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The Key Role of SMEs in the European Defense Ecosystem with Emphasis on Quantum Technologies

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***Abstract*— The research paper focuses on the important role of Small and Medium Sized Enterprises (SMEs) in the development of the European defense ecosystem with emphasis on quantum technologies, incl. with dual use. The research is based on interdisciplinary approach. In addition to the methods of analysis and synthesis of primary and secondary sources of information, generalization, inductive and deductive research approach, the study uses Drexler/Sibbet Team performance model as well as Joseph Schumpeter's theory from the entrepreneurial ecosystem, which claims that SMEs play a crucial role in economic development through "creative destruction" and innovation. The research is based on the key strategic documents of the European union such as the White paper for European defense - Readiness 2030, the Quantum Europe Strategy, the Enrico Letta's Report on the Future of the Single Market, the Mario Draghi's report on EU competitiveness, the Sauli Niinistö's Report on Strengthening Europe's Civilian and Military Preparedness and Readiness as well as the Global risks report of the World Economic Forum. The results of the study identify quantum technologies both as innovation drivers, but also as risk multipliers across many domains - security, defense, cognitive warfare and geopolitics. At the same time contrary to the perception that the defense sector is mainly reserved for traditional defense contractors and large established firms, the study shows that SMEs act as key accelerators of dual-use technological innovation and development of market niches due to their agility, flexibility, cross-sector adaptability, and closer ties to civilian markets, making them an important player in the process of building open strategic autonomy for the EU. In conclusion, the publication draws certain conclusions and recommendations for the importance of social dialogue and SMEs' integration into EU defense-industrial ecosystem through their participation in quantum technologies, as it is essential for European defense market and competitiveness.**

Keywords— cognitive warfare, competitiveness, EU defence, quantum technologies, SMEs

I. INTRODUCTION

The aim of this publication is to emphasize the role of the small and medium sized enterprises (SMEs) for the development of the defense and quantum industries and to foster awareness of the importance of quantum technologies - not only for science, but also for building resilience, defense and competitiveness in European union (EU).

The article focuses on the nexus between defense, cognitive warfare, innovative quantum technologies, and SMEs, start-ups, scale-ups. The study examines the complex character of the threats and challenges in the contemporary geopolitical, geo-economic, and defense environment, which calls for a paradigm shift toward more effective cooperation at the national and EU levels as well as the active involvement of stakeholders from the European defense and quantum ecosystems in building open strategic autonomy. A special emphasis is placed also on the role of the social dialogue for ensuring trust and legitimacy.

The publication guides readers through the maze of the newly developed strategic documents at the European level in the field of quantum, security and defense, by emphasizing on the importance of SMEs as agent of "creative destruction" and innovation.

The relevance of the study is determined by second quantum revolution which is underway and the changes in the security environment related to the emerging technological threats, the new cognitive battlefield as well as to the lessons learnt from the short case study of Russia-Ukraine war from 2022. It is in line with the: White paper for European defense - Readiness 2030, the Quantum Europe Strategy, the Enrico Letta's Report on the Future of the Single Market, the Mario Draghi's report on EU competitiveness, the Sauli Niinistö's Report on Strengthening Europe's Civilian and Military Preparedness and Readiness as well as the Global risks report of the World Economic Forum.

The publication is particularly timely in light of the forthcoming debate on the Multiannual Financial Framework (MFF) 2028 - 2034 and the proposed new Competitive fund with a total envelope of € 409 billion, as well as the upcoming proposal for legislative Quantum act. The next European budget is expected to be centered on priorities like security and defense, economic competitiveness, and Europe's strategic autonomy, with a central theme of greater agility and flexibility, while the

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EU Quantum Act will aim to position Europe as a global leader in quantum innovation, ensuring strategic autonomy in this pivotal field.

The research paper consists of the following three points of analysis: 1) European defense and quantum ecosystems with emphasis on SMEs, and through the prism of Joseph Schumpeter's "creative destruction" theory; 2) Quantum Europe Strategy through the lens of Drexler/Sibbet Team performance model; 3) Quantum technologies as innovation drivers and risk multipliers.

II. MATERIALS AND METHODS

The study has been based on institutional analysis and a wide range of official materials, including legal and strategic documents at European, international and national levels dully referenced in the paper.

For the purposes of the publication have been utilized various analytical and synthetic methods, including the analysis and synthesis of primary and secondary sources of information, as well as the methods of induction and deduction, secondary data analysis. The research employs also short case studies from representative European quantum companies and the Ukraine's defense industrial base in order to analyze the changes in modern warfare and the role of SMEs and start-ups in dual-use and quantum technologies.

In addition, an interdisciplinary approach has been implemented, combining political science analysis of the EU, with theories and concepts from the entrepreneurial ecosystem such as - Joseph Schumpeter's theory, which claims that SMEs play a crucial role in economic development through "creative destruction" and innovation as well as the Drexler/Sibbet Team performance model which supports teams in developing and realizing their full potential by outlining seven different stages, each characterized by specific actions and resolved challenges. Moreover, a SWOT analysis was conducted to assess the main strengths, weaknesses, opportunities and threats of the EU quantum's state of play.

III. RESULTS AND DISCUSSION

1) European defense and quantum ecosystems with emphasis on SMEs, and through the prism of Joseph Schumpeter's "creative destruction" theory

Creative destruction plays a key role in entrepreneurship and economic development. Coined by economist Joseph Schumpeter in XX century, the theory of "creative destruction" suggests that business cycles operate under long waves of innovation [1]. The process of creative destruction incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one [2].

SMEs are not only a large part of the economy but also, almost by definition, are at the heart of the Schumpeterian process of creative destruction, since most new firms entering are small (as are most of the exiting firms). The heart of the growth potential of a Schumpeterian business fabric lies in the presumption that small entrants bring to the market new and better processes or products, displacing firms with older and/or less efficient products or technologies. Innovation is at the core of the Schumpeterian growth process and small and medium enterprises are the most promising actors in the Schumpeterian dynamics, as they are considered to have a key role in creating new ideas and developing them into successful innovations. A lack of small new innovators may thus reduce particularly the introduction of radical breakthrough innovations, which lay the foundations of completely new markets. Missing small new innovators may also reduce the innovativeness of incumbent firms, lacking the challenge to adopt the latest innovations to escape competition and lacking the opportunity to acquire small firm ideas to further improve on [3].

