices almost in real time.
- Risk modeling and identification - an increase in the calculation capacity can guarantee an improvement in risk models and more precise identification of the risks associated with the production activity.
- Portfolio optimization - the quantum computer will be able to determine the attractiveness of a portfolio based on a detailed analysis of the underlying interconnected variables.

The market is evolving, such as the experimentation of the quantum computer in several sectors. For example: a major global bank is working on using quantum algorithms in foreign exchange trading and arbitrage. Many financial institutions are investigating the potential use of quantum computing in areas, such as asset pricing, capital project budgeting, and data security. The adoption of the quantum computer in industrial sectors can guarantee the acquisition of a significant competitive advantage. Its importance is therefore a priority, the dimensions of the phenomenon, the associated risks and challenges and the current size of the reference market will be analyzed in the next paragraphs.

2. Hype Cycle

To evaluate the importance of the quantum computer, it is possible to use the diagram that describes the technological hype cycle. The model divides the life of a technology into five phases: from its discovery (innovation trigger) to its obsolescence due to the emergence of a new technology (plateau of productivity). The hype cycle allows to evaluate the advantages or disadvantages deriving from the adoption of a technology in a given time period. The positioning of the solution along the curve determines the effects generated in terms of competitive advantage and market share.

Quantum computing (applied to the Machine Learning) is the new bleeding edge of technology that promises to become a game changer across multiple sectors. It is currently at the beginning of its hype cycle. According to Gartner, its plateau of productivity, where mainstream adoption of the technology is expected, will take over 10 years.



Source: Gartner

3. Main Opportunities

The table below shows the short and long-term impacts resulting from an implementation of the quantum computer in multiple sectors. As can be seen, the phenomenon is progressively increasing in importance, generating positive outputs under multiple dimensions.

The main impacts in the application sectors will be then analyzed in the following chapters.

Sector	Near term impact	Long term impact
Consumer	Vehicle Routing	Distribution Supply Chain Freight Forecasting Irregular Behaviors Disruption Management Consumer Offer Recommender Quantum LIDAR / improved sensors Secure Communications Quantum-proof encryption
Energy, Resource & Industrials	Surfactants, catalysts Chemical product design Materials Discovery	Oil shipping/trucking Refining processes Feedstock to product Process Planning Supply Chain Fabrication Optimization Seismic imaging Drilling locations Quality Control Structural Design & Fluid Dynamics Secure Communications
Financial Services	Transaction Settlement Portfolio Management Financial Modelling Insurance pricing optimization Credit/Asset Scoring Trading strategies	Derivatives Pricing Irregular Behaviors Investment Risk Analysis Finance Offer Recommender Secure Communications Quantum-proof encryption
Government & Public Services	Vehicle Routing Advanced materials research	Supply Chain Irregular Behaviors Disruption Management Secure Communications Quantum-proof encryption
Life Science & Health Care	Drug Discovery Protein Structure Prediction	Medical/Drug Supply Chain Accelerated Diagnosis Clinical Trial Enhancements Genomic Analysis Disease Risk Predictions Quantum-proof encryption
Technology, Media & Telecommunications	Network Optimization Semiconductor materials discovery Materials process optimization	Irregular Behaviors Secure Communications Quantum-proof encryption

Source: Quantum Computing – Hype or Reality? - Deloitte Internal documents

4. Challenges

While the adoption of quantum technology within an organization has numerous benefits, on the other hand there is no lack of challenges for its correct implementation.

Let's see some of them in detail:

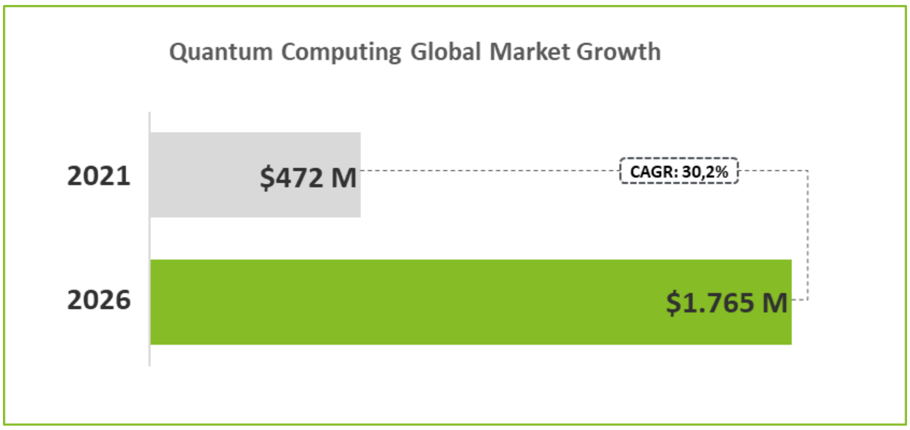
- **External factors:** quantum computers are extremely sensitive to external factors (such as atmospheric temperature) and require more attention and maintenance than traditional computers.
- **Computation dimension**: by construction, the qubit is much more complex than the traditional bits used by today's computers. For this reason, the evaluation of the computational capacity can be difficult.
- **Computational errors:** compared to traditional computer science, the quantum computer is subject to greater calculation errors. This determines the need for an increase in controls in the results produced.

