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Transforming Government: People, Process and Policy

# Navigating the quantum frontier: examining government strategy to the next technological revolution

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## Abstract

**Purpose** – This study aims to clarify the status of national strategies regarding quantum computing (QC) technology and evaluate whether and how governments worldwide are aware of potential threats and benefits, as well as anticipate actions, drawing from recent experiences in artificial intelligence.

**Design/methodology/approach** – Extensive research was conducted on academic papers, national strategies, policy documents, government official statements and reports and announcements from major technology companies.

**Findings** – The geopolitical dynamics for QC reveal a complex scenario influenced by defence strategies and research efforts aimed at gaining competitive advantages. However, a quantum future that addresses social challenges seems weak in national strategies.

**Originality/value** – Given the paucity of the QC literature in public management, this study encourages proactive governance research on disruptive technologies, such as QC.

**Keywords** Digital transformation, Digital governance, National strategies, Quantum technology

**Paper type** Research paper

## 1. Introduction

Quantum computing (QC) will be foundational in next-generation digital ecosystems, with significant economic and security implications [European Commission. European Political Strategy Centre, 2025; Rath *et al.*, 2024]. In current complex geopolitical dynamics, quantum technologies have emerged as crucial enablers of national competitiveness, offering revolutionary potential across numerous applications while substantially impacting national security considerations (Mehmood *et al.*, 2024). Although these technologies have not yet been widely adopted, they are expected to mature in the coming decade and coordinated efforts between public research institutions and industry are accelerating their development trajectory. This joint advancement underscores the growing recognition of the strategic importance of quantum technologies in shaping future technological sovereignty and competitive advantage. Quantum

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technologies could add up to $1 trillion to the global economy by 2035 (The Quantum Insider, 2024). A potential "quantum divide" between nations with established quantum technology programmes and those without may result in significant imbalances in key areas such as cybersecurity, defence, health care, finance and manufacturing (Ten Holter *et al.*, 2022).

Although QC is now central to substantial scientific literature in technical fields such as computer science and physics, a significant gap remains in disciplines like management and public administration. On December 30, 2024, a query of the Web of Science database using the search term "quantum technology" returned 33,409 scholarly publications. When the identical query was executed on 7 July 2025, the results had expanded to 44,610 publications, representing a 33.5% increase in just 6 months. However, most publications still focus on computer science and physics, reflecting the field's highly technical foundations and the current emphasis on fundamental research and technological advancement. Excluding conference papers, Management studies increased from 48 to 50 publications, while political science contributions rose from 12 to 14 articles. Interdisciplinary social science publications increased from 22 to 28 and business research articles rose from 29 to 32, while Public Administration remained stable at only 1 paper.

This disparity is notable, given that governments worldwide have invested heavily in quantum technologies and have recently developed and are continuing to develop dedicated national strategies.

While artificial intelligence (AI) continues to dominate academic discourse, the implications of quantum technology require immediate government action, strategic investment and proactive risk management. The potential consequences of knowledge gaps or, more concerningly, misinformation about QC and its associated risks could be detrimental to both government operations and societal well-being (Kop *et al.*, 2024). Contemporary research emphasises the need for anticipatory governance approaches to quantum technologies, learning from the delayed regulatory responses observed in AI development (Blanchard *et al.*, 2024).

This research aims to contribute to the public management literature by:

- analysing existing national quantum strategies across countries that have developed comprehensive approaches; and
- proposing future research directions in public management that also offer practical support for policymakers.

The article is organised as follows. Firstly, an introduction establishes the research context and outlines the study's contribution to the emerging field of quantum technology governance within the field of public management scholarship. The theoretical background section provides essential contextual grounding through two main components: first, a technical overview of QC fundamentals to understand the transformative potential of these technologies and second, an examination of quantum initiatives and investments in the current geopolitical and economic contexts. The methodology section describes the research approach, detailing the document analysis framework used to evaluate national quantum strategies. The results section presents empirical findings through a structured analysis of 16 national quantum strategies, organised around specific evaluative criteria (OECD, 2021). The paper concludes with integrated discussion and conclusion sections that synthesise findings and outline implications for both policy practice and academic scholarship.