Europe's 25 million SMEs are the backbone of the EU economy. They employ around 100 million people, account for more than half of Europe's GDP and play a key role in adding value in every sector of the economy. SMEs bring innovative solutions to challenges. In the diverse industrial landscape, the space and defense sectors are key for the EU's strategic and technological sovereignty and offer great potential for European SMEs [4].

However, defense and high technological spheres are still very closed and often restricted to established players with proven track records. For the traditional defense industry, it remains difficult to realize that the level of demand is extremely high, funding is insufficient, and the willingness of the public and private sectors to take risks is volatile. In such a situation, the involvement of new players such as SMEs, start-ups and scale-ups does not lead to mutual competition, rather than to mutual complementarity and competitiveness. There is a need of a paradigm shift and it's not about choosing between traditional defense industry companies (which have specific expertise, scale and rich experience) and the new small entrants, but about making them work together to innovate disruptively, balance and compensate speed, cost, and risk. SMEs act as key catalysts for dual-use technological innovation and the development of market niches thanks to their flexibility, ability to adapt across different sectors, and closer ties to civilian markets, making them a key factor in the process of building (open) strategic autonomy for the EU.

The EU's open strategic autonomy refers to its ability to act autonomously (i.e. without depending on other countries) in strategically important policy areas, linked to both the economic and non-economic spheres. These areas may include defense, research, energy, health, media, technology, industry, as well as development cooperation, promotion of democracy, protection and promotion of human rights [5].

In this regard, the European Commission boosts cross-border cooperation and new entrants by maximizing the European Defense Fund, through SME-focused calls, bonuses and award criteria, and stronger links to the wider defense community. It also supports disruptive technologies, allowing companies to take more risk and to create economies of scale by seeking synergies between civil, space and defense industries in EU programmes [6]. According to Sauli Niinistö's Report on Strengthening Europe's Civilian and Military Preparedness and Readiness, the race to control disruptive technologies will intensify as it adds to the arsenal for power and global influence. Disruptive technologies offer untold possibilities by shifting the economic performance, but also come with new vulnerabilities and security concerns related to the transformed nature of warfare (unmanned air and naval systems with AI, encryption keys etc.). In this regard, defense and dual-use-related considerations should be fully embedded in the EU's work on critical technologies, such as AI and quantum, especially in terms of promoting the EU's advances in this field to reduce dependencies and protect against technology leakage [7].

The Russia-Ukraine war from 2022 is a kind of a case study, showing the considerable changes in modern warfare, particularly regarding the speed of innovation cycles, drone proliferation, and electronic warfare evolution. The Center for Strategic and International Studies (CSIS) made a thorough report on how Russian invasion dramatically accelerated transformation of

Ukraine's defense industrial base by focusing on: 1) civilian-military fusion with IT professionals and engineers either joining the armed forces directly or providing technical support as well as 2) decentralized innovation which is beyond formal defense industries, entrepreneurs and small groups emerged as significant innovation sources. Dr. Phillip Karber, professor of military strategy and warfighting at the Eisenhower School observed that major changes in drone technology occur approximately every six months, which is dramatically faster than typical Western defense acquisition timelines. He outlines that: "We in the West, including the United States, are just not keeping up. It takes us six years to get it designed". For software-based weapons systems, Kateryna Bondar, CSIS fellow indicated the innovation cycle could be as short as one to two weeks, with immediate battlefield testing and feedback loops. A critical factor identified as enabling rapid innovation was the direct connection between developers and frontline users. In addition, the president of global government at the American manufacturer of drones "Skydio", Mark Valentine, highlighted how traditional U.S. acquisition processes rely on requirements developed years before contracts are awarded, often based on lessons from previous conflicts rather than emerging threats. He said Skydio's drones, built for U.S. wars in Iraq and Afghanistan with uncontested airspace, struggled in Ukraine's contested electronic environment [8].

Although defense field may seem like the exclusive domain of specific experts and organizations, the complex challenges and the predictable unpredictability suppose a more comprehensive and inclusive approach. The complex character of the threats and challenges in the contemporary geopolitical, geo-economic, security and defense environments require a shift in approach and a change in mindset of the governments and stakeholders for responding adequately and timely. This is not an easy task for sectors that are highly sensitive for countries and their sovereignty, namely defense, security and deep tech industry. Despite the fact that countries recognize that they would struggle to guarantee their security, defense, and competitiveness on their own, their tendency to concentrate resources domestically and share only part of their strategic vision slows the resolution of these challenges and leads to a significant fragmentation of efforts. The situation additionally aggravates, living in the AI and the second quantum revolution era.

The traditional risks reports of World economic forum clearly outline the complex where escalating geopolitical, environmental, societal and technological challenges threaten stability and progress worldwide. They focus on multiple global risks and call for urgent actions to proactively prepare for future shocks. Nowadays, Visa's chief economist, Wayne Best, who refers to "small business as the lifeblood of any economy", even defines the economic risks as "persistent disruptions" rather than "episodic shocks" where success depends on adaptability, resilience and the ability to navigate the constant change [9].

This year 2026 edition reveals again an increasingly fractured global landscape, by emphasizing that the global risks continue to spiral in scale, interconnectivity and velocity. It outlines the following top ten risks in two and ten years' perspectives: 1) in two years outlook (by 2028): Geoeconomic confrontation, Misinformation and disinformation, Societal polarization, Extreme weather events, State-based armed conflict, Cyber insecurity, Inequality, Erosion of human rights and/or of civic freedoms, Pollution, Involuntary migration or displacement; 2) in ten years outlook (by 2036), where environmental and technological risks dominate: Extreme weather events, Biodiversity loss and ecosystem collapse, Critical change to Earth systems, Misinformation and disinformation, Adverse outcomes of frontier technologies (incl. AI and quantum), Natural resource shortages, Inequality, Cyber insecurity, Societal polarization, Pollution.

According to the report, progress in quantum technologies is likely to accelerate over the next decade as large companies and governments spend more heavily on seeking quantum leadership. Technology convergence between AI/machine learning and quantum computing is accelerating both fields, giving rise to quantum machine learning. As a result, their combined risk landscape is expected to intensify over the next decade, potentially leading to loss of human control [10].