One risk to consider is the quantum computer's ability to overcome the security limits present in our computers today. In fact, standard cryptography can be easily decoded by this new emerging technology with a risk to private information and a collapse of the information systems and business functions of institutions. Quantum decryption also poses a risk to the blockchain that can easily be overcome by the computational capabilities of the supercomputer. To date, such prospects are still distant, but it is necessary for companies to adopt a proactive behavior aimed at considering the adoption of quantum technology both in terms of productivity optimization and as a source of cyber defense against unwanted attacks.

The adoption of the quantum computer guarantees secure data encryption against widespread cyber-attacks. Financial institutions, government agencies, hospitals, and other organizations need to identify data that have long sensitivity periods and protect them against steal-and-later-decrypt quantum attacks. Organizations will soon be called upon to adopt quantum technology before the quantum computer reaches the peak of the hype cycle. A new era is about to begin, and it is essential to be ready for change.

5. Market Trends

The overall quantum computing market is expected to grow from $472 million in 2021 to $1.765 million by 2026 at a CAGR of 30,2%. The key factors driving this growth are represented by the need to ensure secure digital communications and transactions and the need to manage and optimize information deriving from big data. Below is a brief description of the growth trends of the market with evidence of the leading and first-arrived sectors.



Source: GlobeNewswire.

The growth of the global quantum computing market is expected to be driven by the banking and financial sector in the coming years. The banking and financial sector receive great benefits in terms of cost savings and increased revenues from the adoption of the quantum computer. Leaving aside the private sector for a moment, public investment will also contribute to market growth. Governments are investing large amounts of money in research and development in quantum computing. The objective of the countries is to exploit the potential offered by the supercomputer to increase internal and external security and the efficiency of the public apparatus. However, the projected growth of the quantum computing industry could slow significantly if, as we have seen above, the stability and error correction problems are not resolved in the short term.

As previously described, the banking, financial services and insurance sectors are driving the growth of the market. This is mainly due to three advantages deriving from the adoption of the quantum computer:

- A significant increase in the speed of commercial and trading transactions
- The ability to analyze and process a large or unstructured datasets
- The ability to simulate complex economic scenarios by predicting their future trend.

The possibility of carrying out market simulations is certainly the greatest advantage for these sectors. Traditional computers can only process a small number of variables. Numbers that increase exponentially using a quantum computer. Quantum computing reduces computing time and costs compared to traditional computers and increases the effectiveness and efficiency of risk forecasting. The use of this technology for the construction of simulation models allows a reduction of costs and the creation of new market opportunities.

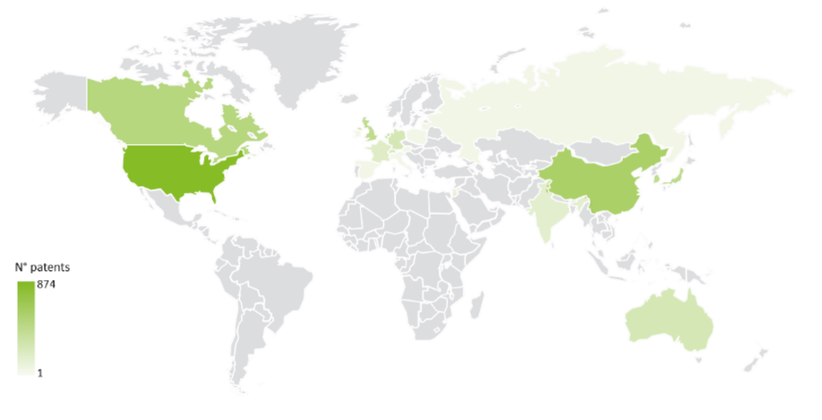
An element of growth in the quantum computer market is represented by the need to safeguard and protect data stored digitally. Cyber security is a priority nowadays and financial institutions invest large capital to keep the corporate and personal data of their customers safe. Due to its construction characteristics, the quantum computer is the optimal solution to guarantee high security standards and to foresee possible hacker attacks. If quantum cryptography allows to encrypt sensitive consumer data, the predictive capabilities of the quantum computer allow to mitigate the risks associated with cyber-attacks and to analyze fraudulent behavior from a predictive point of view. Quantum technology can interface with blockchain and artificial intelligence solutions to exponentially increase their potential. This allows an increase in digital security but also an increase in the speed of transactions, key aspects in the diffusion of this new technology in terms of investments and market share.

