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TRANSITION TO QUANTUM ECONOMY: TRENDS, PROSPECTS AND OPPORTUNITIES FOR CYPRUS AND CYPRIOT BUSINESSES

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1. THE RATIONALE BEHIND THE STUDY

This study coined "**Transition to quantum economy: Trends, prospects and opportunities for Cyprus and Cypriot businesses**" has been jointly conceptualized by BK Plus Europe and the European University of Cyprus for the Employers & Industrialists Federation's (OEB). The purpose is to explore new trends, opportunities and prospects related with quantum technology that would enhance the growth, positioning and efficiency of the Cypriot businesses and of the country as a whole.

The study was drafted for the project titled "Sound Labour Relations, Contemporary Enterprises" (SLR), which is co-funded by the European Social Fund of the European Union and the Republic of Cyprus. The study's findings will be presented to the 12th SLR Network Meeting, an event which is expected to take place in November 2022. The SLRNetwork is an initiative established through the implementation of the SLR project which counts more than 500 HR professionals as active members. The meetings aim in keeping the SLRNetwork's Members updated and informed about the developments and changes that affect their field and thus work while being given the opportunity to exchange applied practices within their companies. At the Network's events, distinguished professionals present and discuss various industrial relations and HR topics with hundreds of attending Members. As such, the concept of quantum economies was decided to be presented at the upcoming meeting.

Latest developments indicate significant advancements with the integration of artificial intelligence and the cultivation of a quantum vision, which are anticipated to underpin and dominate the European agenda and hereto the future operational and business models of various European businesses across different sectors. Currently a trend at the first stages of its development, it is undeniable that quantum technologies will alter our perspective and in turn our daily lives with knock-on effects on communication, travelling, conduct of financial transactions, and even the treatment of illnesses. According to various sources, the game-changing, subversive and disruptive nature of quantum technologies will yield tangible results within the upcoming decade, implying that whoever invests on the above technologies and systems at their early stages will acquire a first-mover advantage.

By realizing the growing potential of quantum, governments around the world are already underway in the formulation of policy overtures, provision of funding and involvement in multiparty ventures (i.e., in the European case) that aim to mature and integrate quantum systems in national but also international market levels. For this reason, the present study effort aims to kickstart a broader policy discussion in Cyprus about the positive dividends that could be generated through a more systematic and engaging approach towards these new technologies. Nevertheless, a successful deployment of quantum systems – from a technical standpoint – does not always guarantee an equally befitting commercialization and in turn maximization of benefits through the market (i.e., the Cypriot businesses). Therefore, this study aims to demonstrate the generated expediency of quantum technologies by providing a comprehensive elaboration of all potentially impacted sectors along with applied business models for quantum development and a list of potential policy pathways, and finally capacity building activities for relevant stakeholders (i.e., HR Professionals of OEB) to facilitate the commercialization and diffusion of these technologies across the market, resulting in its modernization and growth.

In this context, OEB which should operate as a catalyst by reinforcing the capacity of its members and associations to understand, familiarize and integrate quantum technologies in their business models and by undertaking the necessary processes to assist Cypriot businesses in the securement of funds. This comprehensive study will focus on introducing the global and European trends and implications in quantum development for Cyprus and OEB, elaborate a comparative analysis of foreign country business models and formulating a proposal for the most optimal policy pathway for Cyprus through a list of well-thought recommendations.

2. BACKGROUND OF THE STUDY

2.1. HISTORICAL BACKGROUND

Nearly a century ago, Planck's research on "blackbody radiation" and Einstein's "description of the photoelectric effect" set the groundwork for the development of quantum theory. The physics theory known as quantum mechanics describes natural laws at the level of subatomic particles. It involves the capacity of a system to demonstrate the link between particles despite great physical distances between them or to exist in many states (i.e., superposition) simultaneously (i.e., entanglement). It is feasible to store and process enormous amounts of information thanks to superposition. At the same time, entanglement enables delivering a message that is entirely impervious to interception. However, a disruption of these principles in the form of "observation" or measuring of the quantum state can on one hand provide more information but one the other results in the system meltdown. These principles can be further explained in the following picture (*see figure 1*) that was retrieved (Buchholz et al., 2020).

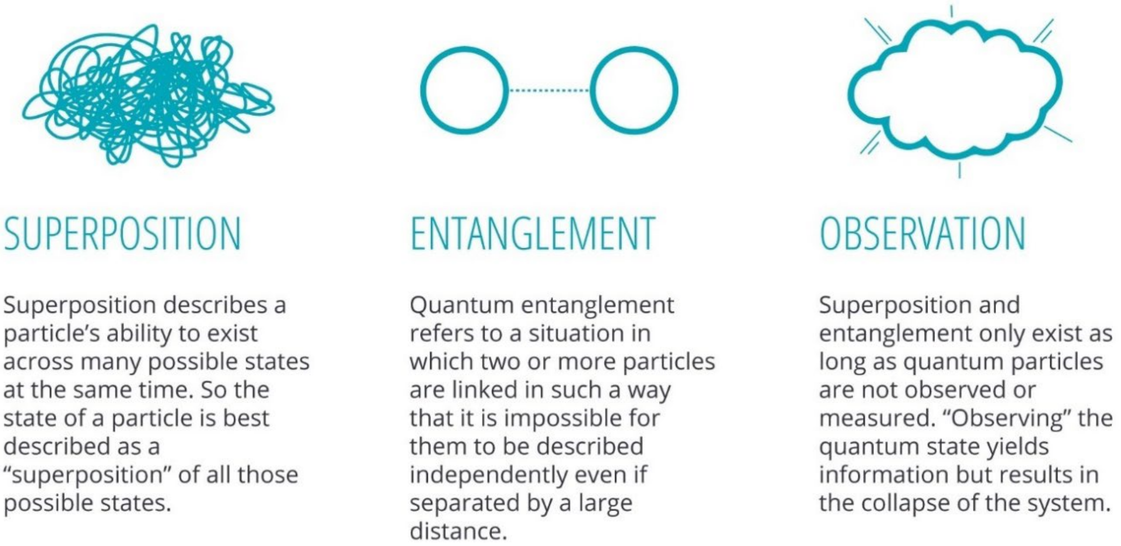

Figure 1: Quantum Principles

The laws of quantum mechanics are used in the construction of a number of widely used technologies, including transistors, lasers, and magnetic resonance imaging (MRI). Although quantum mechanics is highly relevant to every aspect of the Information and Communications Technology (ICT) currently in use, there is still much more potential for the use of quantum resources. Despite its evolutionary tenor, quantum does should not be considered a new concept, since it dates back to the physical reality debates on the 20th century, namely the first quantum revolution. Since then, the emergence of semiconductors from chemical reactions and electronic wavefunctions enhanced computer processing and its application in various objects such as cars, cellphones and digital cameras. Many experts believe that the use of quantum technology, particularly quantum computing, is undergoing a second revolution. As new discoveries, such as ultra-sensitive sensors for biological imaging, secure communication networks, and new paradigms for computation progressively materialize, their effects on industry and society are expected to be dramatically transformational. It is anticipated that the engineering of quantum phenomena would enable the creation of new device classes and computing capabilities, allowing for creative approaches to issues that cannot be solved by the existing conventional technology. Thus, the development of computers, communications systems, sensors, simulations, and small metrological devices can benefit more from the new man-made quantum states with high sensitivity and non-local correlation. Nevertheless quantum engineering still has a long way to go, despite the fact that quantum mechanics has thoroughly developed as a science.

2.2. QUANTUM TECHNOLOGIES IN A NUTSHELL

2.2.1. QUANTUM COMPUTING

Quantum computing is a cutting-edge computing technology that makes use of the principles of quantum mechanics to enhance some applications' performance exponentially and possibly open up entirely new computer domains. Special-purpose quantum computers, often known as quantum simulators, are some of the first quantum hardware devices. A quantum computer functions as a massively parallel machine with an exponentially huge number of computations running at the same time thanks to quantum bits that can be both zero and one at the same time and through immediate correlations across the device. Essentially quantum computing will significantly increase our capacity to "untie the gordian knot" of some of the most complex computational problems spanning across centuries. In fact, quantum computing is said to be as different from classical computing, as a classical computer differs from the abacus. As explained above, whereas classical computers perform calculations using binary digits i.e., 0 or 1, quantum computers represent information using quantum bits – widely known as qubits - which can be in a superposition of both states (0 and 1 at the same time). Qubits enable quantum computers to make multiple calculations at the same time, potentially resulting in an immense augmentation in computational efficiency as opposed to classical computers. There are a number of applications where quantum computers will be particularly transformational:

- Simulation of physical systems for drug discovery and the design of new materials.
- Solving complex optimization problems in supply chain, logistics and finance.
- Combination with artificial intelligence for the acceleration of machine learning.
- Factorization of integers, enabling the decryption of most commonly used cybersecurity protocols (e.g., RSA, an asymmetric encryption algorithm, used for secure data transmission).

The classical difference between quantum computing and today's computing can be better illustrated in the below animated image (see figure 2) which was retrieved from a 2019 report (Vernacchia, 2019):

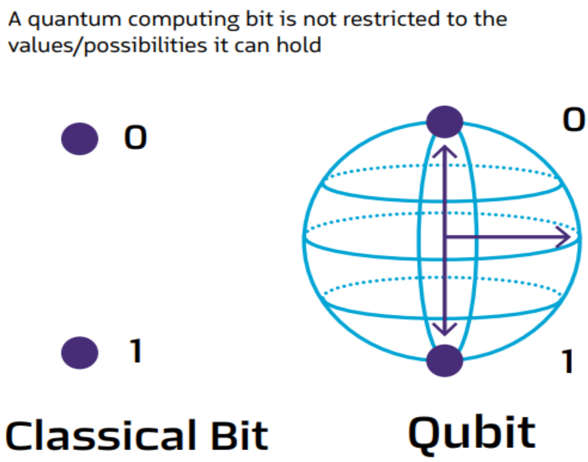

Figure 2: The principle of Quantum Computing

2.2.2. THREE STAGES OF DEVELOPMENT

Although quantum computing has advanced significantly over the past ten years, it is still in its infancy, and a broad commercial application is yet years away. We live in the era of Noisy Intermediate Scale Quantum technology, or "NISQ" for short. Qubit systems have not yet been "error-corrected," which means that noise still causes them to lose information rapidly. The next three to ten years are anticipated to be spent in this stage. Researchers anticipate that several use cases will develop, even at this early and flawed stage. These include improvements in investment portfolio optimization, medicine discovery, and efficiency advantages in developing novel compounds (Lewis, 2017).

After the error correction issues have mostly been handled, a five-to-twenty year period of broad quantum advantage is anticipated to follow the NISQ era. Many big firms have lately revealed roadmaps for quantum computing, making the way to widespread quantum advantage more obvious. Along with error correction, the next ten years will see the development of higher quality qubits, abstraction layers for model developers, at-scale and modular systems, and machine scaling up. However, even if these lofty goals are accomplished, more development is required to gain a quantum advantage. Early technological milestones will affect the timeframe more than other milestones since they are intended to prevent a "quantum winter" scenario, in which investment stops, as it did for AI in the late 1980s. Quantum computing is an ideal candidate for an eventual timeline-accelerating discovery since its success is so tightly tied to ongoing fundamental science (Lewis & Travagnin, 2018).

2.2.3. QUANTUM SIMULATORS

Supercomputers are used in the creation of many more complicated objects, including cars, buildings, and aircraft. Quantum simulators are more straightforward to construct than general-purpose quantum computers since they do not need to have complete control over each and every component. Ultracold atoms in optical lattices, trapped ions, arrays of superconducting qubits, quantum dots, and photons are just a few of the platforms being developed for quantum simulators. In reality, although only for some specific challenges, the first prototypes have already been able to do simulations beyond what is now conceivable with supercomputers. The previous only make obvious that research in this area is developing quickly. With the help of quantum simulators, scientists hope to tackle some of the most challenging problems in material science and carry out calculations that would be otherwise impossible.

2.2.4. QUANTUM COMMUNICATION

The safe transmission of quantum information across space is known as quantum communications. Even in the face of infinite processing power, it could guarantee the security of communications made possible by quantum cryptography. Security in communications is a strategic concern for businesses, governments, and consumers alike. It is now provided by encryption using classical algorithms, which a quantum computer would be able to crack. This drives the creation of quantum-safe cryptography, or encryption techniques that are impenetrable by quantum computers. Quantum random number generation, a crucial basic in most cryptographic protocols, is also commercially available today and secure solutions based on it are likewise resistant to attacks by quantum computers. Quantum information is safe since it cannot be duplicated, but for the same reason it cannot be broadcast using traditional repeaters, they can only operate across lengths of less than 500 km. Instead, global distances require repeaters based on trusted nodes or fully quantum devices, possibly requiring satellites. Quantum repeaters provide the benefit of expanding the distances between trusted nodes.

The US National Institute for Standards and Technology (NIST) and the European Telecommunications Standards Institute (ETSI) both initiated standardization activities on post-quantum cryptography in 2015 and 2016, respectively. Theoretically put forth in 1984, the first experimental demonstration of quantum key distribution (QKD) occurred in 1991. A pre-competitive level of technological readiness has now been attained in certain of its implementations, allowing multiple commercial players to work on QKD systems while also testing system prototypes and conducting field deployments. Given that they are incompatible with current fiber-optic infrastructures, these are especially necessary for long-distance quantum communications (Batra et al., 2022)

2.2.5. QUANTUM SENSING

The newest class of sensors made from quantum systems is known as quantum sensing. It could offer measurements that are orders of magnitude more sensitive than conventional sensors for a number of different quantities - such as gravity, time, and electromagnetic. Quantum sensors can offer higher sensitivity, accuracy and speed of use than current technologies, particularly for gravity and magnetic fields. Such sensors work by harnessing quantum effects such as superposition. This area is already yielding working prototypes, which are being developed to compete in the commercial world. Quantum sensors will enable quick and accurate gravity mapping: detecting minute differences in gravity to reveal underground features. More detailed information would prove extremely useful in building new infrastructure on brownfield sites; exploring and monitoring natural resources, including water; and identifying hazards such as sinkholes and landslides.

3. BUILDING A TRANSITION FROM DIGITAL ECONOMY TO A "QUANTUM ECONOMY"

3.1. USE OF QUANTUM IN SPECIFIC SECTORS

The study has identified – and will concentrate on – prospective use cases in four sectors: pharmaceuticals, chemicals, automotive, and financial transactions, which might benefit most immediately from the employment of the present technology. The total value at risk for these industries might range between $300 billion and $700 billion, conservatively (Biondi et al., 2022). Essentially, the main objective of this study segment is to present the most quantum-conducive sectors that can function as the pillars of the envisaged "quantum economy" and which should be taken into consideration by all states that aim to develop their own quantum capacities and put them into practice in their financial backbone.