As stated in the White Paper for European Defense - Readiness 2030, the geopolitical rivalries have not only led to a new arms race but have also provoked a global technology race. In this regard, technology is expected to be the main feature of competition in the new geopolitical environment. A handful of critical and foundational technologies like AI, quantum, biotech, robotics, and hypersonic are key inputs for both long term economic growth, and military pre-eminence. Boosting innovation is key. Technology diffusion for commercial use must therefore be reconciled with more rigid technology ecosystems to advance national security objectives. Based on the already identified capability gaps in the member states, the White paper outlines "AI, Quantum, Cyber and Electronic Warfare" as one of the seven key domains which are critical to build a robust European defense. Emphasis is given to defense applications using military AI and quantum computing. As AI, cloud and quantum computing, secure connectivity, autonomous systems and alternative energy reshape fundamentally warfare and transform traditional approaches, the EU declares to launch a European Armament Technological Roadmap, initially focusing on AI and quantum and boosting dual-use investment through EU, national and private funding, including via the European Innovation Council and the planned TechEU Scale-up Fund [11].

As highlighted by Mario Draghi, developing Europe's defense can boost competitiveness and innovation. It also requires a level playing field for public and private enterprises, targeted support for SMEs, resilient supply chains and a more integrated European defense market. The Draghi report on EU competitiveness refers to quantum as "the next trailblazing innovation in the computing field, which could open new opportunities for the EU's industrial competitiveness and technological sovereignty".

According to the former European Central Bank President, Europe needs to develop a strong and independent defense industrial capacity that allows it to meet increasing demand for military assets and equipment and remain at the forefront of defense technology. He highlights that currently the European defense industry is fragmented, limiting its scale and hindering operational effectiveness in the field. It suffers from a lack of standardization and interoperability of equipment, weakening Europe's ability to act as a cohesive power. He emphasizes also that as the EU defense spending rises, defense industrial consolidation, integration and technological innovation should be supported by reinforced European preference principles in procurement, ensuring that a minimum share of this rising demand is concentrated on European companies rather than flowing overseas. Currently, the EU invests around €1 billion in defense R&D per year, but most funding occurs at Member State level, with only one-tenth share at EU level despite overall public R&I spending being comparable to the US as a share of GDP [12].

The Draghi report originally identified three necessities for the EU to boost its competitiveness by: closing the innovation gap; decarbonizing our economy and reducing dependencies. The new European Commission's roadmap for economic growth - "Competitiveness compass" sets out an approach to translate these necessities into innovation by: 1) creating a friendly environment for young companies to start and expand, with a dedicated EU start-up and scale-up strategy; 2) helping big companies adopt new technologies such as AI and robotics, thanks to the EU Apply AI strategy; 3) making it easier for companies to operate across the EU by simplifying rules and laws, with a proposal for a 28th legal regime to guarantee one set of rules across the EU, including the EU Inc. company form, making it easier to start and grow a business in the EU and attract investments; 4) supporting the development of new technologies, with action plans for quantum, advanced materials, biotech, robotics and space technologies [13].

Defense is a high-tech industry driven by revolutionary innovation, where maintaining strategic advantage demands considerable R&D investment, and quantum technologies offer a dual advantage by enhancing both competitiveness and defense stability. For this reason thinking outside the box alongside with stronger interaction within and between defense and quantum ecosystems are very important as the challenges are growing together with the costs of addressing them. The common denominator for the both ecosystems are the governments, industry, academia, research institutions, SMEs, start-ups and scale-ups. The development of both European defense and quantum markets can further contribute to the suggested by Enrico Letta new dimension of the Single Market, namely the fifth freedom of research, innovation, and education [14] which is expected to catalyze progress in areas such as R&D, data use, AI, quantum computing, biotech, bio robotics, and space.

SMEs have the opportunity to play a more active role both as subcontractors and partners in the value chain and by offering specialized expertise, services and technologies. According to the European Commission data, more than 2500 small and medium-sized enterprises are playing a central role in the complex defense supply chains in Europe. SMEs active in the defense industry are key enablers of innovation and growth, able to conduct essential research, technology and innovation activities. A substantial part of the European Defense Technological and Industrial Base is made of SMEs [15].

Within the defense and quantum sectors and across their points of overlap, it is common that they coexist in a broader ecosystem where some of the companies are coming from other industrial sectors but through the development of dual-use technologies move from civilian to defense and quantum industries.

According to the analysis of the OECD, the quantum industrial ecosystem comprises 4622 organizations, including 830 core companies whose activities are primarily or entirely focused on quantum technologies. Core quantum firms are typically startups that rely heavily on early-stage investment and public funding [16].

This trend of predominance toward SMEs and start-ups continues at EU level where 83% of all full members of the European Quantum Industry Consortium - Europe's largest quantum industry association, are SMEs. As of April 2026, 18 out of 107 companies (16.8%) were large companies, while the remaining are SMEs [17]. The quantum ecosystem is composed of large established and small companies, universities and PROs coming from different other sectors.

The recent mapping of the global quantum ecosystem based on the analysis and data of the European patent office and OECD has revealed that intellectual property, combination of patenting with partnerships, early stage investments and public funding have a key role in the commercialization and industrial scalability of quantum researches. Thy exemplified it by showing the case studies of two French and one German companies - PASQAL, C12, and Planqc, that moved beyond theory. Founded in 2019, PASQAL was built on technology transferred from Institut d'Optique through an initial patent, proprietary know-how, trade secrets and the involvement of researchers who later became founders. This approach ensured the effective transfer of intellectual assets and made IP a core foundation of the company. PASQAL develops quantum processors based on neutral atoms, using precisely controlled laser light to trap and manipulate high-performance qubits. The company became a large enterprise with 300 employees and offers both on-premises quantum processing units and cloud-based access through its own platform and providers such as Google Cloud, Microsoft Azure Quantum, OVHcloud and Scaleway. Early validation and adoption were supported by procurement programmes led by the European High Performance Computing Joint Undertaking, which accelerated industrial readiness, market adoption and Europe's strategic quantum computing capabilities.