6. Investments

Investment in quantum computing today is likely to bring a considerable competitive advantage in the years to come. The private sector and especially the public sector are investing large amounts of capital in the development of quantum technology. The diagram below shows how the number of patents registered per country deriving from research and development activities in the field of quantum computers are constantly increasing. In the coming years, as previously described, the growth of the quantum technology market will bring new economic investments. The applicability of quantum computing will no longer be limited to the banking and financial sector but will involve a multitude of industries.

N° of patents per year and geographical distribution

Regional distribution of TOP 20 countries



- **32 countries** involved in R&D activities
- **TOP 20** countries account for **98,5%** of total number of patents; **TOP 10** for **93,7%** and **TOP 5** for **81.5%**
- Regional distribution: **North America 60,9%; Asia 22,5%; Europe 14,5%**; Others 2,0%

TOP 20 countries

Source: Quantum Technologies Patents, Publications & Investments, Le Lab Quantique, Septembre 2020

The quantum computer implementation perspectives involve several application areas. For example, some investment and future development possibilities are mentioned for the industries of digital security, medical and pharmaceutical, statistics and financial.

The digital security industry is investing in the development of quantum computers that enable a high level of cyber protection. The computing power of quantum technology can easily surpass the security protocols adopted by traditional computers. This has a disruptive medium-term impact on today's digital security. To counter this phenomenon, investments in this new sector are increasing exponentially.

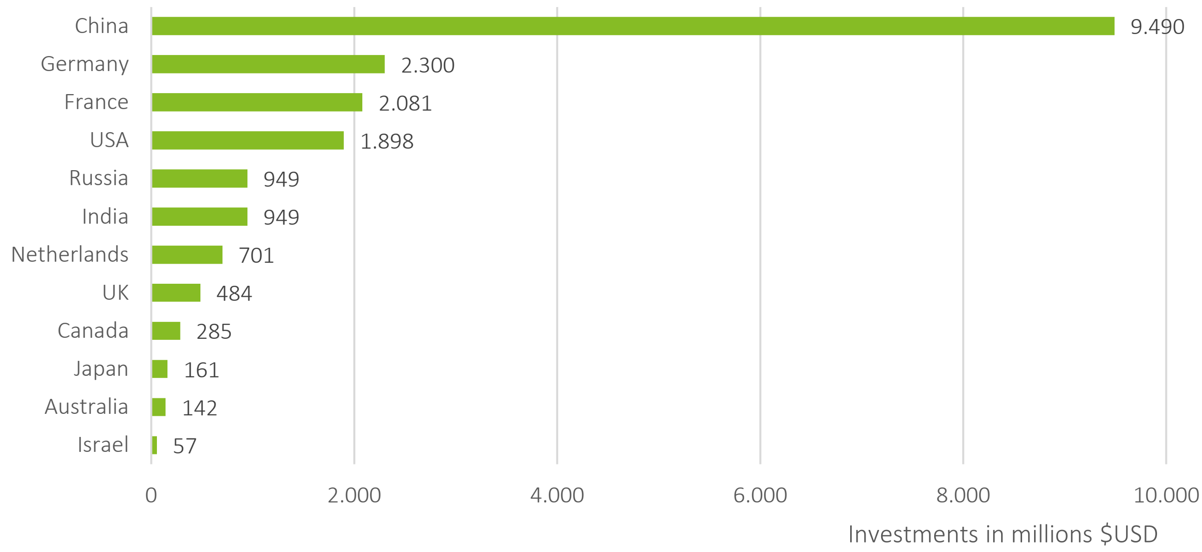
The ability to simulate complex scenarios makes quantum technology particularly applicable to the medical and pharmaceutical industry. Using the quantum computer, it will be possible to study the interaction between molecules and determine the effects of drugs in the human body digitally. Pharmaceutical companies could design targeted drugs for personalized medicine and shorten the initial trial phase with digitally simulated testing. To date, this technology is only in its infancy, but the growth prospects are very favorable.