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## 2. Theoretical background

### *2.1 Quantum computing at a glance*

Quantum technologies rely on the fundamental unit of qubits, which display physical properties such as superposition, interference and entanglement. Qubits surpass classical limits by concurrently occupying multiple states (the traditional binary "0" and "1"), thus enabling parallel computation; furthermore, entanglement produces extraordinary nonlocal correlations between particles regardless of physical distance (Nielsen and Chuang, 2012).

The computational advantage is clear in quantum algorithms, which can outperform classical computation. Shor's (1997) factorisation algorithm shows exponential speedup when factoring large integers, a feat impossible with traditional methods. Similarly, Grover's (1996) search algorithm achieves quadratic acceleration when searching unsorted databases, demonstrating the distinct problem-solving capabilities of QC.

Although fault-tolerant quantum machines are the primary focus of research in QC, their potential applications and disruptive impact are clear now.

The cryptographic field faces two key prospects: the vulnerability of traditional encryption methods and the opportunities for quantum-resistant protocols and secure communications via quantum key distribution (quantum key distribution (QKD)) techniques (Liu and Moody, 2024). Pharmaceutical research could benefit from unprecedented molecular simulations, potentially transforming drug discovery timelines with more accurate behavioural predictions than classical models allow (Golec *et al.*, 2024). Any optimisation problem could benefit from QC modelling in various domains such as logistics, finance, vehicle routing optimisation and portfolio diversification strategies. The intersection with machine learning appears particularly promising; quantum-enhanced algorithms demonstrate superior pattern recognition across vast data sets (Ayoade *et al.*, 2022), potentially transforming image analysis, linguistic processing and predictive modelling (Bayerstadler *et al.*, 2021).

Climate science researchers anticipate improved modelling capabilities, where quantum systems simulate complex environmental interactions with unprecedented accuracy, vital for developing effective climate mitigation strategies (Bayerstadler *et al.*, 2021). Recent developments include quantum-powered satellites and autonomous vehicles, combining QC with AI to achieve higher computational precision and secure data transmission pathways (Golec *et al.*, 2024).

international business machines (IBM) and Google have released roadmaps that highlight notable qualitative advances. However, substantial challenges remain in industrial deployment, especially regarding error correction techniques and the scalability of reliability.

Research priorities have shifted from demonstrating "Quantum Supremacy" to establishing "Quantum Utility". The former milestone was notably achieved through Google's 53-qubit Sycamore processor, which completed sampling calculations in roughly 200 seconds, tasks estimated to take millennia on traditional supercomputers (Arute *et al.*, 2019). However, identifying practical applications where quantum systems show clear advantages remains the critical next step (McGeoch and Farré, 2024). Cloud-based access to quantum prototypes has accelerated experimentation, enabling a wider verification of potential applications (IBM Institute for Business Value, 2024).

As these technologies advance, cybersecurity concerns become increasingly significant, especially regarding traditional cryptographic vulnerabilities (Mosca, 2018). In 2024, the US National Institute of Standards and Technology (U.S. Department of Commerce, www.nist.gov/) approved quantum communication protocols and post-quantum cryptographic (post-quantum cryptography (PQC)) standards, supporting transition initiatives across financial institutions and defence organisations.

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The new paradigm of QC has significant implications across scientific fields and industrial sectors; governments worldwide are adjusting their position, heavily influenced by geopolitical and defence considerations.

### *2.2 Quantum initiative and investments*

Global public investments in quantum technologies (QT) reached $42 billion in 2023; while China and the USA have dominated public investment in QT, new announcements from Germany, the UK, South Korea and India created a more diverse global QT development landscape in 2023 (McKinsey Digital, 2024). Asia leads with 53% of government investments, followed by Europe (31%) and America (14%). However, American investment patterns differ in their annual approach compared to those of others, who often make multi-year commitments. The market is predominantly driven by private investment. Within the European Union (EU), investment patterns exhibit significant fragmentation, with only €1bn (11% of identified funding) originating from communal EU resources, while individual member states contribute the remainder. The UK, Germany and France emerged as the main European investors, with the Netherlands following closely behind (McKinsey Digital, 2024). These nations set a clear goal to establish technological leadership in the quantum sector. The US corporations maintain dominance (Riekeles, 2023), and the US national quantum strategy is primarily inspired by national defence (Liman and Weber, 2023). The EU's strategy is primarily based on collaborative projects and national initiatives that align with the Quantum Flagship, aiming to enhance technological competitiveness (Romaniuk, 2022).