C12, a Paris-based spin-off from École Normale Supérieure, was founded by twin brothers Matthieu Desjardins and Pierre Desjardins. The company develops quantum computers using carbon nanotubes, a novel approach that promises greater stability and scalability, and launched Callisto, a cloud-based quantum emulator for testing quantum algorithms before physical processors are available. In five years, C12 grew into a 60-person company, raising €30 million and building a strong intellectual property portfolio. C12 emerged from a breakthrough at École Normale Supérieure, where researchers created a highly stable qubit by coupling an electron spin in a carbon nanotube to a microwave photon. The founders partnered with CNRS Innovation to secure an exclusive licence for the foundational patent and adopted a "patent-first, publish-second" strategy, protecting innovations through patents and trade secrets. By 2025, C12 had raised approximately €30 million from investors including 360 Capital, Airbus Ventures, Bpifrance and the European Innovation Council Fund. It established a nanofabrication laboratory in Paris and partnerships with CEA-Leti, OVHcloud, Thales, Air Liquide and TotalEnergies. C12 is another example how a disciplined IP strategy can transform a scientific discovery into a globally competitive quantum technology business platform [16].

Planqc is based in Garching, Germany and has emerged in 2022 from groundbreaking research into one of the leading companies in the development of digital quantum computers. Utilizing this unique technology based on neutral atoms as qubits, Planqc is pursuing the fastest path toward building industry-relevant quantum computers. The company has more than 100 employees from more than 30 nationalities and total funding and contracts secured amounting €80 million [18].

As Schumpeter emphasized the entrepreneurs incessantly create something new which gives them a temporary advantage over their competitors. For this reason, the member states and their established defense industry players need such renewal and "agents of disruptive innovation" that are the first to recognize the signs of the future and turn them into viable businesses [19]. In the economic arena, if you are not open for business, you are out of business. When translated into the language of security and defense policy, this maxim raises the stakes for the very existence of states and the protection of their citizens and territories to a much higher level.

The changes in security environment and the emerging complex threats show the need of rapid innovation and productive civil-military fusion in the European way.

2) Quantum Europe Strategy through the lens of Drexler/Sibbet Team performance model

Early national quantum strategies in United Kingdom, European Union, and United States (U.S.) initially focused on research and development, but since around 2021 have increasingly shifted toward commercialization, applications, and industrial deployment, with ongoing policy developments highlighting the need to better translate research into market-ready solutions. According to the OECD analysis - Austria, Czech Republic, Germany, France, Netherlands, Denmark, Finland, Sweden, Spain, Italy and Ireland are working actively on the development in the quantum technologies' field. Some of the countries elaborate comprehensive national quantum strategies and/or formulate relevant policies to support development and adoption of quantum innovations, other rely heavily on EU funding notably NextGenerationEU and its Recovery and Resilience Facility for investing in quantum R&D, infrastructure and collaborative projects, which in turn supported the development or formalization of national quantum strategies [20]. Germany, France, Netherlands are among the most active in the field of quantum technologies and apart from the significant national investments they also initiated a trilateral cooperation with over €30 million for R&D programme.

These countries have a vision with a time horizon 2030 and a strong ambition for sovereignty and leadership in quantum technologies. An interesting moment in the many of already strategic documents and initiatives is each country's ambition to be among the leaders in the field. While this approach can drive progress and outline the champions in Europe, it can also be a drawback as the focus may shift to a competition among member states where the best emerge individually, rather than building a strong, coordinated EU effort capable of competing and winning globally. In this regard, the European commission strives to fill this gap and to secure the EU technological leadership by adopting in 2025 a new strategy on quantum.

Presenting the High Tech Agenda of the German Government at the quantum world congress, Dr. René Haak, Head of Science and Technology, German embassy once said "Quantum is a team sport - and Germany is a team player"[21; 22; 23]. By drawing a similar analogy with the "Quantum Europe Strategy: Quantum Europe in a changing world" and applying the Drexler/Sibbet Team performance model, the analysis attempts to determine at what stage the EU is in its transformation from a group into a team on issues related to quantum technologies. Allan Drexler and David Sibbet are the founders of the so-called Team performance model that illustrates seven key stages for turning a group into a team - orientation; trust building; goal clarification; commitment; implementation; high performance and renewal, dully outlined in Fig.1. As the member states of the Union are still functioning much more as a group than as a cohesive team on the quantum issues, the model helps for demonstrating the level of its current and potential evolution in the framework of the EU.

The first stage is related to the "orientation". Here the members are supposed to overcome the existing disorientation, fears, uncertainties and to form a common purpose and team identity. Europe's current situation on quantum technologies shows that EU is a global leader in quantum research, concentrating quantum talent and ranking first worldwide in the number of scientific publications in the field of quantum technologies. It is also home to a significant portion of global quantum start-ups. However, Europe lags in commercialization of this technology [25]. In the Quantum Europe strategy, such an "orientation" is given where the EU is currently. On the basis of this analysis and the Quantum Europe strategy, without claiming completeness, the table 1 outlines the main strengths, weaknesses, opportunities and threats of the EU quantum's state of play. The SWOT matrix complements the main text by synthesizing the main provisions of the strategic document and incorporating additional analytical insights in a concise and structured format.

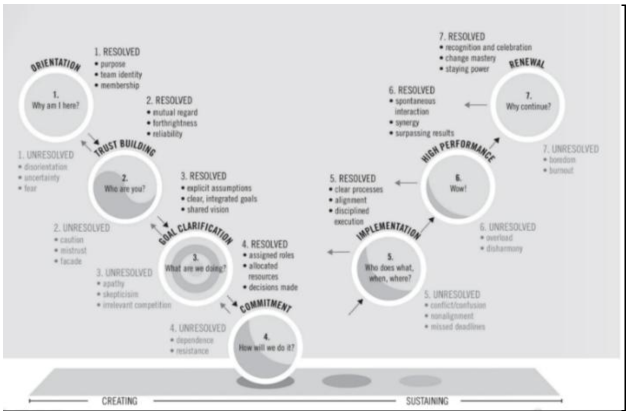

Fig. 1. Drexler/Sibbet Team performance model. The Decision book [24]