The potential to apply the computational capabilities of the quantum computer for statistical purposes is a feature of primary importance. The biggest and most expensive challenge for the analytics sector is certainly the interpretation of large amounts of unstructured data. Quantum technology, thanks also to the possible connection with artificial intelligence tools, can research and determine the link between the variables involved. As of today, this possibility is still being tested, but the results achieved are certainly positive.

Finally, the financial sector, as highlighted in the previous paragraphs to which reference should be made for further information, has great growth opportunities for investments and market share. A priority aspect is represented by the possibility of optimizing the management of financial portfolios through quantum technology. The quantum computer allows to compare historical trends with current trends almost in real time through accurate and on-demand predictive analysis. The ability of quantum technology to be implemented in multiple industrial sectors and its ability to optimize and rationalize processes has led many governments to invest significant amounts of money in the development and evolution of the quantum computer.

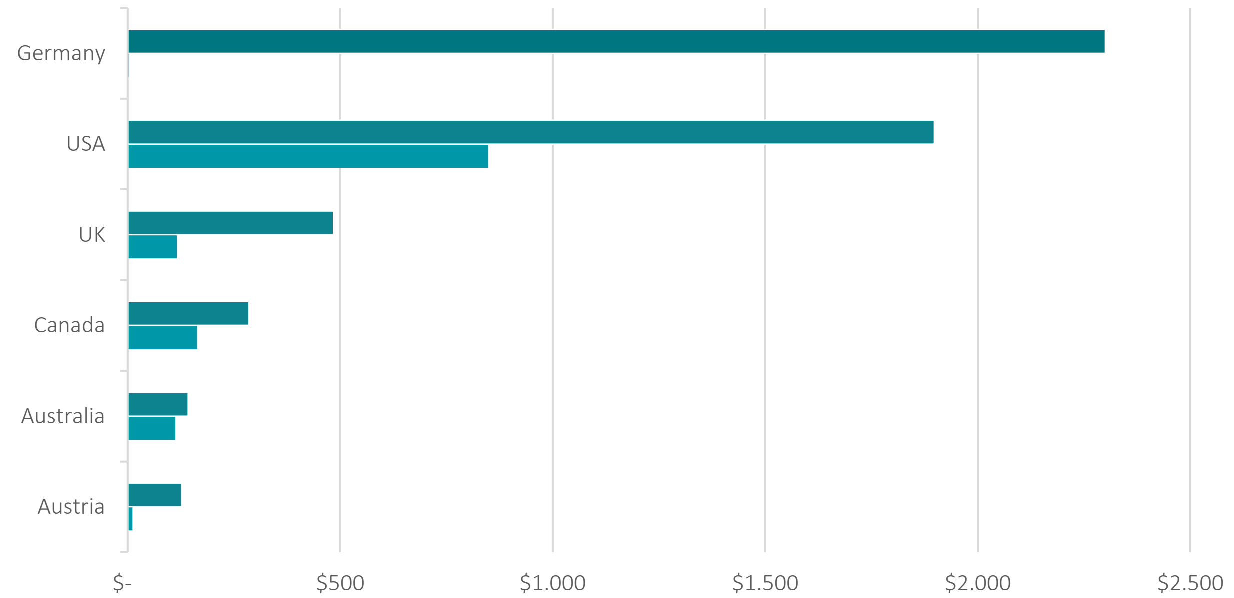
In particular, the countries that made the most significant investments in this technology in 2021 are China (9.490 million USD dollar), Germany (2.300 million USD dollar), France (2.081 million USD dollar), the USA (1.898 million USD dollar) and Russia (949 million USD dollar).

Sovereign Investments in Quantum Technologies as of May 2021 ($USD)



Source: Aggregated values from "Quantum Computing, Hype or Reality?", Deloitte internal document, July 2021. Exchange rate from AUS$ = 1,37

Sovereign and private investments in QC (millions USD$)



	Austria	Australia	Canada	UK	USA	Germany
Sovereign	$127	$142	$285	$484	$1.898	$2.300
Private	$11	$112	$163	$116	$848	$3

Source: Aggregated values from "Quantum Computing, Hype or Reality?", Deloitte internal document, July 2021. Exchange rate from AUS$ = 1,37

The number of investments in Quantum Computing differs among the countries and, mostly, between public and private investments. The table above shows some countries investments and the related sovereign-private split. The difference between private and public sector is evident for every country: governments tend to invest in Quantum technology more than private entities.