3.1.1. PHARMACEUTICALS

The study and development of molecular structures in the biopharmaceuticals sector have the possibility to be revolutionized by quantum computing, adding value during production and farther down the value chain. For instance, new pharmaceuticals developed through research and development (R&D) take more than ten years and an average of $2 billion to commercialize (Evers et al., 2022). By reducing the reliance on trial and error and increasing efficiency, target identification, drug design, and toxicity testing might be far faster, more targeted, and more precise thanks to quantum computing. This promising sector features an emerging pattern of joint R&D initiatives and ventures between IT Companies and Pharmaceutical firm, to accelerate discoveries that could change the global perspective and health sector amidst an unprecedented and onerous COVID-19 pandemic. In particular, the partnership between Accenture and quantum company 1Qbit flourishes and led to the creation of new frameworks for molecular structure examination, is one instance at point. The resulting modeling algorithms were later tested in collaboration with Biogen, proving that their QC-enabled drug discovery platform was just as excellent as or better than current approaches for identifying similar characteristics of compounds and foretelling interactions. Similarly POLARISqb has established a reputation in the quantum-driven drug discovery field and remains one of the first companies to develop their own QC drug discovery platform, proving that high-profile collaborations can accelerate technological innovation. Another example is Google's early ventures in the pharmaceutical sector, and particularly its relationship with Boehringer Ingelheim who vowed to establish its own Quantum Lab with the improved applications that could be developed. This is something that could be explored by Cypriot pharmaceutical companies by seeking a credible and high-profile multinational IT partner.

3.1.2. FINANCIAL SERVICES

The financial sector runs on the tenets of safety and trust, whereby the majority of financial goods rely on trustworthy methods of customer identity verification as well as ways to secure data and communications. The majority of commonly used cybersecurity methods and procedures, like RSA cryptography will not be equally protective against a more developed and undeniably sophisticated quantum technologies. In spite of that financial institutions will need to change their data-security strategies and take RSA alternatives into consideration, like quantum encryption (i.e., QKD)—or enhancing conventional encryption (i.e., post-quantum cryptography), to significantly lower the likelihood of information loss by a quantum computer. In the financial industry, advanced computational approaches are already widely used to handle more complicated goods and activities; these techniques are used in areas like algorithmic trading and risk management, where the main problems are data availability and quality. The energy consumption of calculations across clusters of central processing units (CPUs) and graphic processing units (GPUs) can be decreased, however, by using better computing techniques to further optimize operations or even save expenses.

Nevertheless, the most fertile ground for change is observed in portfolio and risk management applications with revamped credit scoring and fraud-prediction models. Although these insights can still be designated as hypothetical, that could be produced is estimated to be around $100 billion, which still renders this exploration worthwhile (Dietz et al., 2020). Additionally, quantum computing, for instance, could assist in the development of trading techniques to decide whether to purchase or sell particular assets in order to attain a particular rate of return at a particular level of risk, reducing the numerous hours which are routinely spent on the analysis millions of trading strategies. All the previous aside, the risk management and prevention in the banking sector is also considered as ultra-significant potential quantum application. The computation time for a typical risk assessment using a traditional Monte Carlo simulation could be reduced from days to hours by using quantum computing techniques. According to McKinsey's estimate, the 20 top international financial institutions store $800 billion in capital reserves with an annual cost of capital of $80 billion. This buffer might be reduced by 1 to 2 percent by more precise risk assessments, freeing about $0.8 billion to $1.6 billion annually. This aim is reasonable, according to experts, given that traditional risk-management strategies have already achieved savings of up to 10%, with the remaining opportunity for improvement being constrained by legal requirements. The potential quantum applications on this sector represent a critical juncture for Cyprus as well as for other countries, since failure to integrate quantum technologies in a timely manner and secure a competitive advantage, could result in major threats for the sector.

3.1.3. CHEMICALS

The chemical industry now has the opportunity to represent quantum-mechanical systems, such as molecules, polymers, and solids, with a completely new level of accuracy thanks to the development of quantum computing. Thus, before creating a single molecule in the lab, it would be possible to determine the most efficient molecular designs or structures to carry out particular functions and achieve desired results. The effectiveness of R&D departments and the manner new products are generated might both be significantly improved with access to this type of computational resource, with implications for the whole chemical industry. This technology can be beneficial to all stages across the chemical industry from R&D, production, to supply-chain optimization, especially considering the possibility of improving catalyst designs through production by using quantum computing. An increase in efficiency of up to 15% can be achieved with a single catalyst, and new and improved catalysts may also make it possible to replace petrochemicals with more environmentally friendly feedstock or break down carbon for the use of CO2. In the case of the chemicals sector, which spends $800 billion annually on production (of which 50% depends on catalysis), a practical increase in efficiency of 5 to 10% would result in a value increase of $20 billion to $40 billion (Budde & Volz, 2019). Like in the previous example, the design of small molecules or polymers requires a more accurate prediction of molecular characteristics which are necessary for their design. Another instance is during the design of a new cleaning product which relies on the triangulation of a technician's expertise, essentially trial-and-error tests, and theoretical models – although these employed models are often crude simplifications of reality. To better understand how, for instance, detergent molecules interact with a wine stain on a fiber and to determine the optimal active chemicals and formulas to remove it, quantum computing could aid this process with optimization computations. The required calculation time might be slashed to seconds by a team employing a quantum computer and the right algorithm.

Currently, these predictions, albeit effective, are also heavily relying on approximation or marginal information. In cases where no trustworthy computational techniques are now available, quantum computers will enable precise quantum-mechanical simulations, opening up prospects for savings and revenue. The cost of R&D for a new product could be drastically decreased by virtualizing significant portions of present lab-based, trial-and-error experiments. If molecular processes can be precisely predicted by quantum computing as promised, lab-based tests for new product development, which can cost $24 billion to $64 billion, or between 30 and 80 percent of that, could be all but eliminated. Subsequently, this would result in an exponential reduction of quality control processes and toxicity testing. Overall, the prospect of th chemical industry is extremely wide because it also has a low entrance barrier, meaning that deployment of quantum computers will complement the sector's current research strategy. Most importantly, there won't need to be any major adjustments to how research is conducted. This could lead to an increase in industrial demand for and adoption of quantum computing practices.

3.1.4. AUTOMOTIVE

Quantum computing has applications for the automobile sector in R&D, product design, supply-chain management, production, mobility, and traffic control. The technique might, for instance, be used to reduce manufacturing process-related costs and cut cycle times by optimizing components like path planning in challenging multirobot processes, such as welding, gluing, and painting. In the context of an industry that spends $500 billion annually on manufacturing costs, even a 2 to 5 % productivity boost would provide $10 to $25 billion in value annually. In particular, algorithms generated through quantum computing can be used by businesses to improve their supply lines including several forms of transportation, enhance energy storage and improve generative design.

From a broader perspective, original equipment manufacturers (OEMs) could employ quality control measures associated with quantum functions to achieve a variety of improvements throughout vehicle design, including those related to enhancing fuel efficiency. The application of quantum computing could also steer and "train" the algorithms for the design of an autonomous driving software or to carry out sophisticated simulations in fields like vehicle collision behavior and cabin soundproofing. Another crucial application is assisting mobility providers in the simulation of intricate economic scenarios so they can forecast how demand will change depending on the region. The automotive industry has seen various initiatives by Volkswagen (i.e., in the showcase of the first real-time quantum-computing traffic routing system for the buses in Lisbon) with the view to reduce passenger waiting, streamline the scheduling of bus travel times and maximize traffic inflows. Other examples of ventures have seen Toyota partnering with multinational producer company, Denso, in 2017 for traffic data analysis in Thailand – involving 130,000 commercial vehicles.

3.1.5. CYBERSECURITY

Quantum computing will accelerate the capacity to decipher data secured by present public-key encryption methods. A classical computer can efficiently multiply substantial prime numbers, but it would take a long time to perform the opposite operation. According to Peter Shor's 1994 theory, a vast, fault-tolerant quantum computer might locate integers' prime factors in a very short amount of time, rendering many of the prevalent encryption standards used at our times as obsolete in the near future. At present, the most significant functional quantum computers span 50 to 60 qubits without error correction, while the creation of a full-fledged quantum computer that can break RSA 2048 or an equivalent public-key encryption is predicted to be at least ten years away. Despite the latter the ramifications for stored data, civilian communications, and national security are profound. More precisely, numerous processes and systems, including digital identification, communications, e-commerce, and digital signatures, all depend on defenses that would be weak if asymmetric encryption were to be cracked. Taking stock of the previous, governments attempting to safeguard state secrets and businesses tasked with securing user and customer data, serve as the potential first-targets of the anticipated cybersecurity challenges (Verhagen, 2019).

On a positive note, researchers found out that cryptographic methods for public-key cryptography in the late 2000s seem to be impervious to quantum computer decoding. However, creating quantum-resistant encryption and switching to a new security protocol take decades. In this regard, the lack of a sufficiently robust, fault-tolerant quantum computer to verify an algorithm's resistance to a quantum assault presents a problem for developing quantum-resistant encryption. Although testing techniques will continue to advance, it will take time for a quantum-resistant algorithm's security to be confirmed. More impediments are encapsulated in the willingness of users to adopt less secure and quantum-resistant but faster services, and in the estimation of cost increase for the internet in turn resulting in wider energy and economic challenges.

The very fact that in 2016, 80% of EU enterprises reported a cybercrime event, calls for a proactive rather than a reactionary approach should be embraced by the business community and governments across the globe. Additionally, the transition to 5G in the telecommunications industry will introduce new security risks, with hundreds more attack vectors than the older 4G networks. Even more worrisome is the growing risk pattern of the "harvest now, decrypt later" threat, which involves data interception by hackers at present with the objective to decrypt when quantum-designed computers enter the market. In this regard, government leaders, even those in nontechnical positions, should have a basic understanding of quantum systems and the emerging national security challenges so they can take steps to protect information and prepare their organizations, teams, and business practices for the quantum world. A welcoming step has been recorded during the last year, when NATO announced the establishment of the NATO Center for Quantum Technologies in Copenhagen. Hosted by the locally-based Niels Bohr Institute, this NATO Center will operate both as an accelerator and incubator areas with the primary goal of assisting companies in maturing and commercializing their technologies to the market, whereas a test center facility will appraise the technological edge of quantum components (i.e., sensors, encryption devices, computers).

At this stage, there are four ways that quantum computers can be used to weaken cyber-driven attacks and are condensed in the following:

- **Quantum computers will be able to decipher information that was intercepted in the past if it was correctly recorded and stored**. State actors or criminals may gather encrypted data in the belief that further improvements may make it possible for them to decrypt it, which is an unavoidable risk that exists now. There are just a few strategies to prevent data pre-capture. Applications should switch as soon as possible to quantum-resistant encryption to reduce this danger.
- **Systemic data vulnerability will be a problem for organizations that do not evaluate their risks and transition to quantum-resistant encryption in a timely manner**. Due to the digital ecosystem's high degree of interconnectedness, this danger is systemic. More crucial data, communications, and services are dependent on the security of our networks as connectivity spreads throughout society. Additionally, increased interdependence increases the possibility that events in one area of the ecosystem could have an impact on organizations on the other. To build resilience against the growing threat of quantum computers, we must make sure that our systems are secure via end-to-end workflows, supply chains, and shared infrastructure.
- **Companies that delay and then rush to switch to quantum-resistant encryption are likely to have design and implementation problems across all IT platforms, which can be taken advantage of by hackers without access to quantum computers**. Organizations should design a strategy for switching to quantum-resistant encryption and proactively examine quantum vulnerabilities.

- **The trust and confidence in the digital ecosystem will continue to decline unless there is clear disclosure about our preparedness for the cybersecurity dangers of quantum computing.** This risk could be reduced with the support of quantum preparation plans from public and private sector organizations and explicit federal instructions on the switch to quantum-resistant encryption.

Up to this point, in-depth evaluations have been conducted on hybrid risks relating to artificial intelligence (AI) and the effects of quantum computing. Combinations of both are widely viewed as ways to overcome the impeding challenges, whether it be real, virtual, or informational. If an opponent, for instance, gets access to these technologies, a variety of attack vectors are feasible, including information attacks by using improved bots to generate specialized material, for example, fake news and deep fakes. By considering the synergistic relationship between quantum computing and artificial intelligence, T. Gabor et al. go one step further. Others expect a halt in AI development, rising research expenditures (which up to now have been the status quo), and the creation of new AI algorithms requiring fewer resources (Bruze et al., 2021).

Combining QC with AI might increase the effectiveness of hybrid threats in the following ways:

- ✓ Phishing tools with improved text and image generating capabilities.
- ✓ By simulating various attack scenarios, for instance via reinforcement learning, adversaries could better plan their strikes.
- ✓ Planning and carrying out intricate (dis)information campaigns in the information arena, maybe in conjunction with kinetic and cyberattacks.
- ✓ New advances in quantum technology research and development have the potential to bring exciting new capabilities to the military. Given the sizable interest and funding for quantum technologies from both civilian industry and governments, it is expected that the technology will mature and that new quantum applications will become available in the coming five to ten years.
- ✓ Allied militaries could bring significant added value to existing efforts in industry and academia by providing testing & validation infrastructure (i.e., test centers), access to end-user military operators.

3.2. CONTEMPLATING FUTURE PROJECTIONS FOR QUANTUM USE

3.2.1. ELECTRIFYING OUR LIVES

Quantum computing has the potential to shift the economics of decarbonization and revolutionize the battle against climate change, helping to keep global warming to the desired level of 1.5°C. Notably, to achieve carbon-free electrification, batteries are a crucial component. Lithium-ion (Li-ion) battery uses in electric vehicles and energy storage are made possible by increasing the energy density of these batteries at a reasonable price. While battery energy density increased by 50% between 2011 and 2016, only 25% increased between 2016 and 2020, and only 17% is anticipated to increase between 2020 and 2025, innovation has halted over the previous ten years (Cooper et al., 2022). According to recent studies, quantum computing will be able to model battery chemistry in ways that are not currently possible. Advancements in electrolyte complex creation, the search for a cathode/anode replacement material with the same qualities, and/or the removal of the battery separator could all be made possible by quantum computing. Batteries for heavy-goods electric cars might thus be developed with a 50% higher energy density, which would significantly advance their economic use. Since these cars are anticipated to cost parity in many nations before the first generation of quantum computers becomes online, the carbon benefits of passenger EVs would not be particularly significant, but consumers would still see cost reductions. Additionally, grid-scale storage can be accomplished with higher-density energy batteries. The effect on the global grids might be seismic. A significant increase in the usage of solar power, which is becoming economically competitive but is constrained by its generating profile, might be made possible by halving the cost of grid-scale storage.

3.2.2. REFORMING FOOD AND FORESTRY

Agriculture is responsible for 20% of yearly greenhouse gas emissions, with methane from livestock and dairy being the main source (7.9 gigatons of CO2e, based on 20-year global-warming potential). Low-methane feed additives can efficiently reduce methane emissions by up to 90%, according to research (Cooper et al., 2022). However, administering those compounds to cattle that is raised outside is very challenging. An anti-methane vaccine that generates methanogen-targeting antibodies is an alternate remedy. While this technique has shown some promise in the lab, it struggles to work in a cow's gut, which is constantly moving due to food and gastric fluids. Instead of using an expensive and time-consuming trial-and-error approach, precise molecular simulations enabled by quantum computing could speed up the hunt for the ideal antibodies. Using statistic s from the US Environmental Protection Agency to predict uptake, we arrive at a carbon reduction of up to an extra gigaton per year by 2035.