TABLE 1: SWOT - QUANTUM EU

Strengths	***Weaknesses***
-tradition in quantum science research -highly qualified engineers, excellence in research -world's largest concentration of quantum talent -ranks first globally in the number of scientific publications -one of the largest quantum startup ecosystems according to McKinsey & Company (2024) -one third of all quantum companies worldwide are based in the EU	-lagging behind in translating its innovation capabilities and future potential into real market opportunities -Europe's efforts remain fragmented across Member States and funding bodies -duplication of efforts, inefficient use of resources, and growing competition for talent among Member States -undermined EU's ability to build critical mass and scale, slowing down the commercialization pipeline -Europe attracts only 5% of the global private quantum funding, compared to over 50% captured by the USA - five of the top ten tech companies globally in terms of quantum investment are based in the US and four in China -insufficient public and private funding
Opportunities	***Threats***
-ranks third globally in patents filed for quantum computing, sensing, and communication -uses the full range of opportunities given in the five strategic areas for Quantum Europe - research and innovation, quantum infrastructure, stronger EU quantum ecosystem, dual uses potential quantum technologies (security and defence), quantum skills -simplifies rules and laws, with a proposal for a 28th legal regime to guarantee one set of rules across the EU, especially for innovative SMEs, start-ups and scale-ups	-the loss of EU most promising companies and talent -diminishes the globally competitive EU industrial capacity and increases the gaps in priority areas and market translation -speed of technological development and changes, undermining the democratic oversight and accountability -ecosystem remains fragile, with start-ups facing unstable revenues, limited capital, and low industrial demand. -defense and security instability, threatening the very existence of states and the protection of their citizens, businesses and territories -adverse outcomes of frontier technologies (incl. quantum, AI)

The second stage is related to the "trust building" and better mutual awareness. Here the members are supposed to demonstrate mutual regard, forthrightness and reliability by overcoming potential caution, mistrust and facade. In the Quantum Europe strategy, EU focuses on strengthening the vibrant and interconnected EU quantum ecosystem through investments in start-ups and scale-ups, securing supply chains and the industrialization of quantum technologies. In addition to the trust among the stakeholders in the ecosystem, a special attention is also given to the public awareness, societal understanding and informed policy engagement in the field of quantum technologies. Moreover, the European economic and social committee (EESC) always stresses on the role of social dialogue and the involvement of civil society for better transparency, legitimacy and accountability of the relevant policies, thus increasing the democratic oversight and public trust. The EESC calls on the Commission to promote public confidence in the new technologies on the one hand, and to identify (at the earliest possible stage) any negative economic, social and employment repercussions on the other [26]. So that, the speed of the technological changes and disruptions should not be at the expenses of the democratic scrutiny.

The third stage is about "goal clarification" and the presence of a shared vision. In the Quantum Europe strategy, EU clearly outlines its level of ambition by 2030 to be an industrial powerhouse and a global market leader in quantum technologies by strengthening its competiveness, scientific leadership and technological sovereignty.

If every country pushes to be a "leader", it often leads to fragmentation, duplication of effort, and weaker collective impact. In the geopolitical context and the fast-moving, resource-intensive fields like quantum and AI, that can slow EU down compared to the competitors from Asia and North America. The national ambition in itself is not a challenge as it stimulates countries to be champions and stay in good shape. The European problem lies in the lack of sufficient coordination among these efforts for excellence. For this reason, the EU should think more like a single team competing globally rather than many teams competing internally. In addition, if the team is made up of champions, the chances of success increase significantly.

The fourth stage is about "commitment". Here the strategic document outlines the five key strategic areas for Quantum Europe - 1) research and innovation by consolidating excellence across Europe to lead in quantum science and its industrial transformation; 2) quantum infrastructures by developing sustainable, scalable, coordinated infrastructure hubs to support production, design, and application development; 3) ecosystem strengthening by securing supply chains and the industrialization of quantum technologies through investments in start-ups and scale-ups; 4) space and dual-use quantum technologies in the field of security and defense by integrating secure, sovereign quantum capabilities into Europe's space, security and defense strategies, and 5) quantum skills by building a diverse, world-class workforce through coordinated agile education and training systems and programmes and promoting talent mobility across the EU. Specific actions have been identified to meet the strategy's objectives, such as: launching the quantum Europe research and innovation initiative; establishing a quantum design facility and six quantum chips pilot lines; launching a pilot facility for the European quantum internet; expanding the network of Quantum Competence Clusters across the EU and establishing the European quantum skills academy in 2026, developing a quantum technology roadmap in space with the European Space Agency and contributing to the European armament technological roadmap [27].

While the stages may seem obvious, experience shows that all teams go through each one, and any omitted stage is typically revisited later [24]. The first four stages (Orientation, Trust building, Goals clarification, Commitment) focus on team formation. The last three (Implementation, High Performance, Renewal) maintain high performance as the team progresses. In the context of quantum technologies, the European union is still forming the team and is at the stage of commitment where members should confirm their specific roles and responsibilities and commit to their part and to the EU team. As defense and quantum security issues remain within the scope of competences of national authorities, here the leaders of the members states represented at the European council together with the relevant competent ministers sitting at the Council of the EU have a key role to play. The Council, as a co-legislator in the process of adoption of the forthcoming Quantum Act will assume legally binding decisions for the member states in three complementarity dimensions: 1) coordination of the relevant research and innovation investments across the Member States, 2) improvement of the EU industrial capacity in designing and producing quantum technologies, 3) ensuring the security and resilience of quantum supply chains [28].

The rest of the stages are related to the - Implementation, High Performance and Renewal. From now on, the EU and its member states are expected to demonstrate clear processes and division of work, alignment and disciplined execution giving the answers of the questions who does what where and when. Having a common vision, pooling and sharing their resources, and acting as a cohesive power that effectively interacts and uses the innovative and technological potential of its ecosystems, would give the Union opportunities for synergy and high performance. Once this is achieved, and even if the results surpass expectations, it is very important to maintain momentum through renewal and change mastery. To this end, the EU should cease developing subsidiary documents alongside the main ones, focus on allocating funds across key areas, promote synergy among member states, traditional defense industry research institutes and SMEs, and provide greater clarity to ecosystem participants on its objectives and how they will be achieved. Using the "creative destruction" and innovation potential of the SMEs, start-ups and scale-ups as well as completing all seven stages of the team performance model, the EU can further develop its open strategic autonomy, being inclusive and open for partnerships and at the same time capable of holding its own in global competition.