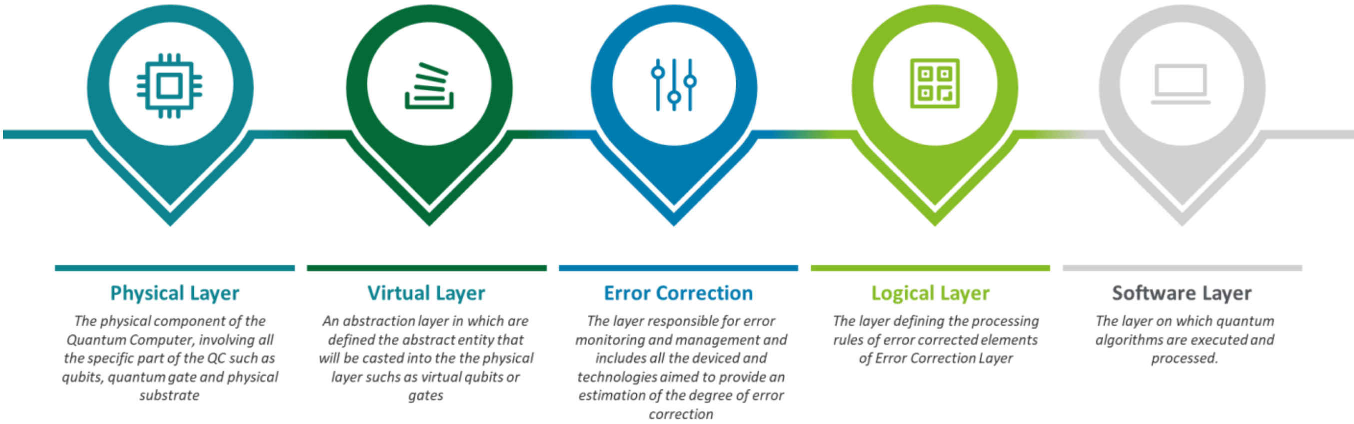
On the European side, Germany overcomes other countries with its public investments, while USA leads private investments with two-thirds of the global private sector investments. Otherwise, comparing the amount of USA and Germany public investments and their GDP (Gross Domestic Product) values, Germany investments stand out considering more limited financial resources.

Regarding the other countries (UK, Canada, Australia and Austria), although investments are more limited, they can be considered significant once again in relation to their annual GDP. As it is shown, global countries are moving towards Quantum innovation with different paths, investing in different types of resources.

The Quantum Computing Challenge

Quantum Computing Ecosystem

Like classical computer, quantum computer architecture is built up on different technology layers, each providing a specific contribution to quantum computer operation. Whenever an operation is executed, each layer will issue a command in order to process the results. By designing architecture in this manner, the result will be to focus on individual challenges.



Physical Layer – The Physical layer, which is also the lowest layer, takes in account parameters such as degree of error and time scale of operations, which determines the speed of the computer. Such layer includes the physical components of the QC such as 1) the qubit, 2) the environment on which qubits are located, 3) the quantum gates dedicated to qubits manipulation.

Virtual Layer – The Virtual layer represents the abstract layer of the quantum hardware, in which information is casted into the physical layer. Such layer includes the virtual qubit and all the virtual components needed for qubits interaction and measurement

Quantum Error Correction – The quantum system is necessarily in contact with a larger system and that is its environment. For a large-scale quantum computing, the involvement of fault tolerant Quantum Error Correction is crucial. This layer includes all the devices aimed to determine the strength of error and to provide an estimation of the degree of error correction.

Logical Layer – The Logical layer is aimed to allow logical quantum computing with the help of fault tolerance resources from the Quantum Error Correction stage.

Application Layer - The Application layer is a quantum-programming environment in which the quantum algorithms are executed. The Application layer consists of application qubits and gates; such application qubits are logical qubits, which are used by a quantum algorithm.

Information gathered from Provider websites and public sources

In such scenario, different players are joining the race, specializing themselves in different kind of services.

End-to-End Providers. End-to-End Providers are usually identified with big tech companies and well-funded startups. IBM has been one of the first to invest in quantum computing technologies and continues leading the development of the field. In the last decade several other leading-edge organizations have joined the race, developing and providing full-stack services. Among big tech companies, Google and Alibaba have drawn a lot of attention while Microsoft is active but has yet to unveil achievements towards actual hardware.