3.2.3. DECARBONIZING POWER AND FUEL

In a net-zero economy, solar cells will be one of the main sources of electricity generation. They are still far from reaching their theoretical maximum efficiency, despite the fact that they are becoming more affordable. The efficiency of modern solar cells, which use crystalline silicon, is around 20%. A more effective substitute would be perovskite-based solar cells, which have a theoretical efficiency of up to 40%. However, they pose difficulties since they lack long-term stability and could be more hazardous in particular forms. Additionally, the technology has not yet been made in large quantities. By enabling accurate simulations of perovskite structures in all combinations using various base atoms and doping, quantum computing could assist in overcoming these difficulties by identifying solutions that are more effective, more durable, and nontoxic. In addition, in many sectors of the economy, including those where high temperatures are required but electrification is either impractical or insufficient, or where hydrogen is required as a feedstock, such the manufacturing of steel or ethylene, hydrogen is often seen as a viable alternative to fossil fuels. Green hydrogen was around 60% more expensive than natural gas prior to the gas price increases of 2022. However, enhancing electrolysis might considerably reduce the price of hydrogen.

4. INTRODUCTION TO THE "QUANTUM RACE"

4.1. THE INTERNATIONAL SPECTRUM OF QUANTUM DEVELOPMENT

Governments all over the world have realized that communications security is concurrently (i) a determinant of economic development, (ii) a critical ingredient for national security, (iii) an integral element of defense, and (iv) a pertinent factor for geostrategic prominence as the era of global electronic mass communications made the economic implications of cryptography unavoidable. The Chinese competition with the United States of America (USA) over quantum development over the during the past ten years is considered the most apparent trend in the global arena and another layer of their in-between confrontation. In the Chinese mindset, the Chinese technological push in quantum communications has likely also been influenced by the growing perception that developments in quantum computing pose a threat to national communications security. On the opposite side, the USA undoubtedly enjoys a significant advantage in developing a fully functional quantum computer to minimize emerging threats.

Meanwhile the competition ground also extends in the business sector where US has mobilized the excellence of its industry players like IBM, Google and Microsoft, which are also developing the requirements for "quantum supremacy", while dominating the market against their Chinese counterparts like Alibaba. In October 2019, Google claimed to have achieved quantum supremacy on its 53-qubit quantum computer. However, critics say that the problem solved in the Google experiment had no practical value and that the race for quantum supremacy is still on. Last September, IBM announced a road map for developing its quantum computers, including its goal to build a quantum computer with 1000 qubits by 2023 (Lewis & Travagnin, 2018). Meanwhile, Google has its own plan to build a million-qubit quantum computer by 2029 (Biondi et. Al, 2022). According to expert reports, governments are stepping up their game in order to acquire the necessary hardware capacity for quantum, a fact which can better be visualized in the downward graph (see figure 3) that was retrieved in Biondi's et al., 2022 research paper:

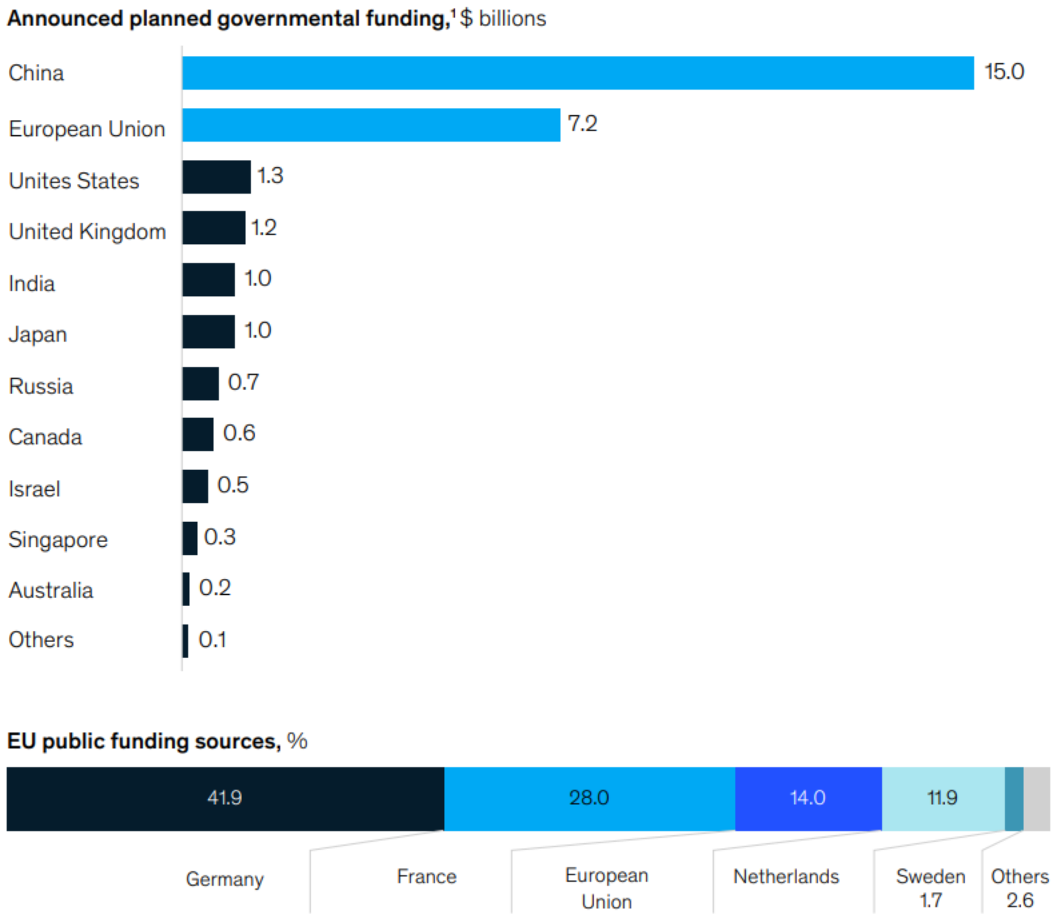

Figure 3: Quantum Investments per Country

This ongoing competition will be reflected in this study section, by highlighting the national policies of EU countries (i.e., France, Germany and Finland) and non-EU countries (i.e., with a focus on quantum giants like U.S.A and China and an emerging player like Japan) in order to provide an informational outline of policy decisions. In the same mindset, the study will briefly touch on the existing EU efforts and initiatives that have an impact in the national quantum planning of all 27 Member States. The selection of the countries has been made based on the organization of their quantum frameworks and the advancement in the research and innovation levels.

4.1.1. PEOPLE'S REPUBLIC OF CHINA

By 2035, China is expected to surpass all other countries in the field of innovation, putting an end to its reliance on imported technology. This is one of the key reasons why quantum computers and quantum communications assume a central stage in its current planning, with government-led expenditures anticipated to reach billions of euros. At present, the Chinese overture is pursuing an ambitious goal that has not yet been matched by Western actors in financial and technical levels. A tangible manifestation of that is the emerging National Laboratory for Quantum

Information Sciences in Hefei, estimated to cost $10 billion, despite scant information on total spending in China in this field (Singer, 2022). Apart from being a game-changer in terrestrial communications, China also dominates the space component in quantum technology. While many ponder the reasons of the Chinese technological attainments, its operational success should be attributed the constancy and volume of investment devoted to quantum information science and the protectionist tactics used by the state apparatus. Apart from the governmental support, progress has also been occurring in the academic sector, where cooperation with Austria has been slowly culminating with the main objective of extending the Chinese Micius Quantum Communication Satellite across Europe.

The main institutional framework which structures the quantum policy of China is the current Five-Year Plan (2021-2025) which emphasizes the idea that China's long-term economic, social, and national security goals depend on domestic acquisition of state-of-art technologies. The emphasis on domestic invention is not a recent phenomenon; the idea has its origins on the China's National Long-Term Plan for the Development of Science and Technology, published in 2006. Since then, efforts to develop self-sufficient technology have gained significant traction, as seen by the idea of Strategic Emerging Industries (SEIs), the controversial Made in China 2025 industrial program, and a slew of industry-specific growth plans. The Chinese scientific community has already produced cutting-edge telecommunications and cryptography systems as a result of its emphasis on quantum communications, culminating in the inauguration of the communication connection between Beijing and Shanghai in 2017 – in a what has been called as the longest unbreakable communication cable in the world. Although China remains the only nation to gain a quantum edge in both photonic and superconducting quantum computing with two of the fastest computers in the entire world and could be classified as a quantum superpower, it should though address and overcome systemic challenges associated with the development of quantum systems. These domestically-developed systems have not yet been applied, meaning that existing quantum systems can still experience high fault rates, while the maintenance of colling temperatures through special devices is still not considered a fait-accompli. Finally Chinese semiconductors - which are essential for advances in quantum technology - are also subjected to restrictions and embargoes endangering the sustainability and materialization of the Chinese quantum vision.

4.1.2. THE REPUBLIC OF JAPAN

Japan has achieved the installation of a substantial quantum network in Tokyo, cooperatively constructed by several private and public partners and launched in October 2010. The Japanese teams working on the project were mainly originating from the National Institute of Information and Communications Technology (NICT) and private Japanese businesses like NEC, Mitsubishi Electric, and NTT. According to the website for the UQCC Project, the assignment is being implemented also by a number of European teams, including those from Toshiba Research Europe, ID Quantique, the Austrian Institute of Technology, the Austrian Institute of Quantum Optics and Quantum Information, and the University of Vienna. This pattern suggests that governments will seek the formation of international consortia aiming to maximize shared capacity and knowledge management on projects of common interest. The NICT has also engaged in space-based QKD, optical satellite transponder development, and telescope ground station equipment. Even in the absence of significant public funds towards quantum, Japan appears to be an exceptional country case where private businesses are putting forth the most effort. A good indication is the fact that communication equipment manufacturers, telecom providers, information technology corporations, and electronic corporations are consistently supporting the development and deployment of QKD devices and systems across the country.

4.1.3. THE UNITED STATES OF AMERICA

The USA passed the National Quantum Initiative Act (NQI Act) in 2018 and expanded opportunities for quantum information science (QIS) education and training due to the potential for advancements and the related consequences for jobs and national security. One of the key drivers for the adoption of relevant legislation was to "provide for a coordinated Federal program to expedite quantum R&D for the economic and national security of the United States". In addition, the NQI Act also mandates that the civilian, defense, and intelligence sectors of the US Government work together to coordinate their QIS and R&D initiatives, with the focal point being the National Institute of Standards and Technology (NIST), which is tasked with the support of American innovation and industrial competitiveness by performing open and top-tier research with its core specializations being on precision metrology and cybersecurity (G. Raymer & Guha, 2022). One of its key actions has been the setup of the Quantum Economic Development Consortium (QED-C) which amplifies the national capacity quantum research by creating the necessary future supply chain for the quantum economy. In parallel with NIST, the US environment is highly influenced by the work of the National Science Foundation (NSF) which supports scientific progress by channeling funds towards more than 2000 national academic institutions. Moreover the NSF has extended its scope of activities through the provisions of the NQI Act by acquiring the mandate to develop new transdisciplinary Centers for QIS research and educational programmes. An instance was the allotment of $9.75 million for Quantum Computing Faculty Fellows, as a locomotive to encourage more institutions to include QIS-related professor positions.

In the international level, the United States and Denmark signed a Joint Statement on Cooperation in Quantum Information Science and Technology on June 8th, 2022. The collaboration scheme between the two parties aims to explore the shared capabilities of both nations in quantum information science and technology (QIST) and other sectors that support QIST, in order to pursue creative research, expand the market, create a solid supply chain, and develop the next generation of talent and skills. Another move which demonstrates the shift of policy focus towards quantum is the signature of a package of directives by the Biden Presidency on May 4th 20202, with the goal of boosting national QIS projects. More precisely, President Biden signed the National Security Memorandum on Promoting United States Leadership in Quantum Computing While

Mitigating Risks to Vulnerable Cryptographic Systems (the "Memorandum") and an Executive Order on Enhancing the National Quantum Initiative Advisory Committee. All the previous efforts both in institutional but also in the fit-for-future academic level – along with the fast progress of US tech giants like Microsoft, IBM and Google – contribute to the classification of the USA as one the two, if not the most, prominent nations in quantum development in global level.

4.2. QUANTUM DEVELOPMENTS AND PRACTICES IN THE EUROPEAN LEVEL

4.2.1. FROM THE QUANTUM FLAGSHIP INITIATIVE TO THE EMERGENCE OF THE EUROQCI

Discussions about the future of technology has always been at the forefront of the EU agenda, although not to the same extent as with the incumbent EU Commission. In 2016, the latter published its Commission Staff Working Document on Quantum Technologies and the European Cloud Initiative - Building a Competitive Data and Knowledge Economy in Europe with the aim of reinforcing the EU preparedness by setting up a long-term flagship initiative along with the private sector. This idea gained significant publicity and traction in Brussels and throughout Europe and received public endorsement by various stakeholders from the field of science, industry and from some Member State governments via the launch of the "Quantum Manifesto" shortly afterwards. The Manifesto contained around 3600 signatories and was formally presented it to the Commissioner for the Digital Economy and Society in May of the same year.

Since then, the EU has benefitted from its strong science base in quantum technology through the channeling of projects and financial opportunities of Framework mechanisms such as Horizon 2020, Future and Emerging Technologies (FET), European Research Council (ERC), and Marie Sklodowska-Curie Actions (MSCA). In addition, programs sponsored by the European Fund for Strategic Investment (EFSI) and pre-commercial procurement were also underscored as effective tools for advancing quantum technology. The European Commission's main goal for the next ten years in terms of its strategic direction for quantum computing is to create a world-class European quantum technology ecosystem by 2030. This goal is embodied in the 2018-launched Quantum Flagship which is expected to run for the next ten years, with an expected budget of €1 billion.

Europe is the world leader in quantum physics – with around 50 per cent of all scientific publications and almost 40 per cent of all researchers in this field. At the same time, EU has established around 10 quantum focused labs. These increasing capabilities along with the launch of the flagship further scaled up expectations and requirements for the realization of quantum technologies spanning across Europe. One of them is the build-up of infrastructures for quantum communications across the EU Member States. There were very compelling arguments for the development of a pan-European secure quantum communications infrastructure:

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- First, there are currently an increasing number of vital facilities on European ground with examples including networks for banking, navigation, and air traffic control, as well as networks for coordinated intelligence.
- Second, in order to overcome the challenge and keep up with other nations, it will be necessary for various nations to pool their resources. This will enable them to advance to the same level as China or the US and avoid falling behind.

These arguments materialized when all 27 EU Member States signed the European Quantum Communication Infrastructure (EuroQCI) Declaration since June 2019. This declaration foresees the design, development, and implementation of the EuroQCI in close collaboration with the European Commission and the European Space Agency (ESA). The existing vision is for the EuroQCI to be fully operational by 2027. By incorporating quantum-based technologies into current communication infrastructures and adding an additional security layer based on quantum physics, the EuroQCI will protect sensitive data and crucial infrastructures. The advancement and attained-maturity of the existing technologies required to make the EuroQCI a reality will only but help Europe's scientific and technological prowess in quantum computing and cybersecurity for the ensuing decades. This will occur by fortifying the defense capabilities of the EU governmental institutions, data centers, hospitals, energy grids, and other critical facilities, in leading to the increase of the Union’s industrial competitiveness and digital sovereignty. The EuroQCI will have a satellite-based space element as well as a terrestrial part that relies on fiber communications networks to connect key locations at the national and international levels.