3) Quantum technologies as innovation drivers and risk multipliers

In the first quantum revolution of the early twentieth century, scientists learned to understand and apply quantum mechanics (the interactions of atoms and particles) enabling technologies like transistors, lasers, and microprocessors that underpin modern systems. Now, a second quantum revolution is underway, as researchers can detect and manipulate individual particles to develop new technologies in computing, sensing, simulation, cryptography, and telecommunications [29].

In the German quantum strategy, quantum technologies are outlined as a future technology that have the potential to disrupt and offer particularly promising prospects for use [22]. According to Australian army research center, a quantum technology is one whose functionality derives from engineering the states of individual quantum systems. This distinguishes quantum technologies from earlier 20th century technologies (for example, lasers, magnetic resonance imaging, semiconductor electronics) that employ quantum phenomena (for example, coherence, quantized energy, tunneling), but do not directly initialize, manipulate and measure the states of individual quantum systems. The qubit (quantum bit) is the simplest quantum system and the basic building block of most quantum technologies, respectively the number of qubits is the amount of information that can be encoded and processed by the computer [30]. They are already impacting key areas of the economy, giving rise to new solutions to hitherto unsolved problems, new industry players and innovative business models [31].

As stated by OECD, although quantum technologies offer great potential for innovation, they also present considerable risks, especially concerning digital security and privacy. Quantum computers have the capability to compromise commonly used encryption methods, putting financial information, sensitive data and critical infrastructure at risk. Post-quantum cryptography standards have been developed, with adoption and integration into existing systems to follow. In addition, the advanced capabilities of quantum sensors raise concerns about arbitrary or unlawful surveillance and potential privacy infringements. Applications in cryptanalysis, intelligence gathering and weapons development, among others, pose national security risks that are prompting countries to build domestic quantum capabilities [20]. Professor Peter Shor proposed the basis of factoring large numbers into primes using a quantum algorithm that can perform this calculation exponentially faster than a classical computer [32]. Shor's Factoring Algorithm put quantum computing on the proverbial map. By threatening modern cryptography, it forced governments, industries, and the public to take notice of this emerging technology. Decades later, it remains the standard bearer of quantum algorithms. Efforts to protect financial systems and national security continue, as there is a clear geopolitical risk that a state actor could achieve enough quantum power to use Shor's algorithm before quantum-safe cryptography is fully deployed [33].

Quantum technologies have been identified as having substantial disruptive potential across a range of military applications for the future Joint Force. They offer significant military advantage to early adopters especially in the field of communication, navigation, computational power and high precision sensing as well as simulation, encryption and artificial intelligence [30]. Over the past five years, the EU and the Member States have invested more than EUR 11 billion in quantum technologies. While several Member States have developed their own national strategies and roadmaps, insufficient coordination has led to duplication of efforts, inefficient use of resources, and growing competition for talent. In the second half of 2025, the EU has elaborated a comprehensive strategy to secure its leading position for Europe in the global quantum race by supporting the development of these technologies with dual-use potential in the Union [29].

Although strategic documents in many countries, incl., EU ones, often include the three key quantum technologies pillars - computing, sensing and communications, they rarely emphasize in an explicit and exemplified way their application in defense. By contrast, the army of Australia presents them in a clear and accessible way for a wider audience and connects military and civilian quantum research, which is why its information has been used in this publication without claiming to be exhaustive.

a) Quantum computing

The most critical threat lies in quantum computing's ability to break classical cryptography, potentially leading to mass decryption, the collapse of digital trust infrastructures, and cascading impacts across cyber, economic, and physical systems. At the same time, uneven access to quantum capabilities may deepen global inequalities, concentrate economic power, and drive geopolitical competition toward winner-take-all dynamics [10].

As the analysis of the European Parliament research service show, by the 2030s, quantum computers might compromise traditional cryptography, putting digital infrastructure at high risk in the EU and around the world. Quantum computers pose a significant threat to the security of classical cryptography (symmetric and asymmetric, with asymmetric cryptography more affected than symmetric cryptography by the quantum threat) because they would be able to efficiently solve certain mathematical problems that classical computers struggle with. This is due to the fact that quantum computers operate on quantum mechanical principles, which would allow them to perform certain complex calculations much faster than classical computers. Algorithms to break traditional cryptography using quantum computers already exist, with Shor's algorithm being the most notable example. Post-quantum cryptography (which uses classical computer properties) and quantum cryptography (which uses quantum mechanical properties) are the two types of critical technology able to protect digital infrastructure from quantum computer attacks. Robust post-quantum cryptography algorithms have been identified, but swift and efficient implementation is crucial before malicious actors exploit the power of quantum computers. Experts stress the need for quantum preparedness to be put in place now, with some of them even warning of a 'quantum cybersecurity Armageddon'. The EU's security union strategy and cybersecurity strategy both highlight encryption as a key technology for achieving resilience against cyber-attacks (e.g. for securing digital systems and defense capabilities) [34].

The EU plans to develop in 2026 its Quantum Computing and Simulation Roadmap. In addition, it outlines its ambition to expand the number and capacity of EuroHPC-based quantum computing systems and set up a monitoring framework for quantum computing. The long-term goal is of achieving a full-stack quantum computing capability by 2030 [29]. Rather than replacing high-performance computing (HPC) systems, quantum computers are expected to complement them, acting as accelerators to boost the overall performance of the computing solution, delivering results much faster and in a much more energy efficient way.

Breakthroughs in quantum computing could also rapidly accentuate economic and industrial inequalities among countries. Disparities in access to existing technologies have already created a digital divide, which is likely to become deeper with quantum [35].