Each company offers its own cloud-based open-source software platform and different levels of access to hardware, simulators, and partnerships. In 2016 IBM launched Q Experience, arguably still the most extensive platform to date, followed in 2018 by Rigetti's Forest, Google's Cirq, and Alibaba's Aliyun, which has launched a quantum cloud computing service in cooperation with the Chinese Academy of Sciences. Microsoft provides access to a quantum simulator on Azure using its Quantum Development Kit. Finally, D-Wave Systems, the first company ever to sell quantum computers (albeit for a special purpose), launched Leap, its own real-time cloud access to its quantum annealer hardware, in October 2018.

Hardware and Systems Players. Hardware players are specialized on developing and building hardware only. These players include both big tech companies (e.g. Intel) and startups, such as IonQ, Quantum Circuits, and QuTech. In such scenario, a variety of different companies have joined the race, specializing the effort on the engineering of specific piece of hardware. Quantum Circuits, a spinoff from Yale University, intends to build a robust quantum computer based on a unique, modular architecture, while QuTech—a joint effort between Delft University of Technology and TNO, the applied scientific research organization, in the Netherlands—offers a variety of partnering options for companies. One example of hardware and systems players extending into software and services is QuTech, which launched Quantum Inspire, Europe's first quantum computing platform with access to quantum simulator supercomputing.

Software and Services Players. Another group of companies is working on enabling applications and translating real-world problems into the quantum world. They include Zapata Computing, QC Ware, QxBranch, and Cambridge Quantum Computing that provide software and services to users. These companies see themselves as an important interface between emerging users of quantum computing and the hardware stack. However, they each present very different commitments and approaches to advancing the original quantum algorithms.

Specialists. These are mainly startups, often spin off from research institutions, that provide focused solutions to other quantum computing players or to enterprise users. For example, Q-CTRL works on solutions to provide better system control and gate operations, and Quantum Benchmark assesses and predicts errors of hardware and specific algorithms. Both serve hardware companies and users.

The ecosystem is dynamic and the lines between layers are easily blurred or crossed, particularly by maturing hardware players, extending to higher-level application layers, or even service layers. End-to-end integrated companies continue to reside at the center of the technology ecosystem; vertical integration provides a performance advantage at the current level of industry maturity. The largest investments to date have flowed into the lower layers of the stack, but no single winning architecture has yet emerged.

Quantum Computing Challenge – Where to Play

As Quantum Computers keep evolving and more players are joining the challenge, the attention is arising around the possible area of application of this new technology. Even if quantum computers will not be general-purpose machines, for some industries the benefits look clearer than others. In the following paragraphs we will discuss how quantum computing will be able in the future to tackle some of the challenges of different industries.

Chemicals & Petroleum. In the energy sector, one scenario for utility optimization is the prevention and timely resolution of outages. Quantum computing can make outage management a proactive exercise by processing information about network quality and status and key risk factors, as opposed to the data processing limitations of a traditional computing environment. Risk factors can range from external, uncontrollable factors (such as weather) to maintenance issues (such as equipment depletion) and by preventing these factors from occurring, improvements in customer service, security and revenue would be achieved.

Distribution & Logistics. In logistics, finding the optimal route is always essential. In fact, for the global market in this field, it is expected to have a compound annual growth rate of 3.48% from the years 2016-2022 and to increase in value $12,256 billion by the year 2022. Over the years, with the increasing globalization of markets and the growing demand for transportation of products from one place to another, logistics has become a significant factor in many economies' development. The operation of a supply chain is an essential and decisive point in a competitive business, but at the same time, transportation activity has negative consequences on human life, as it turns out to be one of the main contributors to air pollution and greenhouse gases.

Financial Services. Quantum computers can revolutionize the financial system through faster and more accurate resolution methods. In fact, compared to classical computers, quantum computing has advantages in the areas of simulation, optimization, and machine learning (ML). Quantum computing can perform efficient near real-time simulations in critical areas such as pricing and risk management. Optimization models are key activities in financial institutions, aimed at determining the best investment strategy for a portfolio of assets, allocating capital, or achieving productivity improvements. Some of these optimization problems are nearly impossible for traditional computers to tackle, so approximations are used to solve the problems in a reasonable amount of time. Quantum computers could perform faster and much more accurate optimizations without using any approximations.