The operational realization of such as ambitious EU project, will allow the Union to remain on the map of the quantum security technologies that are also being developed in other states such as USA, China, Japan, Canada and Australia and ultimately encourage the growth of a new high-tech sector devoted to the creation of quantum-based security solutions. This would encourage the creation of an independent European quantum communications manufacturing capability, which would eventually grant strategic autonomy in addition to being a valuable economic resource (Lewis & Travagnin, 2022). The state-of-play suggests that the EU Commission is administering the work on the terrestrial component of the EuroQCI, while ESA is in charge of overseeing work on the space segment.

The participating nations are starting to develop and build their own national quantum communication networks concurrently. The common denominator in the developed infrastructure would be to take some initial steps towards the building of operational quantum key distribution (QKD) services, a highly secure type of encryption – something that has been stimulated by the Horizon 2020 OPENQKD project. Additionally, cross-border connections to other networks that will function both on the ground and in space are now being planned. To guarantee that the essential elements of EuroQCI are built using European technologies, the participation of European business partners and SMEs is pivotal.

The concept of the QCI presents a handful of advantages which can be summarized in the following points:

- Data centers are essential parts of the communications and data network infrastructures that house enormous amounts of data (i.e., 7,500 globally, 2500 in Europe). Because of the high impact of a successful cyberattack, the QCI will give protecting data centers first attention by revamping their communication lines with QKDs to ensure redundancy and business continuity. This is done as a physical security measure.
- The Network and Information Systems (NIS) Directive, which identifies some fundamental services that are very important for society and are potentially vulnerable to digital attack, recognizes cyber-attacks on critical infrastructure as a European-level threat. These services include energy, digital services, air transport, banks, water supply, and healthcare. The QCI should ensure the confidentiality and integrity of the data being shared and stored, as well as the authentication of the entity requesting access, for all infrastructure-related use cases.
- Power distribution, telecommunications, and financial trading are just a few examples of strategic networks that depend on precise synchronization of time-related network processes. Through the Internet of Things (IoT), smart cities, smart transportation, and e-commerce, new generation wireless telecommunications (i.e. 5G networks) will have a significant impact on society. At all core-locations, synchronization of better than 20 nanoseconds is necessary, along with real-time control and monitoring systems to assure stability under more complicated settings is smart power distribution networks.
- The utmost level of protection is required for government data. If the confidentiality of data held in or transferred between government centres is breached, it might have catastrophic results given the secrecy lifetime of up to 50 years. It is necessary to provide both long-term secure storage and defence against "harvest-now-decrypt-later" assaults, hence the higher protection level offered by QKD is unquestionably beneficial.

As outlined in the detailed technological explanations in the final section of this paper, many quantum technologies could have security implications. However, this does not constitute the only concern as there other considerations that result in the lagging of EU in the so-called "quantum race". The first issue – albeit exacerbated – stems from the "brain drain" of EU quantum-orientated start-ups which are attracted to join US companies. While they acknowledged the value of programs such as the EU Quantum Flagship for increasing funding for quantum research, some of the CEOs interviewed emphasized that there were challenges inherent in developing a quantum start-up in Europe, due to differences in available funding levels compared to the US. While there are likely to be stronger funding opportunities in the US, especially in terms of venture capital, additional EU funding could at least begin to mitigate this scenario. However, there is also a growing sense within the scientific and technical community that international collaboration on quantum research and development is becoming increasingly challenging as quantum technology is seen more widely as not only commercially valuable, but also significant from a national security perspective. This can in turn result in further complications such as the increased securitization of the field of quantum research, with less state funding available to finance international collaborations on quantum technologies due to national security concerns. However, common standards, transparency, the freedom of research-related information as well as the exchange of research personnel would allow both the EU and US to maximize their competitiveness in the field of quantum information science, while strengthening their bilateral collaborative relationship. Maintaining a competitive edge is important, given that funding of quantum research is increasing in other countries, for example, China. The securitization of quantum technologies, to the extent that deeper collaboration is inhibited, should be limited in order to enable competition.

4.2.2. THE 2018 QUANTUM FLAGSHIP

According to the previous section, the Quantum Flagship was established in 2018 aiming to pave the way for the development of a "quantum network" and more broadly a quantum industry in Europe, in which quantum computers, simulators and sensors are interconnected via quantum communication networks. The Flagship is funded by national funds, Horizon 2020 and its successor initiative i.e., Horizon Europe. The overarching goals of the flagship are the following:

- Establishment of a well-connected European quantum technologies community centered on the shared objectives listed in the Strategic Research Agenda.
- Fostering of a European ecosystem that will provide the information, technologies, open research infrastructures, and testbeds required for the growth of a knowledge-based sector in Europe that is at the forefront of the field, resulting in long-term economic, scientific, and societal advantages.
- Advancement in the fundamental science underpinning advanced quantum technologies, while bringing them from the lab to industry with tangible prototype applications and marketable products, in order to continually find new applications and find more effective ways to address unresolved technical or scientific problems.

4.2.3. QUANTERA ERA-NET COFUND IN QUANTUM TECHNOLOGIES

Another important initiative since 2014 is the launch of the QuantERA initiative (QT). The first partners agreed to participate in QuantERA by signing a joint Letter of Intent in August 2014. As the number of signatures grew over the ensuing months, it became evident that a critical mass was available for the program's implementation. Since then, cooperative efforts have been made to set up a Consortium of RFOs built on trust with the goal of preparing the QuantERA Program, which was introduced in 2016.

According to the official website, the objectives of the Programme are:

- The successful provision of Calls for Proposals in quantum to the European quantum community.
- The promotion of excellent research in quantum.

- The encouragement of transnational collaborations in quantum.
- The mapping national, regional & European public policies in the quantum area.
- The dissemination and maximization of research excellence across the European Research Area (ERA).

4.3. QUANTUM POLICIES OF EUROPEAN COUNTRIES

4.3.1. FINLAND

Finland is outperforming its peers by investing in technology and seeking out cutting-edge solutions, a commitment that dates back many years. The OtaNano center at Aalto University, which has 2,600m2 of manufacturing space, 200 researchers, and a specialized quantum lab, is a noteworthy example. The Quantum Technology Finland project, which receives annual state financing of $13.36 million and is supported by 11 different research teams, casts a shadow over it. In addition, Finland's inherent advantages as a quantum hub are already apparent. The ultimate goal of a quantum computer development project sponsored by the Finnish Ministry of Economic Affairs and overseen by Finland's VTT Technical Research Centre is to develop a 50-qubit system by 2024.

This project, which will be overseen by VTT, will create the necessary components, manufacturing and testing methods, and algorithms for quantum technology. The QuTI consortium has 12 partners and a budget of about €10 million. It is partially funded by Business Finland and includes Afore, fore, Bluefors, IQM Quantum Computers, Picosun, Quantastica, Rockley Photonics, Saab, and Vexlum. Numerous industrial partners listed above are already part of Finland's quantum ecosystem. For instance, BlueFors, a global leader in cryogen-free low-temperature systems, now generates annual sales of over €80 million. In contrast, IQM is constructing Finland's first 54-qubit commercial quantum computer to raise $46 million in funding by 2020 from global investors like Tencent.

For its part, the Finnish government makes a lot of effort to foster ties between industry and research institutions. As an illustration, the recently founded BusinessQ institute helps businesses embrace and create quantum technology and solutions. This is a component of a larger quantum ecosystem that unites the Finnish communities of education, research, and innovation under one roof. During the last year, the Finnish Government signed a “Joint Statement of the United States and Finland on Cooperation in Quantum Information Science and Technology” suggesting that stronger partnerships between businesses are also more likely to occur. In this regard, global tech goliaths from Accenture and IBM have recently placed their faith in a Finnish quantum future, going beyond case studies like BlueFors and IQM. At the same time, the nation is already conducting its advanced planning for the future, as Helsinki envisions itself as a key player in the long-term development of a complete quantum internet.

4.3.2. GERMANY

Germany represents a unique case for the EU standards on quantum since it initially made its intentions crystal-clear of developing its own quantum computer capacity. Towards this direction, the Corona stimulus bill that was unveiled by Angela Merkel's administration in the summer of 2020 foresaw the commitment of additional funding in the already committed 650 million Euros through an earlier framework program. In the spring of 2021, the German Federal Government finally made its movements explicit by announcing the distribution of 1.1 billion euros by the Federal Ministry of Research and Education, and 878 million euros will be provided by the Federal Ministry of Economic Affairs and Energy. A further 50 million euros will be distributed to projects managed by the Federal Ministry of Finance (Kumagai, 2021). The objective was, and still is, to increase Germany's and Europe's technological dominance in a new digital core technology (Süssenguth , 2022). These investments would be concentrated on hardware for quantum computing, with the government inadvertently putting the wagon before the horse by declaring its intention to immediately assign qualified consortia the task of building at least two quantum computers. This is proven by the fact that German companies are among the top manufacturers of lasers and other fundamental quantum technologies, while their academic engagement and research excellence has resulted in the funding of seven clusters in quantum physics at universities in the latest round of the Federal Government and Federal States' Excellence Strategy. However, while Germany is indeed well positioned to take a leading position in various quantum areas, an analysis by the German National Academy of Science and Engineering at the beginning of 2020 showed that essential components of an ecosystem are lacking when it comes to quantum computing.

The epicenter of the German ecosystem approach revolves around the three-area nexus between tech demonstrations, a user network, and university finance. The first (i.e., tech demonstrations) deals with funding for the creation of technology prototypes for the many technological foundations that a quantum computer may be built upon. The first recipient of such financing was revealed in November 2021: The Finnish-German startup IQM received 40 million EUR in funding. Later financing phases are expected to use the demonstrators as the building blocks for platform-specific hubs. The second area (i.e., user network) is meant to assist prospective users in identifying applications for this novel technology in their workplaces or organizations. Last but not least, institutions will get cash in the third sector (i.e., university finance) to increase the range of courses they offer in the pertinent subjects. Two consortiums, one concentrating on hardware and the other on software for quantum computing, will be funded by the Ministry of Economic Affairs. Both are meant to collaborate closely with both SMEs and major corporations.

Along with its aspirations to establish an industrial innovation center focusing on quantum computing, the German Aerospace Center is charged with organizing this project. According to former German Chancellor Merkel the goal is to "build a comprehensive innovation ecosystem that develops into a new industrial base". At the German National Metrology Institute, a competency center for quantum technologies will be established. The formation of QUTAC, a group representing important industries, supported this announcement of significant actions by two Federal Government Departments. The QUTAC has been founded by BMW (automotive), Bosch (industrial technology), Infineon (semiconductors), Merck (chemistry and pharmaceuticals), Munich RE (reinsurance), SAP (software), Siemens (industrial technology), and Volkswagen. By discovering and assessing use cases, highlighting funding requirements, and exchanging experiences, it seeks to hasten the commercial and industrial adoption of quantum computing. One of the consortium's goals is to strengthen Germany's technological and digital sovereignty and develop its first national – and in parallel European - exascale computer.

4.3.3. FRANCE

From the Nobel Prize winners in Physics Albert Fert and Serge Haroche, who created spintronics and cavity quantum electrodynamics, to the ground-breaking research on quantum entanglement by CNRS Gold Medalist Alain Aspect and the quantum simulators created by the digital transformation company Atos, France has established expertise in the field of quantum technology and intends to continue to be a key player in international competition. The Quantum Plan outlines steps to promote industry, academic and professional training, as well as research (i.e., particularly for quantum computers, sensors, and communications). It is similar to the AI Plan, which was unveiled in 2018. It is funded to the tune of €1.8 billion by the PIA43 and the France Relance economic recovery plan. Over the following five years, the French government is projected to invest €200 million annually, totaling €1 billion. The remaining €800,000,000 will be provided by industrial contributors (€500,000,000), European finance (€200,000,000), and investors associated with the French startup ecosystem (€100,000,000). The universal quantum computer will get €430 million toward implementation of France's policy, and quantum simulator programs will receive €350 million. Quantum sensors will receive €250 million, quantum communication systems will receive €320 million, and post-quantum cryptography will receive €150 million. Last but not least, €300 million will go toward related quantum technologies like cryogenics (Machi, 2022).

The French Ministries for the Armed Forces, the Economy, Finance and Recovery, and Higher Education, Research and Innovation are involved in the strategy, which integrates many critical elements like encrypted communications and increased processing power. Quantum technology is a "growth area" and an "important market" whose performance is "closely connected to anticipated advancements in research." This "very specific" plan intends to protect national sovereignty, especially in light of the fact that China and the United States are making significant investments and that corporate behemoths like Google and IBM are stepping up their research efforts with substantial budgets and "first-class results." The plan focuses on how academia and industry can work together to advance quantum engineering. It aims to support nationally prominent theme ecosystems based on a comprehensive research program. Large university centers have started a structuring process recently through their associated laboratories and those of its partners in anticipation of the Plan's enforcement.

Nevertheless, France has also intensified its bilateral cooperation on quantum development with other countries (i.e., Netherlands). The French-Netherlands Memorandum of Understanding was signed last year with the goal of enhancing bilateral cooperation in quantum innovation. The two nations want to hasten the formation of a cutting-edge quantum industry by combining their respective quantum ecosystems, both of which are leaders in the area. Major repercussions are anticipated in terms of economic performance and sovereignty (Pollet, 2021). In particular, the silicon sector is the initial target of the agreement because it is essential to the creation of quantum processors. As part of the European Quantum Flagship effort, the two nations are already cooperating on the Quantum Large Scale Integration in Silicon (QLSI) project. Therefore, it seemed that this industry would be one of the primary areas of collaboration in the MoU. The goal is undoubtedly to have a bigger impact on the Quantum Flagship program's approach. The accord also calls for the establishment of "quantum houses" or centers to serve as bridges between the business and academic realms. France has increased its efforts in recent years to create startups and unicorns generally (e.g., under the "French Tech" name) and specifically in the deep technology sector (notably through initiatives by French public investment bank BPI). Reinforced cooperation with the Netherlands, which has a very strong business culture, can only be advantageous for maximizing the significant economic potential that results from Dutch academic achievement.

4.3.4. NETHERLANDS

The Netherlands has been at the forefront of cutting-edge quantum research for many years. As the first nation in Europe to make the transition from scientific to technology development of quantum, the Netherlands institutionalized the establishment of QuTech by the Delft University of Technology and TNO in 2013. In light of this more general context for policy, the Dutch Government has acknowledged the unique role that some important technologies, such as quantum technology, can play. Six parties made an agreement in 2015 to provide €135 million over ten years to QuTech, the Delft-based institute for quantum technologies. QuTech has experienced tremendous success, growing more quickly than anticipated, securing significant business alliances with companies like Microsoft, KPN, and Intel, and succeeding in domestic and international calls. Over time, the quantum ecosystem has expanded significantly. The Quantum Software Consortium, a partnership between researchers from Delft, Leiden, and Amsterdam, received an €18.8 million grant from the Gravitation Programme 2016–2017 from the NWO research council, highlighting the importance of holistic endeavors between the software and hardware components of quantum (IQT News, 2022).