Examples for potential technologies in the field could be: Noisy Intermediate - Scale Quantum computers (incl. integrated in classical networks), error-corrected mainframe computers (incl. capable of cryptography; in quantum networks). The nearest term and lowest technological risk being in delivering enhanced image/signal processing, planning and autonomous systems. Specifically in the defense can be outlined the following: 1) Enhanced signal and image processing and searching intelligence, surveillance and reconnaissance (ISR). Edge quantum computers can improve filtering, decoding, and feature identification in signals and images from ISR devices, reducing network congestion from raw data streaming. Distributed and centralized quantum computers may also expand the ability to search and extract intelligence from large unstructured databases; 2) Enhanced optimization of plans and logistics. Quantum computers may be employed at various levels to provide timely optimization of complex plans and logistics systems; 3) Enhanced artificial intelligence/machine learning in automation, robotics and cyberwarfare. Quantum computers promise to accelerate machine learning sub-routines, learning, and model optimization, enabling enhanced performance and in-mission relearning. Combined with improved signal and imaging processing, this may enhance decision-making in autonomous systems, robot populations, and new cyber tools; 4) Enhanced operational simulation and geophysical modelling. Quantum computers can accelerate the simulation of stochastic dynamics and complex differential equations (e.g., weather, ballistics, ocean dynamics), supporting superior decision-making; 5) Enhanced defense science and industry. Quantum computers offer unprecedented capabilities in simulating complex molecules and materials, accelerating innovation in bio-/nano-technology and materials engineering. They can also enhance engineering design and process optimization, enabling higher-performing technologies and more efficient manufacturing; 6) New cryptography capabilities. Quantum computers could break public key encryption using efficient factoring algorithms, though this requires many error-corrected qubits and is unlikely within the next 10 years. However, as this falls within the lifetime of some cryptographic systems, the risk must be considered. New decryption methods may emerge, driving a race between decryption and encryption technologies.

b) Quantum sensing

According to the World Economic forum, quantum sensing is starting to lead to important enhancements in military and industrial applications and the leading players in the field are United States, China and Germany. The risks report outlines the emerging practical applications of quantum sensing for military use such as the quantum sensing's potential to be able to identify submarines or stealth aircraft via gravitational or magnetic anomalies, putting at risk key military assets [10]. These technologies and applications in positioning, navigation and timing, detection of gravitational and magnetic anomalies and microwave spectroscopy are valuable in defense [30].

As outlined in the Quantum Europe Strategy, quantum sensing uses quantum properties to measure physical features with unprecedented sensitivity and precision, significantly surpassing classical sensor capabilities. A special focus has been given to the quantum gravimeters, Quantum Magnetic Resonance Imaging (Q-MRI) and to the forthcoming development of a European Quantum Sensing Roadmap. In 2026 the Union is planning the deployment of a distributed system of gravimeters across Europe - a network of mobile and stationary quantum gravimeters, which allow for the detection of subsurface features located up to several tens of kilometres underground, including water reservoirs, gas deposits, mineral resources, magma chambers, or buried infrastructure. In parallel, the EU is planning to launch a first quantum space gravimetry Pathfinder Flight after 2030 and to develop ground, airborne and space-based gravimeters for Earth observation purposes, supporting both scientific research and strategic applications, including those with dual-use potential [29]. Examples for potential technologies in the defense field could be: 1) Enhanced positioning, navigation and timing. Quantum accelerometers, magnetometers, gyroscopes, and clocks offer the stability and precision needed for accurate GPS-independent navigation. Advanced atomic clocks also enable precise timing, improving positioning and digital communications, and enhancing robotic, autonomous, missile, Command, Control, Communications, Computer (C4I), and fire control systems; 2) Enhanced situational awareness. Quantum gravimeters and magnetometers enable advanced geospatial mapping and anomaly detection, such as locating subterranean structures. Quantum microwave spectrometers offer high sensitivity and continuous detection, enhancing radar range and precision and improving detection of electromagnetic emitters; 3) Enhanced medical and environmental analysis Quantum nanosensors offer unprecedented capabilities for biological and chemical sensing and imaging in medical diagnosis, treatment, and environmental monitoring. These range from injectable nanoparticles for tracking and imaging to lab-on-a-chip analysers and enhancements to existing techniques like Magnetic Resonance Imaging (MRI); 4) Enhanced human-machine interfacing. Quantum magnetometers may enable wearable high-resolution magnetoencephalography for real-time brain activity imaging, which could be a key step toward practical non-invasive cognitive communication with machines; 5) Enhanced defense science and industry. Quantum microscopes, spectrometers, and nanosensors can drive innovation in materials science and nano-, bio-, and medical technology. They enable advances such as imaging complex molecules for drug design and chip-scale Nuclear Magnetic Resonance (NMR) spectrometers that expand access to precision chemical analysis [30].

c) Quantum communication

Quantum communication enables ultra-secure data transmission, protects critical infrastructures, and safeguards sensitive information against future quantum-enabled cyber threats. It also enables to establish quantum communication networks necessary for interconnecting quantum devices such as sensors and computers, into a so-called 'Quantum Internet'[29]. Quantum communications is about the use of quantum networking protocols for the purposes of establishing trusted communications links between sites. Quantum networking allows the transmission of information in the form of qubits between quantum computers, sensors and memory. Quantum networking is expected to allow the development of larger quantum computers from connecting smaller, modular systems of qubits and performing larger distributed computations between them [31]. Quantum communications can be used also to network quantum sensors to correlate and enhance sensitivity over large areas (for example, synchronize clocks within a communication network). Quantum communications can securely access remote quantum computers or transmit data between classical devices (e.g., encryption keys). This is called Quantum Key Distribution (QKD), which enhances security by enabling the safe exchange of one-time private encryption keys between remote nodes of a conventional encrypted network. Security in quantum communications is physically assured by the projective nature of quantum measurements, making it impossible to copy qubit information without modifying it. Interception can thus be detected with known statistical confidence, which depends on the number of qubits used to distil the encryption key and the noise in the communication channel [30].