Health Care & Life Science. Quantum computers provide powerful tools to study complex systems such as human physiology and the impact of drugs on biological systems in living organisms. For this reason, quantum computing will play an essential role in pharmaceutical R&D, especially in the early stages of drug discovery and development. An example supporting the potential of quantum mechanics in this area is the use of synthetic chemistry, which provides researchers the tools to exclude potentially inactive compounds and to support the synthesis of more challenging compounds.

Manufacturing. Quantum computing is expected to help develop breakthrough products and services that will disrupt and redefine manufacturing leading chemical discovery, product development, and process optimization among the manufacturing areas.

- Discover - Materials with more advantageous strength-to-weight ratios, batteries that offer significantly higher energy densities, more efficient synthetic and catalytic processes are only some benefits that quantum computing could provide.

- Design - Today, many products are designed and pre-tested using computer simulation. Quantum computers are expected to execute these simulations accurately calculating system loads, load paths, noise, and vibration. By performing this type of analysis, it is possible to optimize the production of individual components within an overall system.

- Control - The combination of quantum computing and machine learning, as well as its application to optimization, is expected to have significant impact in manufacturing in several areas such as semiconductor chip fabrication, production flows and robotics scheduling, software validation and fault analysis.

- Supply Chain – In this area, quantum computing potentially could accelerate decision-making and enhance risk management to lower operational costs, as well as reduce lost sales because of out-of-stock or discontinued products.

CHEMICALS & PETROLEUM	DISTRIBUTION & LOGISTICS	FINANCIAL SERVICES	HEALTH CARE & LIFE SCIENCE	MANUFACTURING
• Chemicals • Oil & Gas • Energy	• Logistics • Travel & Transports • Retail & Consumer Products • Telecom. & Utilities	• Banking • Financial markets • Insurance	• Life Science	• Automotive • Aerospace & Defense • Electronics • Industrial products
Understanding nature and chemistry as has never been done before. Implications of QC could be in making environmental predictions, optimizing energy grids and generating breakthroughs in carbon-capture technologies	Nowadays, the largest computing systems are adopted to address logistics and transportation optimization problems. QC could bring advantage when increasing complexity of the studied system, as well as increasing number of variables taken into account	Financial istitutions are exploring QC to dramatically speed up immensely complicated calculations improving their accuracy. They strive to better manage risks and opportunities related to their portfolios, refining classical mathematical models (e.g. Monte Carlo simulation)	Computational intensive problems are usually found in the management of real-world genomic data. QC can also help in discovering new drugs and proteins. In particular, it could be exploited to tackle the long- standing protein folding problem (prediction of 30 structures)	Manufacturing may become an early beneficiary of QC. Chemistry and materials science departments would reap the first benefits, followed by optimization applications in production planning, fabrication, logistics and supply chain, as well as machine learning, for example for quality control

Quantum Computing Challenge – Use Cases

Although quantum technology is not a fully widespread technology, some companies have already started to invest in it and to develop some quantum computing project. Following we report some of these use cases, with application spacing from financial services to telecommunication optimization.

Leading financial group in Spain. In 2019, the Group decided to invest in Quantum Computing in order to explore the potential for quantum computing technology in this field. Risk assessment, fraud detection, portfolio selection and allocation, and data mining optimization are some of the applications studied by their experts.

The first project using quantum computing was aimed at carrying out risk assessment simulations for financial assets. Given the advantages brought by this application, the bank continues its investments in Quantum Computing exploring the use cases in financial world. A recent use case consists of a collaboration aimed at improving documents classification process using quantum inspired algorithms.

Leader in automotive sector. In the automotive field, some players announced that they are actively pursuing QC research, sometimes partnering with companies in the upstream part of the QC value chain. The investigation is about quantum simulation for material sciences, aiming to improve the efficiency, safety, and durability of batteries and fuel cells. Advantages of QC pilots in vehicle routing area have already been demonstrated. The company is running across the path through QC Strategy targeting several use cases, many of these belonging to vehicle manufacturing domain.

Government authority. One of the key goals for the Transport for *Future Transport Technology Roadmap 2021-2024* launched in March 2021, was to investigate quantum technology to become a global leader in transport quantum computing. Such national transport authority plans to use quantum technology to manage the transportation network with the goal of saving travelers time as quantum technology will increase the computing power needed to reduce delays, improve reliability, and optimize travel.

To carry on this project, the Department of Transport is establishing a Center of Quantum Technology that will employ an expert advisory board comprised of pioneers from the government, industry and academia. The authority is also seeking to attract interest from industry leaders, academics, and global start-ups to help research, develop and implement quantum technology trials across the transport network.