Midway through 2018, the Dutch government formally declared that its innovation strategy would center on the advancement of critical technologies such as photonics, AI, nano, quantum, and biotechnology, however, no specific financing plans for these important technologies have yet been made public. One of the key policy motives of the country, is the prevention of geopolitical dependence, since it is deemed as desirable to maintain independence from technological advancements made outside of the EU. Additionally, from that vantage point, the Netherlands' future course is generally consistent with the direction the European Union may follow, enjoying a significant competitive advantage thanks to its extensive pool of experts, engineering knowledge, and future talent. Academic institutes like TU Delft and CWI, regarded as leaders in quantum computing and quantum algorithms, respectively, are well-known outside. Other R&D centers focused on quantum technology and related fields may be found in Amsterdam, Leiden, Twente, Eindhoven, Maastricht, and Nijmegen. Additionally, organizations like the European Quantum Internet Alliance, led by Dutch QuTech has received a €10 million grant to construct a quantum internet. The main focus of Dutch quantum computing research is on public-benefit initiatives like quantum internet and its related algorithmic applications.

On the Ministry of Economic Affairs and Climate Policy's suggestion, the Dutch quantum technology community submitted a National Agenda for Quantum Technology in September 2019, which functions as the most important institutional framework in the country. The agenda was developed in close collaboration with a focus group of 40 participants, a core team from QuTech, QuSoft, QT/e, Leiden, TNO (the Netherlands Organisation for Applied Scientific Research), Microsoft, Techleap, and AMSI-X (Amsterdam Internet Exchange). The Agenda has receive positive acclamations and comprises of three "catalyst projects" that are suggested within its compendium, in an effort to hasten consumer access to emerging technologies that will be produced in labs in the upcoming years. Consequently, the Quantum Delta NL foundation (QDNL) was established in September 2020 to further the implementation of the National Agenda. The Dutch government just gave Quantum Delta NL €615 million, to foster its advancement in three key areas: quantum networks, quantum sensing, and quantum computing. Meanwhile, the House of Quantum, a special facility for this "quantum environment," will start operating in 2024. By 2027, money will be spent in the Netherlands to train 2,000 researchers and engineers, scale 100 start-ups, and house three corporate R&D centers. <u>All the previous render the country as one of the most technologically-progressed and institutionally-prepared EU Members to steer this herculean effort of quantum integration within the next decade.</u>

4.4. A COMPARATIVE ASSESSMENT OF THE DIFFERENT QUANTUM-DRIVEN BUSINESS MODELS

The previous articulated strategies of international and EU countries validate the existence of different quantum-seeking business models. These quantum-based models exhibit different organizational tenets and policy elements that are predominantly shaped by the political culture, geopolitical positioning and technical prowess of each quantum-seeking nation. Therefore, the study clusters the different policy and strategy frameworks in four dynamic and unique pathways that underpin quantum development for each country case and could be leveraged in a standalone or blended format to stimulate appertaining actions in Cyprus.

Taking stock of the above, the following business models have been fabricated within the context of this study:

The "State-Driven Research" Model: This model which has been mainly followed by China finds in its epicenter an in-house capacity development on quantum fostered by laboratory on the University of Science and Technology of China (USTC). The latter has produced in a short timespan large-scale scientific advancements in quantum in communications (i.e., high-level and state-of-art cryptography systems and construction of the Micius satellite to safely link and ultra-secure data between two terrestrial nodes). In parallel with the scientific progress, the Chinese government has integrated quantum in its strategic planning with a view to assert its "quantum autonomy" over the Western world and maximise its investments. This was evident from the inclusion of a quantum vision in the running 14^{th} Five Year Plan 2021-2025 (FYP 2021-2025) rendering the technology as a cornerstone of the future state planning. Essentially, China leverages its unique political system and state structure to expedite and control efforts through state-operated institutions. The establishment of National Laboratory for Quantum Communication Technologies in Hefei costs 10 billion euros and proves all the more the previous points.

The "transnational cooperation" model: Although cooperation schemes are slowly starting to materialize – and upsize – between countries in the European continent, this pattern is more visible when it stretches beyond continents. This model is seemingly employed by Japan which has built and launched its quantum network in 2010 at Tokyo. While the backbone of the network is operated and administered by the National Institute of Information and Communications Technology (NICT), the role of private companies is more than prominent in the project. While some of these private companies emanate from Japan (i.e., NEC, Mitsubishi Electric and NTT) there are several European firms that participate in the project such as ID Quantique, Toshiba Research Europe, the Austrian Institute of Technology, the Austrian Institute of Quantum Optics and Quantum Information and finally the University of Vienna. Even in the absence of an all-important financial planning, the effort by private Japanese and non-Japanese companies manages to advance the technology in the country and provide an apt paradigm of inter-state cooperation on the field.

The "Legislation-First" and Institutional Model: The United States is the first country case which has officially set legal boundaries and in turn formalize its R&D processes for quantum development across the country. More precisely, in 2018 the United States had passed the National Quantum Initiative Act (also known as the NQI Act) offering increased educational and occupational opportunities on quantum information science (QIS). Although colossal investors like IBM, Microsoft and Google display a major role in quantum innovation and industrial development, the U.S Government has been equally stimulating QIS programmes through its competent "spearhead institutions" (i.e., the National Institute of Standards and Technology, the National Sciences Foundation and Department of Energy). In other words, the NQI was fabricated under a "science-first" approach with the aim to facilitate and set the necessary building blocks for scientific breakthrough. Another step that signals the prevalence of institutions for quantum research is the fact that the U.S Congress funded earlier this year the setup of a new directorate on NSF – called the Directorate for Technology, Innovation and Partnership which of course has included quantum in its mandate and planning – proving that the current Biden administration has recognized the gradually increasing role and technological edge of quantum technologies – especially with regard to the cybersecurity sector. A final sign that corroborates all the previous is that through an executive order signed this year, the U.S President Joe Biden has elevated the reporting status of the NQI Advisory Committee directly to the White House. All these elements compose a unique business model that can facilitate and accelerate quantum development through the institutional pipelines of the state – one that should be taken into account.

The "Quantum Ecosystem" Model: This model – which encompasses – a parallel set of actions and initiatives across different operational dimensions (i.e., government, academia and the private sector) has seen significant traction in Germany but also in the Netherlands which predominantly embraces the above. The latter has developed its quantum policy by capitalizing on the research excellence and innovation of quantum-orientated research institutes like QuTech which is situated at Delft and came into being in 2013. The institute has not only enjoyed massive success by realizing significant alliances with "technological giants" like Microsoft and Intel but has also been at the frontline of the ecosystem development across the country. Concurrently, the Dutch government has supported research efforts by cooperating with the quantum community to formulate a National Agenda for Quantum, while establishing the Quantum Delta NL Foundation (QDNL) in 2020 to extend the implementation mechanisms of the quantum agenda. The systematic coordination and the multistakeholder initiatives were important in rendering a disparate set of standalone measures into a coordinated and cohesive ecosystem of public-private structure that aims to spearhead the organization and advancement of quantum strategies across the country – always under the support of the government.

5. ANALYSIS OF THE CYPRIOT BUSINESS ENVIRONMENT

5.1. AN INTRODUCTION OF THE OVERALL CYPRIOT BUSINESS ENVIRONMENT

Cyprus has established a solid reputation as a hub for global commerce and functions as a tax-paradise for the integration of cutting-edge technology and telecommunications companies. More precisely, Cyprus acquires one of the lowest corporation taxes on income across Europe (i.e., 12.5 %) while dividends, interest, and royalties are tax-free. Despite the nation's welcoming stance toward international businesses and experts from other countries, a new Action Plan was unveiled by the Cypriot government in 2021 to encourage investment by international businesses. The strategy was launched in January of this year after drafters took best practices from other European nations into consideration. Another reason for the classification of Cyprus as a fertile ground for business expansion is the associated low administrative-operating costs and quick setup procedures, meaning that a business sector can be entered without limits or a license as long as it complies with the required rules (i.e., banking and financial services or media). In parallel, the Cypriot "non-financial business economy" is predominantly supported by SMEs with high contribution value to employment and significantly higher averages than the corresponding EU ones of 56.4% and 66.6%. However, the performance of the country fluctuates accordingly based on the assigned evaluation areas. A tangible example is that while Cyprus ranks above the EU average on state aid, public procurement, entrepreneurship and responsive administration, its single market and access to finance for SMEs are strongly underperforming. Between 2015 and 2019, OECD unraveled that 52.8% of Cypriots were fearful of failure as a barrier to start their own business, an indicator which surpasses by far the EU average i.e., 45%.

Despite the delicate equilibrium between positive and negatives, Cyprus still represents a prospective market for the attraction of quantum investments and for this reason the study will elaborate on the most contributing sectors of the Cypriot economy, which could potentially be strengthened and modernized with the integration of quantum-specific practices. The selection of these sectors also included considerations based on the international quantum applications on the described sectors. This will allow foreign businessmen to evaluate the wider opportunities and benefits of quantum technology development and potentially expand their operations in the insular country. In the same spirit, the study will also display a baseline for Cypriot business leaders across various industries who aim to become frontrunners in the search for use cases in this promising technological field.

5.2. ANALYSIS OF THE CYPRIOT TOURISM SECTOR

5.2.1. INTRODUCTION

The Cypriot tourist industry has always been a significant contributor to the nation's economy, which is itself growing healthily, exceeding expectations, and retaining its promising outlook. One of Cyprus's key economic sectors, tourism has seen rapid expansion over the past five years, setting records for both arrivals and income. This can be further corroborated if one takes into account that from 2014 to 2019, the number of tourists arriving in Cyprus increased by 100 percent, with winter months (November-April) seeing the greatest rise.

5.2.2. MARKET GROWTH AND GDP CONTRIBUTIONS

One of Cyprus's main economic sectors, tourism has grown significantly during the past ten years, with visitor arrivals rising to almost 3.9 million in 2019 from about 2.1 million in 2009. (86 percent increase). Regarding tourism arrivals, which are getting close to the 4 million mark, both 2018 and 2019 broke records (3.93 million and 3.97 million respectively). In parallel, numerous accolades have been given to Cyprus' tourism industry, and 65 of the country's most popular beaches have received the prestigious Blue Flag designation. From 2014 to 2018, the tourism sector's revenue rose by 34%, from €2.0 billion in 2014 to €2.7 billion in 2018. After many years of good growth, Cyprus experienced its first revenue decline of -1 percent in 2019 compared to the prior year. Even though the number of tourists visiting Cyprus is still rising steadily, the sector's income took a turn for the worse in 2019. In addition, while the sector's share of the country's GDP increased from 2014 to 2017, it fell in 2018 and 2019 despite the fact that the number of tourists visiting Cyprus continued to rise steadily. In 2017, tourism revenues in Cyprus made up 13.2 percent of the country's GDP; while in 2019, they made up 12.2 percent. These unfavorable trends can be the result of a number of national and worldwide events that have harmed the tourism industry, with the most recent being the COVID-19 pandemic.

5.2.3. ECONOMIC OUTLOOK

Tourism can solidify its position and ranking among the top economic performers by 2030 through a clearly defined vision and strategy to initiate the full rebranding of Cyprus and establish the island as a year-round destination. This will be achieved not only through direct revenues but also through the significant indirect impacts that tourism has on the local economy. The goal of the new Cyprus Tourism Strategy is to improve seasonality and develop Cyprus in a way that has a positive impact on the economy and civil society. More ambitious objectives are being set such as the realization of 39% of overnight stays between November and April and increasing the number of overnight stays in rural areas three times more, namely from 100,000 in 2018 to 400,000 by 2030. Significant investments have been underway, with the construction of the Ayia Napa Marina estimated around €220 million and anticipated to be finished in 2022. Meanwhile progress in other fields is more evident at present, for example the choice of Cyprus by Hong Kong-based Melco International Resorts and Entertainment to expand its flagship brand name outside of Asia can – and should be considered – as a sign of success. Construction activity that is tied to tourism is strongly suggestive of the shift to large-scale, high-value initiatives, further bolstering the already robust hotel industry. The value of new hotel developments was estimated at €610 million in 2019, and hotels made up 16.4% of the total value of building licenses.

While desk research suggests that there are no available quantum applications that could be suitable for the tourism industry, the inclusion and visibility of this nationally-conducive and profit-making sector in the context of this study sets the target to instigate a new round of international R&D and innovation searching for the added-value of quantum across the tourism sector, since the latter represents an important niche of many national economies around the globe.

5.3. ANALYSIS OF CYPRIOT FINANCIAL SERVICES SECTOR

5.3.1. INTRODUCTION

A rapidly diversified financial services industry has played a key role in Cyprus' reemerging as a dominant force in the Mediterranean business scene. The island is now marketing itself as a heaven for investment fund managers, crowdfunding platforms, and fintech entrepreneurs, pushing beyond good banking and corporate formation. In particular, Cyprus is gaining footing as a management hub in critical industries and is developing a reputation as a quality-efficient and cost-competitive choice for regional and international financial services organizations. Cyprus's financial services industry has grown thanks to its proven international finance and investment track record dramatically. The island has made a lot of effort to rebuild the confidence lost due to its financial crisis in 2013. Throughout this period, the financial market in Cyprus has undergone a significant transformation due to regulatory change, economic restructuring, and the discovery of new development drivers. According to global best practices, the nation now offers top-tier fund management and trust administration services. From a regulatory standpoint, the nation established the foreign exchange market and is branding itself as a significant player in the wealth management sector. Apart from its long-standing business links with Russia and various countries of Central Asia (i.e., Kazakhstan, Uzbekistan etc), Cyprus is viewing an increase in investment from other parts of the world, such as Asia, the Middle East, and Africa. This trend is anticipated to pick up speed in the upcoming years.

5.3.2. MARKET GROWTH AND GDP CONTRIBUTIONS

Because of the dire effects of the European debt and banking crises, the Cypriot financial industry was on the verge of collapse almost six years ago. Financial issues arose as a result of the collapse of the Greek economy, in which Cypriot banks made large stakes. During the region's debt crisis, Cyprus turned to the eurozone for financial assistance as the fifth nation after Greece, Ireland, Portugal, and Spain, and was ultimately bailed out to €10 billion by the European Commission, the European Central Bank, and the International Monetary Fund. One requirement of the bailout was a banking system reform for Cyprus, which, when combined with other policies like developing lucrative investment opportunities that draw foreign interest, resulted in a robust economic recovery in the following years. For many years, the industry was primarily focused on banking and corporate structuring, significantly aiding investments into Europe, the Middle East, and Africa, as well as Russia and Eastern Europe, thanks to a fiscally favorable tax regime and extensive network of tax treaties. After the island's debt crisis, Cyprus sought new economic catalysts and emphasized diversifying its financial sector by including investment funds, fintech, and investment migration into its portfolio. Since its inception, the Cypriot financial services industry has expanded tremendously and has been expanding at a noteworthy pace of 6.5% annually.