Thanks to its dual-use potential, it is supporting both civilian applications (e.g., protecting financial transactions, securing public networks) and defense needs (e.g., secure communications for military and national security operations). Through initiatives like the EuroQCI [36] and the Quantum Internet, the EU is building fully autonomous and trusted quantum communication infrastructures, which will protect critical data flows, secure public communications and critical infrastructures, and strengthen Europe's internal security [29]. Applications in the field include: Quantum cryptography including QKD for secure cryptographic key establishment; Quantum radio frequency receivers; Quantum network repeaters for long-distance transfer of quantum-encoded information; Quantum random number generators for improved randomness in cryptography; Transfer of quantum sensor data for storage, computation, or quantum machine learning. Specifically in defense sector can be outlined the following: 1) Enhanced security of communication via QKD. QKD securely distributes one-time private encryption keys, enhancing the security of encrypted communication over public key methods; 2) Enhanced network synchronization. Distributing entanglement can be used to precisely synchronize distant clocks, improving the speed and accuracy of digital communications and enabling better detection and localization of anomalies through correlated sensors; 3) Enhanced sensitivity and large-area quantum sensing. Quantum communications can entangle quantum sensors, improving their combined sensitivity beyond classical limits. Entangling distant sensors also enhances their ability to correlate measurements and more precisely detect or locate anomalies; 4) Enhanced security and performance of quantum computing. Quantum communications can enhance data exchange between quantum computers, combine their computational power, and enable secure access. Networking them is expected to expand performance and applications, similar to the impact of the internet on classical computers [30].

d) Quantum cognition, technologies and cognitive warfare nexus

Just as the development of new technologies transforms the security and information environment, the new threats arising within that environment likewise influence the ways these technologies are applied.

With the digital transformation of the economies and societies worldwide, an increasingly active new battlefield has seen emerging, which often lies in the so-called "gray zone" between peace and war. This is the cognitive warfare, which was suggested by the NATO Allied Command Transformation (ACT) Innovation Hub to be considered as the sixth operational domain alongside with the land, air, sea, cyberspace, and space. Cognitive warfare can be viewed both as a standalone phenomenon and as part of hybrid warfare, which involves the combination of kinetic and non-kinetic instruments and tactics. The European Union, for its part, views the challenges associated with it within the broader framework of hybrid threats. Retired Lieutenant-Colonel of the French Army François du Cluzel, defines cognitive warfare as the "manipulation of the enemy's cognition" aimed at weakening, influencing, delaying, and even destroying the enemy [37]. Cognitive warfare influences human decision-making and extends its reach to the public, society, and the military. Information is weaponized across numerous platforms to target individuals, governments, and mass consciousness, justifying adversaries' strategic objectives. Cognitive Warfare can also be described as the use of all knowledge, strategies, and available tools to impact human behavior through cognition, with the end goal of manipulating and altering decision-making [38].

The nexus between cognitive warfare and quantum cognition, computing and sensing can be viewed as mutually reinforcing. As stated in the Chief Scientist Research Report on Cognitive Warfare: NATO is entering an era of disruptive technologies that affect cognition and human life in both war and peacetime. Here two perspectives can be considered the one of Jerome Busemeyer and Peter Bruza related to quantum models of cognition and decision, and the other one of the Australian army about the most promising quantum technology applications related to enhanced human-machine interfacing (HMI) and magnetoencephalography where engineering meets human psychology by considering consumers' preferences and instincts. Jerome Busemeyer shows how to use quantum theory to compute probabilities for cognitive and decision-making applications. It is a mathematical theory about the human behavior, focusing primary on judgements and decisions. The quantum models of cognition and decision related to question order effects, conjunction and disjunction errors, compability and quantum rationality, concept combination and human semantic space, conjoint memory recognition and episodic overdistribution effect, bistable perception application and categorization decision-making reveal on how people make context-dependent and non-classical decisions [39]. This is particularly relevant to the cognitive warfare where opponents use uncertainty, ambiguity, emotional conditioning, and the resulting effects to influence decisions. Considering that the "brain is the battlefield of the future" as Dr. James Giordano farsightedly declared several years ago, another important aspect is the use of quantum technologies for data collecting and visualizing in real time the human brain and reactions. Enhanced human-machine interfacing. Quantum magnetometers may enable wearable high-resolution magnetoencephalography for real-time brain activity imaging - a key ingredient to practical non-invasive cognitive communication with machines. Magnetoencephalography is a non-invasive technique for investigating human brain activity. It's a neuroimaging technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain, using very sensitive magnetometers [30].

The competition for citizens' minds and emotions as voters and consumers are taking an increasingly central role that impact both the democratic societies and markets development. In this regard, quantum cognition and technologies can be both a cause for emergence and a tool for overcoming the vulnerabilities in open and democratic societies.

IV. Conclusions

On the basis of the analysis provided, the following three key conclusions can be drawn:

1) The SMEs as part of the European defense and quantum ecosystems are of key importance for the development of European defense and competitiveness and for building an open strategic autonomy that gives the EU the opportunity to be simultaneously inclusive and willing for international partnerships and at the same time capable of standing on its own in the global competition. The ongoing second quantum revolution is paving the way for new waves of innovation and the emergence of new technological threats, which require speed, flexibility, cross-sector adaptability and creative destruction potential of the SMEs for recognizing the signs of the future and turn them into viable dual-use businesses.

2) While new technologies are transforming the landscape of security and the information environment, emerging threats are simultaneously shaping their application, which can be viewed in the context of the use of quantum technologies in cognitive warfare. The changes in security environment and the emerging complex threats show the need of rapid innovation and productive civil-military fusion in the European way. The interrelated global risks and the lessons from the war in Ukraine show the need of a paradigm shift in member states and traditional defense contractors and large established firms in order to use the full potential of the EU defense and quantum ecosystems, involving and cooperating with SMEs, start-ups and scale-ups, keeping European scientific and entrepreneurial talents and seeking synergies between civil and defense industries. The global predictable unpredictability supposes a more comprehensive and inclusive approach, a true European spirit and shared vision among the member states, completing all the seven stages for transforming their group into an EU "champion team".

3) Quantum technologies could be innovation drivers, but at the same time risk multipliers. As outlines the World economic forum "quantum" is set to become a large new industry in itself, creating a new manufacturing supply chain, new quantum service business models (e.g. subscriptions to access quantum computing time) and generating a new set of high-skilled jobs. At the same time the national quantum strategies, namely the one of Australia clearly demonstrates quantum defense applications with special focus on quantum computing, sensing and communication that have the potential to significantly shape the battlefield of the future. In this regard, the investments in defense and advanced technologies' capabilities must go hand in hand with raising public awareness and improving societal understanding, trust, and informed engagement in quantum and defense policies. In this context, social dialogue and civil society play also a key role in translating policies into citizens' language, while ensuring that the pace of technological change and transformation does not come at the expense of the democratic oversight.

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