Italian leader in TELCO sector. Optimization problems is a common theme across several industries, from supply chain management to portfolio asset management. One particular application of this family of problems is related to the optimization of line of communication, involving specifically TELCO industry and companies.

In Italy the first network operator of the country, has developed a quantum computing solution for 4.5g-5g cell management. Specifically, the solution involved the planning of network cell identifier (crucial in smartphones connection to the network) ensuring a better quality of service for users. Such solution has been obtained via a QUBO (Quadratic unconstrained binary optimization) quantum algorithm on a quantum computer, allowing to calculate the best parameters for cell identifier management in real-time, with a speed of execution ten times faster than classical solution implemented so far.

Portugal. Portuguese experts are working on the creation of a high-tech building in order to test and certify network solutions built under quantum technologies. In particular, an important Global Telecom Networks Center, in Portugal, will host these research activities of network solutions based on quantum computing.

The main functions of this innovative structure are:

- Bring the firms together
- Interconnect different Global CoE
- Manage global partnerships
- Support the definition of relevant use cases and prototypes.

This project will help the firms to move on towards quantum technology adoption and to define new quantum communication solutions.

Quantum Computing Challenge – How to play

Some of the top global companies have already started to provide market solution for QC learning and development; such solutions are mainly delivered in form of Quantum Computer as a Service (QCaaS). Such services are aimed to provide access to quantum computing hardware via the cloud, allowing users to experiment and develop quantum computing algorithms without caring about hardware layer.

Among these services, it is possible to identify two different delivery approaches:

Cloud access to multiple quantum computers and simulators. Cloud providers that grant access to quantum hardware owned and developed by a third-party company; it is the case for example of AWS or Microsoft, giving access to computation power deriving from several quantum hardware developers.

Cloud access to their own quantum computer directly. Cloud providers that own and develop quantum computer hardware and grant access to users via cloud services; it is the case for example of IBM and its IBM Quantum System One.

Access to such QC services can present different pricing models, the most common by now being a periodic fee (monthly or hourly based), or a per-task charge.

Conclusions

Given the current scenario, an increase is expected in the diagnostic and preparation initiatives for the integration of the QC with the current networks and software available in the market **(IMPROVEMENT 2023).**

The current estimates are prudential as in recent years there has already been a progressive contraction in terms of time of the evolutionary road map. Since the middle of this decade, it is estimated that the size of the hardware may be compatible with data centers and not with large complexes **(ADOPTION 2025).**

The technology is currently being under continuous refine, the outlook is very promising and in this decade a level of robustness will be reached by bringing the "error correction" to values considered reasonable **(AFFIRMATION 2029).**

There are in place all the conditions to consider the preparation and the setup of advisory framework to sustain the development and respond to the business needs. The direction is to jointly co-operate with the players that are currently sharing their interests to generate value leveraging this game changer Technology.

Glossary

CAGR (Compound Annual Growth Rate)	The rate of return that would be required for an investment to grow from its beginning balance to its ending balance, assuming the profits were reinvested at the end of each period of the investment's life span.
Entanglement	Quantum phenomenon, not reducible to classical mechanics, for which, under certain conditions, two or more physical systems represent subsystems of a larger system whose quantum state cannot be described individually, but only as a superposition of several states.
QCaaS (Quantum Computing as a Service)	Providing on demand services of quantum computers. A cloud service that provides customers access to quantum computing platforms through the internet.
Quantum gate	Basic quantum circuit operating on a small number of qubits. They are the building blocks of quantum circuits.
Quantum ML (Quantum Machine Learning)	Integration of quantum algorithms within machine learning programs.
Qubit (quantum bit)	Elementary information unit of quantum computing. It is homologous to the "bit" of classical computation, with the difference that, in addition to the two traditional states 0 and 1, it also admits the quantum superposition of the two states.
QUBO (Quadratic Unconstrained Battery Optimization)	Combinatorial optimization problem (NP hard) with a wide range of applications from finance and economics to machine learning.
Superposition	The first postulate of quantum mechanics states that two or more quantum states can be added together ("superimposed"), and the result will be another valid quantum state; and conversely, that each quantum state can be represented as the sum of two or more other distinct states.
NISQ (Noisy Intermediate Scale Quantum devices)	Devices that are composed of hundreds of noisy qubits, qubits that are not error-corrected, and therefore perform imperfect operations in a limited coherence time.

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