In 2019, the Gross Value Added (GVA) from financial activities and professional services was 7.6% and 8.2%, respectively. The nation's financial services regulator, the Cyprus Securities and Exchange Commission (CySEC), oversees over 760 organizations employing close to 20,000 people, with corporate services, financial services, and fintech/digital finance being the niche focus of today's activities. Cyprus has long drawn foreign companies because of its affordable services and privileged access to fast-growing markets. This has progressively rendered investment funds, trust services, and private wealth as expanding sectors of the island's financial industry. In addition, the construction of an innovation center for fintech entrepreneurs offers a stable and conducive environment for the creation of fit-for-future business models, facilitating the next stages in the transmutation of the financial sector. All the previous projects demonstrate the economic boost that Cyprus's well-rounded financial services sector experiences, which has grown to offer a wide range of services and has little in common with the sector from just a few years ago.

5.3.3. ECONOMIC OUTLOOK

As previously states, Cyprus represents a top location for structuring investments in Europe, the Middle East, Africa, Russia, and Eastern Europe. This conviction derives from the fact that the insular country enjoys a stable EU environment, carries conflict-distant political positions and has institutionalized low corporate tax rate of 12.5%, associated with 65 country tax treaties. In just a few years, Cyprus transformed a sector that was essentially nonexistent and propelled itself into prominence by revamping and modernizing the regulatory structure. Specifically, Assets under Management (AuM) rose from €2.7 billion in 2016 to €8.3 billion in 2019, sealing a 200% rise and proving that Cyprus can compete with Europe's more established fund domiciles. The country has received increased interests from fund professionals around the world who are interested in accessing the EU market and particularly from Europe, Asia, and the Middle East. Essentially, this has resulted in the perceptual cultivation of Cyprus as a relatively affordable alternative to the major European fund centers, Luxembourg and Ireland.

The current trend which seems to gain traction revolves around financial technologies – the so-called fintech – like the IoT, AI, Blockchain and potentially quantum. The connection between financial services and physics is characterized by longstanding engagement, with numerous applications of physics being employed for the most cumbersome financial problems. This mindset was also reflected in upper section that focused on applications that could alter the sector. More precisely, quantum could assist in achieving greater compliance, preventing massive frauds with more robust algorithms, employing behavioral data to enhance customer engagement, and reducing risk prevention, all while increasing the preparedness towards of each economical structure to market volatility.

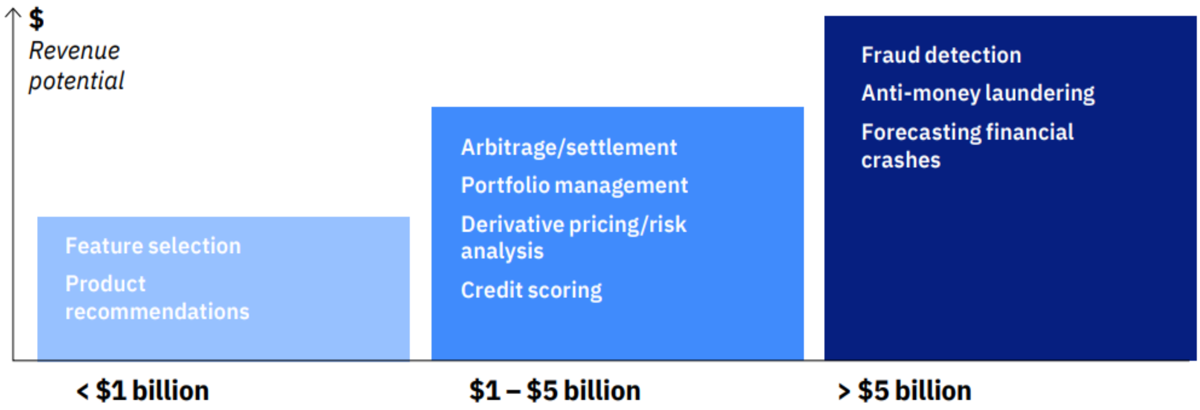

Figure 4: Quantum Computing Benefits on Financial Services

An indicative depiction and further elaboration of the above elements with rough estimations of potential savings was also underscored by an IBM report (Yndurain et al., 2019) which featured the below graph (*see figure 4*). Therefore it is more than evident that by developing or importing quantum-functional systems or tools for the update of the existing algorithms, the Cypriot financial services industry can further grow and flourish by gaining an early-mover advantage over other countries. For this reason, the Cypriot public and private sector should boost its engagement and financial ventures with cross-national formations and schemes, in order to be able to quickly secure the deployment and functional know-how for the use of these economy-critical technologies.

5.4. ANALYSIS OF CYPRIOT HEALTH SECTOR

5.4.1. INTRODUCTION

Cyprus has thrived in managing the global COVID-19 pandemic, quickly immunizing the majority of its population and winning praise from around the world for its endeavors. Cyprus is home to world-renowned scientists and a national health system with advanced access to high-quality healthcare for thousands of people. With its highly skilled and internationally experienced experts, specialized medical services, and internationally famous research, Cyprus' health industry has been acknowledged for decades as being particularly well-known for its exceptional private healthcare. The vast bulk of its medical professionals received their education at prestigious universities in the UK, Greece, Western Europe, the US, and Russia something that has been primarily shaped their international expertise and specialization on the healthcare sector. In this regard, Cyprus saw the most significant rise in the relative ratio of doctors between 2013 and 2018 by 27.5%, or numerically-wise from 320 to 407 doctors per 100,000 people. The long-awaited revamped national health system (NHS), which set the goal of transforming the Cypriot healthcare into a more streamlined, transparent, and cost-effective system, entered full operation in 2020, marking a significant industry-specific milestone. The success of the new NHS can be easily deduced by the fact that more than 892,000 people signed up as beneficiaries, after the inauguration of the new system, which aims to integrate cutting-edge technology, and innovation in its operational architecture.

5.4.2. MARKET GROWTH AND GDP CONTRIBUTIONS

From a broader perspective, Cyprus spends less on healthcare than the majority of EU countries. In 2019, the country saw a per capita health expenditure of EUR 1.881, which is less than half of the EUR 3.521 average for the EU as a whole. This sum amounts to 7% of GDP, a much lower percentage compared to the average for the entire EU of 9.9%, notwithstanding progressive growth over the past decade. In addition, compared to a 14% EU average, only 8% of the governmental expenditures was allocated to the health sector. Despite of the lack of public funding, according to Bloomberg's 2019 edition of its Healthiest Country Index, Cyprus is ranked as the 21st healthiest country in the world. Another health-specific index i.e., the Healthcare Access and Quality Index (HAQ), a study supported by the Bill & Melinda Gates Foundation ranked Cyprus 24th out of 195 nations in terms of accessibility to high-quality healthcare services surpassing obvious frontliners such as Germany, Israel, and the US, which are ranked 25, 28, and 37, respectively. At present, the overall financial commitment of the Cypriot state accounts for 9.63% of the government budget and 7% of GDP.

5.4.3. ECONOMIC OUTLOOK

The Cypriot Ministry of Health (MoH) is concentrating on digitizing medical provisions and creating an integrated e-health monitoring system as part of its ambitious goals to modernize the national health sector. Among the list of changes, the use of digital health records, the spread of integrated healthcare to rural regions through telemedicine and robotics, and accessibility to global medical data banks represent a sample of the existing planning. This will require a number of steps to attract new investments in industries like e-health, medical tourism, rehabilitation services, medical schools, and pharmaceutical services. The first integration towards this direction took place with the integration of a blockchain technology that was domestically developed the by Mediterranean Hospital and Aretaeio Hospital. With this technology, patients could have a digital healthcare passport and an encrypted NFC card, allowing them to securely manage their medical records and automatically identify themselves at the registration desk. An additional benefit that facilitated patients was the fact that by using their mobile device, they could check their place in line.

A survey by BIS Research projects disclosed that worldwide healthcare market expenditure and investment on blockchain-based technologies will reach $5.61 billion by 2025. The COVID-19 pandemic, like most other nations in the world, has injected new life in the willingness for state reforms in order to pursue new innovative opportunities in the health and medical sectors. For this reason investors and innovators should keep a close eye on Cyprus, where there is still a lot of untapped potential.

Despite the fact that blockchain has already been applied to a minimum extent, quantum-driven technologies represent an important enabler for the healthcare of the future. This was also mentioned in the upper sections where quantum applications on the pharmaceutical sector were concisely explicated. Nevertheless, the added-value of quantum in the healthcare sector provides a different set of benefits which can be synopsized in the following areas (Flöther et al., 2020):

- *Diagnostic Assistance*: The use of quantum computing will facilitate early diagnosis, resulting in the reduction of treatment costs. The undertaking of meta-analysis in diagnostic procedures will not only result in additional cost reductions, but also enable the more systematic data-driven decision-taking by healthcare providers and governmental institutions.
- *Precision Medicine*: Because of the human biology's complexity, the provision of individualized medicine is strongly considering extra-medical care parameters. In this regard medical care only accounts for 10% of outcomes, while health-relevant behaviors, socioeconomic factors and environmental aspects account for the 80-90% of decision over which medicine should be provisioned. The interdependency and correlations among these diverse contributors have created formidable challenges with regard to optimizing treatment effectiveness. A result of this has been that many therapies have not been successful or even result in the acceleration of saddening events, with tangible indications emerging from the area of cancer treatment. Quantum computing acquires the capacity to accelerate the obtainment of additional health data that could reinvent the way that problems are addressed during the subscription of specific therapies and medicines.
- *Pricing*: The elaboration of a pricing strategy takes into account a wide number of factors, which like in the previous case depend on interdependencies and different variations, such as population health levels and disease risks, treatment suitability and costs, and the risk exposure a health plan is willing and able to accept based on corporate strategy and regulations. While progress has been made with classical data sciences techniques, a more granular model with lower uncertainty calculation still remains a distant reality. The use of quantum computing could not only prevent healthcare fraud costs and refute fraudulent claims against healthcare institutions. In turn, this will lead to the optimization of pricing strategies and offer lower premiums due to having lower associated costs with fraud loss.

For this reason, the Cypriot companies and institutions in both the pharmaceutical and healthcare sector should take into close consideration the above and proceed in the necessary moves in order to enhance their IT structures with quantum computing systems and administrators that could perform these computational exercises. An initial point of departure could be the intensification of synergies between Cypriot health-relevant companies and big IT multinational businesses in order to expedite the acquisition of the most contemporary quantum applications in the sector, once they are developed and tested.

6. STAKEHOLDER MAPPING OF THE QUANTUM "AGENTS OF CHANGE"

6.1. EUROPEAN UNIVERSITY OF CYPRUS

The European University of Cyprus (EUC) represents one of the most academically-credible institutions in the country and one of the key stakeholders for the fostering of quantum capacity. The responsible entity and protagonist for this task is the Centre of Excellence in Risk and Decision Sciences (CERIDES) by embracing a cross-disciplinary approach and operating under the auspices of the EUC. The Centre is mainly occupied with the analysis of risk and decision science touching upon various horizontal areas such as safety, cybersecurity, telecommunications, critical infrastructure protection, and industrial processes. Apart from an innovation hub for creating and developing goods that can be sold later, the Centre has been broadly acclaimed for its excellence and top-notch organizational and academic level, receiving more than 4 million euros from various frameworks and funding mechanisms (i.e., Horizon 2020, DG ECHO, DG Home, Erasmus +, Norwegian Grants). Recent events have – more than ever – increased the involvement and credibility of the EUC, since one of its employees Dr. Konstantinos Katzis has been appointed as the coordinator for the deployment of the first Cypriot quantum communication network after delivering a successful 7.5 million euros research project to the Digital Europe Programme. The so-called CyQCI will be implemented along with the Cyprus University of Technology, the Deputy Ministry of Research, Innovation and Digital Policy, the Department of Electronic Communications, the Digital Security Authority, the Cyprus Telecommunication Authority, the Cyprus Research and Academic Network and Hellas-Sat. The CyQCI is projected to connect the most critical governmental, academic and commercial end-users of the three most important cities and tangibly supporting the wider establishment of a EuroQCI. Because of its involvement the EUC will be a necessary stakeholder on materialization of the quantum vision on the way forward.

6.2. THE CYPRUS INSTITUTE

The Cyprus Institute's (CyI) Computation-based Science and Technology Research Center (CaSToRC) is another important stakeholder for the quantum initiative on Cyprus. The CaSToRC functions as National High Performance Computing (HPC) Competence Center and overall aims to pioneer and promote the development and employment of sophisticated computational techniques. Among its portfolio of actions, the Center strives to satisfy the demand of computational and data intensive applications for academia, government, and industry, while quantum computing represent one of its specialization areas. Undeniably, CaSToRC operates as a portal to the top-tier resources, including some of the most powerful computers worldwide, providing their high-level expertise to Cyprus and the surrounding area. There are two important moments for the Cyprus Institute that should be highlighted in the context of this study; the first dates back to 2009, when CyI signed a Memorandum of Understanding (MoU) for joint-research ventures in computational sciences with IBM; The second one is the recent award of a prestigious

ERA Chair Grant for the project "Quantum Computing for Excellence in Science and Technology (QUEST)" which will receive around 2.5 million euros to upgrade the quantum readiness of Cyprus and close the gap between the country and other EU Member States on quantum technologies. The project will feature a consortium between CaSToRC and the German Electron-Synchrotron (DESY) and will be overseen by Professor Constantia Alexandrou. With its latest attainment, the CyI represents a prospective partner for the quantum initiative that could advance and stimulate the buildup and testing of quantum computing systems across the island.

6.3. THE CYPRUS UNIVERSITY OF TECHNOLOGY

With a total of 40 million euros financing of over 227 research programmes in and outside of European soil, the Cyprus University of Technology (CUT) consistently strives to promote research excellence and is recognized on a global scale. The CUT's most successful HORIZON 2020 programme in Europe to date has received a funding that is estimated around 9 million euros. Among its latest accomplishments, CUT has participated in the construction of a RISE Excellence Center for technological and commercial innovation and has made a significant contribution to the creation and acceptance by the Cypriot state of pertinent laws to support the incubation of start-ups by universities for direct interconnection with the economy and productivity. Additionally, the CUT also serves as a communication link between the academic and the global business community, n areas of excellence in relation to economic trends like shipping, the hotel industry, and energy sources management and regularly cooperates with governmental organizations such as the Research Promotion Foundation (RPF), the European Programmes Office, and the National Research and Innovation Committee of the Ministry of Education and Culture and regional agencies like the Limassol Chamber of Commerce, the Limassol Municipality. The involvement of CUT in the setup of the CyQCI suggests that it should participate actively in the proposed quantum ecosystem across Cyprus.

6.4. DEPUTY MINISTRY OF RESEARCH, INNOVATION AND DIGITAL POLICY

The Deputy Ministry of Research, Innovation and Digital Policy (DMRID) seeks to create a modern and efficient state that is competitive on the European and global levels, as well as a dynamic digital economy where every citizen and every business will be able to grow and prosper. It represents the focal point with institutional competency over areas that are close to quantum – although there still not a quantum-specific branch in its structure – and will provide its support towards the establishment and deployment of the CyQCI along with all previously mentioned partners from the side of the central administration. For this reason it represents as an inseparable piece of the envisioned quantum ecosystem under this study and will function in unison with OEB to materialize, not only in technical but also in policy terms, the integration of quantum considerations across every administrative level.

7. OUR PROPOSED MODEL FOR QUANTUM DEVELOPMENT IN CYPRUS

The study has already elaborated and analyzed different business models for quantum development spanning across European and non-European countries with a view of moving forth a similar discussion about Cyprus. The coordination of actions and selection of a specific pathway is unidirectional towards the capitalization of quantum development from scientific to an economic level – with the diffusion of generated technical and non-technical advantages – across and beyond Cyprus. For this reason, the study will propose a preliminary outline that could be further developed and transmuted through various consultations and policy adjustments into a fit-for-future and groundbreaking model for quantum development within the EU. The role of OEB will be pivotal as stimulator and coordinator of this nationwide inclusive network that will aim to integrate quantum considerations in the financial backbone of the Cypriot state (*see figure 1*).

This will happen through the fulfilment of two long-term objectives which are:

- "Connecting the dots" between the central administration, academia, the private sector and the wider civil society in Cyprus and establishing a pan-Cypriot ecosystem.

Ensuring the acquisition of quantum funding opportunities for selected businesses of OEB's sectors, in turn paving the way for the realization of the "quantum economy" concept.

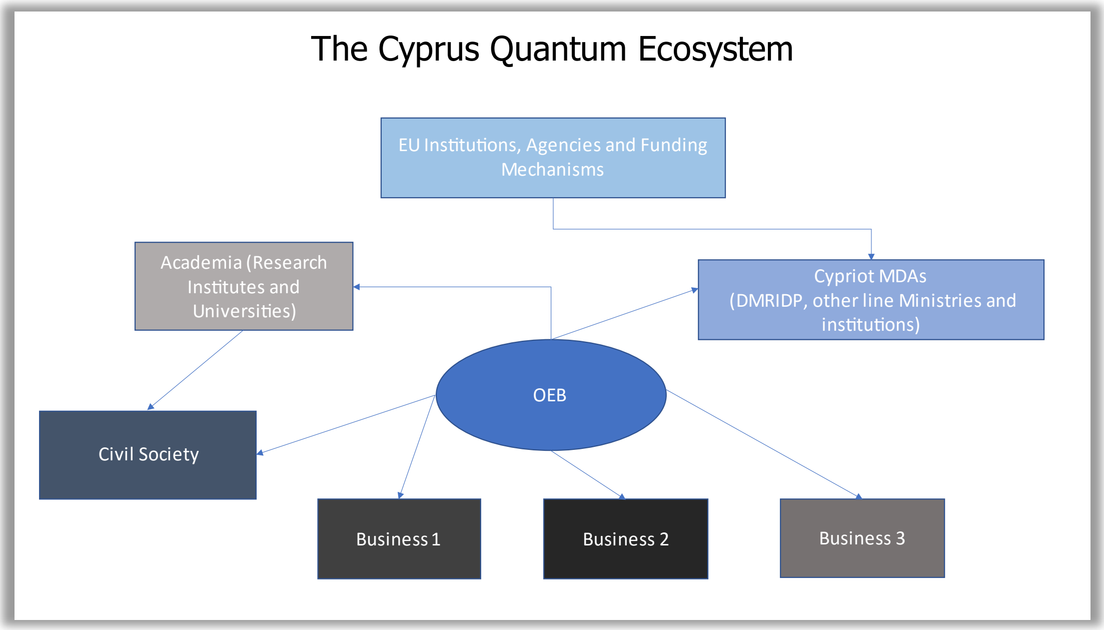

Figure 5: Proposed Quantum Development Model for Cyprus

Concisely, the role of OEB will be to galvanize the governmental initiatives from the Cypriot Ministries and Development Agencies (MDAs), stimulate the involvement of academia in the policy-making processes and spread the positive effects of quantum towards direct beneficiaries i.e., businesses that belong in the selected clusters of the so-called OEB members and areas of interest and in turn to indirect beneficiaries of the actions which are the Cypriot citizens that will benefit from enhanced and more effective services of the Cypriot businesses.

Although Cyprus does not enjoy the same level of technological edge and capacity in comparison with other European countries, which have already developed their own approaches for the development of quantum exploitation strategies and integrated systems, Cyprus possesses an important advantage – as a small country – considering that the chains of command are less rigid allowing for a more flexible and results-oriented decision-making processes. Another critical point that corresponds to the Cypriot paradigm is that although smaller countries may not easily export technological systems, on the other side they represent great importers and early adopters of technologies because of the physical proximity between regulators and stakeholders and the higher-scale feasibility of diffusing new technologies in the private sector – regularly seen as a testbed.

Apart from the previous, Cyprus is also one of the 27 signatory states of the EuroQCI Declaration that has been mentioned above and can thus generate additional payoffs through the formulation of productive and equally-beneficial partnerships with other EU countries. The long-term vision for Cyprus within EuroQCI would be for the country to install a quantum-secured network that will link and secure the governmental offices, data centers and national telecommunication systems. Taking this along with the physically self-contained nature of an island state, this would create a unique opportunity to develop the technology further and render Cyprus as a regional hub for quantum technology across the Mediterranean. This visibility will bring additional value and funding opportunities for Cypriot businesses - to develop quantum capacity - (i.e., SMEs) which should be prioritized over multinational firms in order to reinforce their services towards citizens and end-users. A subsequent – and rather logical – outcome will also be the amplification of Cyprus' digital policy and diplomatic footprint beyond the projected levels.

8. AN OVERVIEW OF QUANTUM-RELATED CAPACITY BUILDING ACTIVITIES

Although regularly seen as complementary actions, capacity building activities represent the capstone of a successful project assignment. Their completion not only ensures a continuum of the project objectives but at the same time ensures the sustainability of the entire initiative. For this reason, the study features an introductory – yet structured outline of potential activities for boosting the capacity of the members of OEB. More precisely, these activities (e.g., workshops, seminars, roundtable discussions) will aim to upskill and reskill the HR Professionals within OEB's structure in order to:

- ✓ Integrate quantum in their business planning and operational strategies of Cypriot businesses.
- ✓ Facilitate quantum awareness by designing and implementing capacity building activities to familiarize their respective employees with the concept of quantum economy and quantum politics in general and
- ✓ Upgrade the skills of Cypriot employees for future occupational positions.
- ✓ Stimulate an outward-looking syndication and business development between Cypriot firms and other EU-based firms that operate under OEB's thematic areas.

*BK Plus Europe can be **catalyst** in further assisting OEB and in turn its members in the organization, planning and implementation of these initiatives.*

It is undeniable that there are close interlinkages between politics and economics, irrespectively of each respective policy area or stakeholder. In this respect, emerging quantum policies in national or European levels do not represent an exception and are highly impacted by the wider policy environment and economic outlook of each country. At the current stage of quantum development across the EU, Cyprus – like other EU member states – should direct its resources and focus towards securing financial opportunities through OEB for their respective businesses across the different economic sectors of interest (i.e., which are not exhausted to the ones included in this study). On this basis, the capacity building activities will emphasize into two overarching areas that will set the groundwork for framing and expediting the advent of a quantum-orientated economy in order to tectonically shape the future business models of Cypriot firms and enhance state preparedness in addressing and integrating quantum considerations in its strategic planning. Hence, the two overarching themes – on the basis of which the capacity building activities will be structured - are the ensuing:

An Introduction to Quantum Policy Frameworks and Business Practices: This thematic area will feature different dimensions of the existing quantum-driven policies and initiatives in international, European and national level as well as analyzing the existing identifiable business models of countries that are included within the remit of this study such as USA, China, Japan, Netherlands, France, Germany etc. This will allow the Cypriot businesses and institutions to adapt their operational models towards the ones that are currently employed by these countries.

Quantum and EU Funding Opportunities: Programmes, Mechanisms and Procedures: This thematic area will feature a mapping of all the available EU funding programmes and mechanisms for quantum along with the necessary procedures. In this regard, the areas will cover and closely examine the following EU funding instruments and their application processes and criteria: The Digital Europe Programme, The Connecting Europe Facility (CEF), The Horizon Europe, Funds from the European Space Agency (ESA), National Funds (incl the already-formalized RRPs). This will allow the Cypriot businesses and more importantly OEB to understand the key requirements for each funding programme and to increase the channeling of financial opportunities towards the Cypriot businesses.

The two previous thematic areas will span across the different capacity building actions that are foreseen by BK Plus Europe and could be jointly implemented with OEB. In this regard, the following capacity building activities for HR Professionals could be organized:

- Workshops about Quantum Developments: This type of capacity building activity represents a more interactive exchange of views on quantum-related issues that is characterized by the *active learning principle* and structured to incite a more participatory approach between the trainers and the learners. This event format can be organized easily by OEB for the HR Professionals and can contribute to the transmission of practical knowledge and pondering on specific issues around the existing quantum developments, policies and future initiatives that could be undertaken – namely the 1st thematic area that was presented above - within the Cypriot companies as well as for the country in general.
- Seminars about Quantum Financial Opportunities: This activity can be organized in a series of two-hour meetings that touch upon the 2nd thematic area – namely for the potential EU funding opportunities related to quantum - where the responsible person from the OEB Secretariat can inform and clarify to all HR Professionals all the required steps for the eligible participation of Cypriot businesses under OEB's umbrella sectors. Each seminar can be dedicated to each funding programme/mechanism explaining its structure and state-of-play with regard to quantum opportunities, demonstrating the important role of OEB as a coordinator and stimulator of future opportunities.
- Quantum Symposiums: This activity represents a wider effort to raise awareness on national level and promote the innovative and fit-for-future role of quantum in both state and market levels. From a broader perspectives symposiums pose a great opportunity to bring together all relevant stakeholders of the society (i.e., government, academia, private sector) and capitalize on their interactions to build new synergies and forge existing ones. In this regard, the academic sector can display a major role especially at a technological level and the presentation of technical findings by prominent research centers such as CERIDES or CaSToRC can generate a major impact on governmental policy planning and in turn for the private sector (i.e., Cypriot businesses) who will be the recipients of these novel products and services. These events should be attended by public officials, scholars and members of academia, product owners and members of Cypriot businesses. Essentially, these events represent the cornerstone of the proposed approach for quantum development in Cyprus.

9. DEVELOPMENT OF CRITICAL PATHWAYS FOR QUANTUM IN CYPRUS

A significant part of the study focused on the external environment and the ongoing "quantum race" that has commenced in the latest decade. Although it remains unknown when quantum technologies will be ready to enter the global markets and redefine the economic and digital policy contours of various countries, the latter are heavily investing in their R&D departments and have already formulated a policy vision for quantum. As previously mentioned, the emergence of quantum technologies is forecasted to redesign the existing business models, corporate processes or supply chains of the private sector and the decision-making processes that could be taken by the public sector. Nevertheless, the global leadership and sovereignty in this field calls for the successful combination of the following parameters:

- Acquisition of government support
- Commitment and buy-in from private companies
- Establishment of a talent incubator for quantum.

While Cyprus does not contend at all on the same playground as the US and China, it is part of the EU family and can strongly benefit from EU-driven initiatives such as the EU Commission's Quantum Flagship and the EuroQCI. However it is important to highlight that the country's positioning within the EU can be strongly reinforced with a forward-looking policy planning and a more growing commitment towards quantum development. According to a Boston Consulting Group's (BCG) report in August 2022 titled "Can Europe Catch Up with the US (and China) in Quantum Computing?", the biggest challenges that have been underscored so far have been the lack of coordination within each – and beyond – each EU Member state, the low-scale investment or lack of investment coming from the private sector in order to match the venture capital powerhouse companies of the U.S such as Google, Amazon or IBM and the lack of sufficient talent development despite the fact that the EU has top universities which acquire quantum computing studies. In this regard, success in this field depends on government commitment – and more broadly public sector intervention - to collaborate together with other stakeholders and closer syndications between academia and the private sector in order to advance the region's quantum computing capabilities and adequately address all three factors that were mentioned. After all, the business environment is committed in the transformation of existing challenges into future opportunities and that is one of the most validating arguments for the creation of a European-wide quantum market.

Taking stock of all the previous segments the study will culminate into the formulation of some "critical pathways" directed to OEB, the Cypriot businesses and the Cypriot Government. The policy recommendations – which should be distinguished from the proposed capacity building initiatives – will function as potential enabling measures that could be initiated in the form of future assignments and instigate further actions in each level with the goal to come closer to the formation of the proposed Cyprus quantum ecosystem.

*In this respect, **BK Plus Europe** acquires the readiness and capacity to extend its scope of services to assist each stakeholder with the proposed policy suggestions of this study.*

These measures are the following:

- <u>Forge stronger engagement and partnerships between OEB and its BusinessEurope counterparts on quantum</u>: Since quantum development represents a European-wide effort, that should also be translated in more coherent syndication between institutions at all levels. In this regard, OEB represents the main beneficiary for this project – and because of its central role as an initiator of the Cyprus quantum ecosystem approach – it should foster and augment its footing on the BusinessEurope – the official lobby group for the representation of all businesses across the EU and in seven non-EU countries through their national focal points. Since OEB carries this role for Cyprus, a potential first step towards that direction would be for OEB to engage with the most quantum-conducive business associations i.e., the following:
- Vereniging VNO-NCW (**The Netherlands**)
- Bundesverband der Deutschen Industrie e.V. – BDI (**Germany**)
- Bundesvereinigung der Deutschen Arbeitgeberverbände e.V. – BDA (**Germany**)
- Mouvement des Entreprises de France – MEDEF (**France**)
- Confederation of Finnish Industries – EK (**Finland**)

The engagement will not only establish a new pattern of joint planning and implementation of activities between the members of BusinessEurope but will also enable Cypriot businesses to participate in cross-national ventures and build credibility into this emerging market. Three additional actions from OEB would be i) to raise awareness of the lobby's role in quantum development across Europe through the inclusion of quantum-related agenda topics in the Research and Innovation Working Group of the Industrial Affairs Committee ii) include a quantum section in its Annual Report and iii) stimulate a wider policy dialogue through its participation in Technical Committee for Technology of the Ministry of Energy, Commerce & Industry (MECI).

- <u>Boost the quantum preparedness of Cypriot businesses:</u> Although industries are become more digitalized on a day-by-day basis, a vast majority of business leaders worldwide support the idea that it will take between 15 to 20 years for quantum to make an impact on the market. This is likely to lead to underinvestment in quantum technologies and skills and fundamentally an existential threat for companies across all sectors because of the excrescent cybersecurity risks and the loss of sensitive information. Another challenge is the siloed approach between companies, whereby quantum initiatives derives from grassroot approaches between few individuals or smaller companies which staunchly call for the maturing of the concept within the existing market. For this reason, companies of every potentially impacted sector should monitor the latest developments and trends in quantum technologies. This can happen through the following actions:
- Establish an R&D or Innovation Department - and/or expand the mandate of the existing Business Department - to monitor existing developments and deliver an annual report on quantum

implications for the assigned business sector. In case the business cannot proceed with the establishment of a new department because of budgetary or other constraints, the option of an external consultant can be strongly considered for these tasks and for the delivery of tailored training sessions.

- Ask each business department/unit/division to incorporate plans related to quantum technology in their strategic planning each year.
- Entrust the business' IT Department to centralize all sensitive data from legacy systems in order to add another layer of protection before the advent of quantum encryption systems.
- Search for the right people and seek stronger partnerships with academic research institutions (i.e., CERIDES Center and CaSToRC).
- Enter the Membership Program – if possible - of quantum-conducive environments like the **Quantum for Business Platform** supported by the Dutch National Quantum Program, featuring a community-based structure and encompasses courses, events and networking sessions connecting businesses with universities that want to pioneer the development of new technologies. Another important EU-wide network event is the **Quantum Business Europe** which is an important and transformational event which brings together industry leaders, early adopters and researchers from a variety of sectors (e.g., finance, energy, defense, agriculture, telecommunications, transport and government and regulatory agencies) and aims to bridge the gap between science and businesses.

- Establish a Quantum Working Group in the Deputy Ministry for Research, Innovation and Digital Policy (DMRID): The role of OEB – as highlighted by this study - is to function as a node of opportunities enhancing the connectivity and synergies between the government, the private sector, academia and the civil society. Nevertheless OEB cannot achieve as a standalone entity a fine-tuned central coordination, implementation and evaluation of actions, programs and mechanisms related to quantum technologies. Additionally, coordination with the EU Agencies will have to be administered by the governmental institutions and agencies in an attempt to avoid policy fragmentation. For this reason, the Deputy Ministry of Research, Innovation and Digital Policy should include in its annual planning of activities the setup of a Quantum Working Group in order to institutionalize quantum policy pathways. The unit will in turn be tasked with the fabrication of a "National Quantum Strategy for Cyprus" and the national coordination of various EU funding programs and initiatives on quantum, bring the government sector at the foreground of the national quantum development planning. This unit will operate as the key coordinator on behalf of the Cypriot Government and will closely cooperate with OEB in order to maximize the benefits through a whole-of-society approach and enable larger-scale venture capital investments. Since both technical and policy capacity are key perquisites, this unit can either be staffed by recruiting renown quantum experts from academic institution and the private sector or seek the expertise of an external consultant with familiarization on the topic at hand.

- Instate a "Quantum Living Lab" to realize the proposed Quantum development model: This recommendation provides a fundamental step towards the realization of the proposed quantum ecosystem approach that was described in the upper study segments. The Living Labs (LLs) are open innovation ecosystems that function as incubators of new and fresh ideas. In this case, this laboratory should be headed by OEB and staffed with credible and high-level scientific individuals on quantum from the academic sector, frontrunner leaders on quantum from the wider business environment and various stakeholders from the government sector. Essentially, the will operate as an orchestrator, namely a multi-stakeholder platform that will be fed with policy, regulatory and market considerations by the public and private sector, which will be transmuted into innovative solutions by the scientific community. The overarching responsibility of the Living Lab would be to generate new ideas, mature existing concepts and architectures, test them in pilot actions and implement – and upscale in case of success – new projects. The differentiating element and concurrently the added-value of a Living Lab is that it is not bounded by the "one problem-one solution" logic and embraces a holistic approach. In this case, the Living Lab can attract EU funds for the sponsorship of its actions which – if successful – can be considered as a paradigm shift in the research and management of quantum technologies across the EU, by supporting implementation of existing landmark actions (i.e., CyQCI) or by expediting advancements in quantum-affected sectors (i.e., energy, chemicals, health sector, financial services).

Another advantage of the Living Lab is that it can simultaneously function as a research hub, a testbed for the development and demonstration of new technological products and as a service providers for businesses offering optimized tools and methodologies to facilitate the integration of quantum in their channels. The participatory design and assessment of all actions by different stakeholders allows for a pluralistic, inclusive and sustainable planning of activities, reduces the failure rate of their implementation and can facilitate the penetration of the Quantum Living Lab in global consortia and in a plethora of financial mechanisms and programmes. The abovementioned flowchart is encapsulated in the following diagram (*see figure 2*)

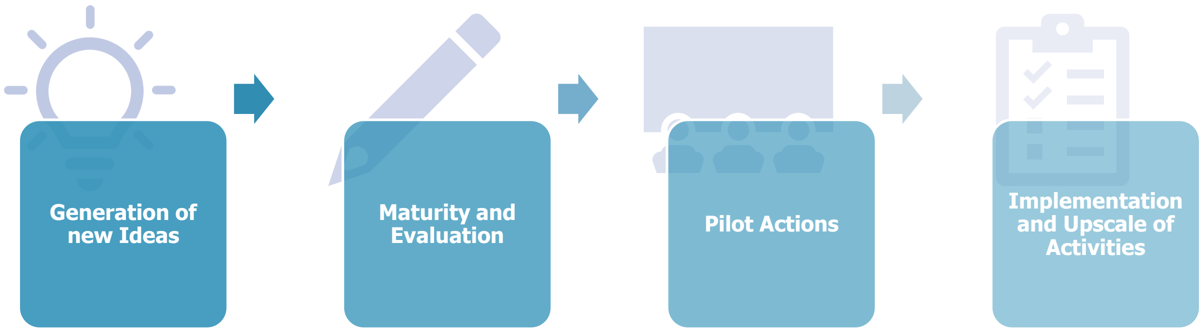

Figure 6: The Quantum Living Lab Approach

10. CONCLUDING REMARKS AND NEXT STEPS

The study has covered with success the following areas:

- The historical background and present developments of quantum technologies.
- The most prevalent quantum use cases (i.e, quantum computing, quantum communications and quantum sensing)
- The prospective industrial sectors where quantum is foreseen to make an impact (i.e., pharmaceutical, financial services, chemicals, automotive and cybersecurity).
- A well-detailed mapping of country policies within – and beyond – EU along with running structure, programmes and mechanisms in the European level (i.e., EuroQCI).
- An exploratory outline of identifiable and functional business models for quantum development.
- The description of the Cypriot business environment and its highest GDP-contributing sectors that could potentially feature quantum practices.
- A preliminary stakeholder mapping of existing – primarily academic - formations and schemes that could function as "agents of change" by fostering the necessary technological capacity and environment to integrate quantum across every societal level.
- The proposed business model for quantum development in Cyprus – taking into account the comparative assessment of the already identified ones.
- A list of thematic areas and capacity building actions that could be undertaken – with the contribution of BK Plus Europe - to increase the awareness and knowledge capacity of HR Professionals on businesses that are operating under the "umbrella" of OEB.
- A list of structured critical pathways in the form of policy recommendations where BK Plus Europe could continue its advocacy over quantum-conducive measures.

All the previous corroborate that quantum is a fit-for-future and mission-critical opportunity for every country and every cluster of the society and concurrently a prelude for a highly-digitalized and largely-automated world. A behindhand and insufficient reaction in the anticipation of this impending transformative environment would not only raise security risks (e.g., loss of sensitive information and national secrets by cyber-attacks) but also entails financial ones. For this reason, Cyprus should not leave aside its untapped potential as a technologically-conducive state and should by all means pursue the realization of a part of the proposed activities in order to expand its footprint on digital. This will be facilitated and spearheaded by a whole-of-society approach featuring a systematic and interactive engagement and syndication between the government, the industry and academia – also known as the **triple helix model of innovation**.

The first step towards this sequence of actions will be carried out in Nicosia at the beginning of October, where the findings of the study will be presented to the HR Professionals and to the relevant stakeholders, with a view bringing together different clusters of the society and stimulating a wider policy discussion among them on the benefits and development scenarios of these early-stage – yet course-changing for our future – technologies

SOURCES

1. Batra, G., Gschwendtner, M., Ostojic, I., Queirolo, A., Soller, H., & Wester, L. (2022, August 9). *Shaping the long race in quantum communication and quantum sensing*. McKinsey & Company. Retrieved September 12, 2022, from https://www.mckinsey.com/industries/advanced-electronics/our-insights/shaping-the-long-race-in-quantum-communication-and-quantum-sensing

2. Biondi, M., Heid, Anna, Henke, N., Mohr, N., Pautasso, L., Ostojic, I., Wester, L., & Webster, R. (2022). *Quantum computing use cases are getting real—what you need to know*. McKinsey & Company. Retrieved September 12, 2022, from https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/quantum-computing-use-cases-are-getting-real-what-you-need-to-know

3. Bobier, J. F., Langione, M. , Tao, E. , & Gourevitch, A. (2021). *What Happens When 'If' Turns to 'When' in Quantum Computing?* The Quantum Hubs. Retrieved September 12, 2022, from https://thequantumhubs.com/what-happens-when-if-turns-to-when-in-quantum-computing/

4. Bruze, E., Paskauskas, R. A., Piesarskas, E., Krilavicius, T., Versinskiene, E., Stankeviciute, S., Versinskas, D., & Cardarilli, M. (2021). *Quantum as a disruptive technology in Hybrid Threats*. JRC Technical Report. Retrieved September 12, 2022, from https://euhybnet.eu/wp-content/uploads/2021/12/Quantum-research-article_final_.pdf

5. Budde, F., & Volz, D. (2019, July 12). *The next big thing? Quantum computing's potential impact on chemicals*. McKinsey & Company. Retrieved September 12, 2022, from https://www.mckinsey.com/industries/chemicals/our-insights/the-next-big-thing-quantum-computings-potential-impact-on-chemicals

6. Buchholz, S., Mariani, J., Routh, A., Keyal, A., & Kishnani, P. (2020, February 6). The realist's guide to quantum technology and national security. Deloitte Insights. Retrieved September 14, 2022, from https://www2.deloitte.com/us/en/insights/industry/public-sector/the-impact-of-quantum-technology-on-national-security.html

7. Cooper, P., Ernst, P., Kiewell, D., & Pinner, D. (2022, May 20). *Quantum computing just might save the planet*. McKinsey & Company. Retrieved September 13, 2022, from https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/quantum-computing-just-might-save-the-planet

8. Dietz, M., Henke, N., Moon, J., Backes, J., Pautasso, L., & Saudaque, Z. (2020, December 18). *How quantum computing could change financial services*. McKinsey & Company. Retrieved September 12, 2022, from https://www.mckinsey.com/industries/financial-services/our-insights/how-quantum-computing-could-change-financial-services

9. Evers, M., Heid, A., & Ostojic, I. (2022). *Pharma's digital Rx: Quantum computing in drug research and development*. McKinsey & Company. Retrieved September 12, 2022, from https://www.mckinsey.com/industries/life-sciences/our-insights/pharmas-digital-rx-quantum-computing-in-drug-research-and-development

10. European Commission. (2021, December 16). The European Quantum Communication Infrastructure (EuroQCI) Initiative. Retrieved September 12, 2022, from https://digital-strategy.ec.europa.eu/en/policies/european-quantum-communication-infrastructure-euroqci

11. Flöther, F., Murphy, J., Murtha, J., & Sow, D. (2020, June). Exploring quantum computing use cases for healthcare. IBM. Retrieved September 14, 2022, from https://www.ibm.com/downloads/cas/8QDGKDZJ#:~:text=Disruptive%20healthcare%20use%20cases,particularly%20relevant%20to%20the%20sector.

12. G. Raymer, M., & Guha, S. (2022, June 13). *How U.S. policymakers can enable breakthroughs in quantum science*. Brookings. Retrieved September 12, 2022, from https://www.brookings.edu/techstream/how-u-s-policymakers-can-enable-breakthroughs-in-quantum-science/

13. The White House. (2022, May 4). *FACT SHEET: President Biden Announces Two Presidential Directives Advancing Quantum Technologies*. The White House. Retrieved September 12, 2022, from https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/04/fact-sheet-president-biden-announces-two-presidential-directives-advancing-quantum-technologies/

14. IQT News. (2022, April 20). *How Dutch ecosystems help the progress of quantum technology*. Inside Quantum Technology. Retrieved September 12, 2022, from https://www.insidequantumtechnology.com/news-archive/how-dutch-ecosystems-help-the-progress-of-quantum-technology/

15. Kumagai, T. (2021, July 15). *German Government Pouring Efforts into Developing Quantum Computer Technology and Putting it to Practical Use | DWIH Tokyo*. DWIH TOKYO. Retrieved September 13, 2022, from https://www.dwih-tokyo.org/en/2021/07/15/quantum-computer/

16. Lewis, A., & Travagnin, M. (2022). A Secure Quantum Communications Infrastructure for Europe: Technical background for a policy vision. JRC Publications Repository. Retrieved September 12, 2022, from https://publications.jrc.ec.europa.eu/repository/handle/JRC129425

17. Lewis, A. M., & Tranagnin, M. (2018). The Impact of quantum technologies on the EU's Future Policies: Part 3 Perspectives for Quantum Computing. JRC Publications Repository. Retrieved September 12, 2022, from https://publications.jrc.ec.europa.eu/repository/handle/JRC110412

18. Lewis, A. (2017). The Impact of quantum technologies on the EU's future policies: Part 1 Quantum Time. JRC Publications Repository. Retrieved September 12, 2022, from https://publications.jrc.ec.europa.eu/repository/handle/JRC105213

19. Lewis, A., Kramer, M., & Travagnin, M. (2016). *Quantum Technologies: Implications for European Policy: Issues for debate*. JRC Publications Repository. Retrieved September 12, 2022, from https://publications.jrc.ec.europa.eu/repository/handle/JRC101632

20. Machi, V. (2022, August 19). Defense and Commerce departments partner on space traffic management. Defense News. Retrieved September 12, 2022, from https://www.defensenews.com/global/europe/2022/01/05/eying-military-gains-france-goes-big-on-national-quantum-technology/

21. Pollet, M. (2021, September 3). *France, Netherlands join forces in quantum technology race*. www.euractiv.com. Retrieved September 12, 2022, from https://www.euractiv.com/section/industrial-strategy/news/france-netherlands-join-forces-in-quantum-technology-race/

22. Singer, P. W. (2022, April 14). *China May Have Just Taken the Lead in the Quantum Computing Race*. Defense One. Retrieved September 12, 2022, from https://www.defenseone.com/ideas/2022/04/china-may-have-just-taken-lead-quantum-computing-race/365707/

23. Süssenguth , F. (2022, January 26). *The German strategy in the race for the quantum computer | Heinrich-Böll-Stiftung | Tel Aviv - Israel*. Heinrich-Böll-Stiftung. Retrieved September 13, 2022, from https://il.boell.org/en/2022/01/26/german-strategy-race-quantum-computer

24. Verhagen, P. (2019). *Understanding the Strategic and Technical Significance of Technology for Security, Implications of Quantum Computing within the Cybersecurity Domain*. The Hague Centre for Strategic Studies. https://hcss.nl/report/understanding-the-strategic-and-

technical-significance-of-technology-for-security-implications-of-quantum-computing-within-the-cybersecurity-domain/

25. Vernacchia, S. (2019, February). Quantum leap: Advancing a strategy for quantum computing that will inspire, support and safeguard economic growth in the Middle East. World Government Summit in partnership with PWC. Retrieved September 14, 2022, from https://www.pwc.com/m1/en/world-government-summit/documents/wgs-quantum-leap.pdf

26. Yndurain, E., Woerner, S., & Egger, D. J. (2019, September). Exploring quantum computing use cases for financial services. IBM. Retrieved September 14, 2022, from https://www.ibm.com/downloads/cas/2YPRZPB3

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