Public funding has stimulated an expanding ecosystem involving private sector participation, from technology startups to demand-side enterprises conducting early experiments to secure future competitiveness benefits. The global chain of QC and communication technology shows promising growth, with 458 active participants across the technological spectrum, from hardware and enabling components to middleware environments and software solutions (McKinsey Digital, 2024). Specifically, 78% represent "quantum-native" enterprises founded with quantum-focused business models (McKinsey Digital, 2024). National strategies often also include educational initiatives to bridge the gap between academia and industry, ensuring a steady pipeline of skilled professionals (Kaur and Venegas-Gomez, 2022).

### *2.3 Government urgency to act*

Learning from AI's development trajectory, governments should assess the threats and opportunities of QC and define proactive strategies rather than respond retroactively (OECD, 2025).

In May 2022, the Biden administration publicly declared the potential of QC for various fields, including materials science, pharmaceuticals, finance and energy, as well as the risks posed by vulnerabilities in existing systems.

Firstly, QC's ability to solve complex optimisation problems, enhance machine learning and accelerate computations enables governments to address some of their most urgent challenges (IBM Institute for Business Value, 2024; OECD, 2025). QC can significantly improve emergency preparedness and response, particularly in managing natural disasters. As climate change intensifies these events, quantum-enhanced analysis enables a more accurate assessment of various options, thereby supporting effective decision-making.

Furthermore, QC can improve transportation systems. Quantum-driven routing and traffic optimisation can increase transportation efficiency while simultaneously reducing climate impacts. Additionally, quantum technology holds promise in detecting fraud, advancing

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precision medicine and supporting health-care research (IBM Institute for Business Value, 2024).

Secondly, the AI landscape has demonstrated how delayed government actions can hinder economic growth and effective regulation. Evidence-based awareness campaigns and balanced communication strategies help policymakers avoid unrealistic expectations while supporting ongoing investment and development (Floridi, 2020). However, recent research uncovers a significant gap in government awareness of QC's most urgent threat: the immediate vulnerability of current cryptographic systems, which necessitates urgent policy actions to prevent potential cybersecurity crises in critical infrastructure and national security systems (Kong *et al.*, 2024).

Moreover, quantum technology is emerging as a vital frontier in geopolitical rivalry, echoing earlier digital revolutions such as AI and cloud computing. Broadening access to QC could be an opportunity to bridge some of the digital divides of the past and perhaps foster a fairer future (Ten Holter *et al.*, 2022; Liman and Weber, 2023). Quantum technology could also further alter global power structures, making technological sovereignty increasingly vital for national security and economic independence (European Commission. European Political Strategy Centre, 2025; Baitulmal and Adem, 2023).

Balancing technological advancement with social impact is a government prerogative, ensuring equitable access while addressing potential economic disruptions and security challenges (Ukpabi *et al.*, 2023; Marchant *et al.*, 2024). However, current research on public policy shows an intention to guide quantum research paths towards narrow commercial or military ends rather than emphasising collective benefits (Roberson *et al.*, 2021). Although quantum scientific research considers potential uses and advantages across various technology sectors, assuming commercial deployment, it also highlights societal benefits (Gill and Buyya, 2024). In contrast, national strategies of major nations convey a sense of competition and urgency (Roberson *et al.*, 2021). Recent research articles have highlighted this governance gap, with researchers advocating for stronger interdisciplinary dialogue between technical and social science communities to ensure that quantum technologies align with democratic values and societal needs (Seskir *et al.*, 2023; Ten Holter *et al.*, 2023; Lukoseviciene, 2025). The emerging quantum governance literature identifies several critical challenges, including the dual-use nature of quantum applications, the fragmentation of international collaboration due to geopolitical tensions and the need for proactive ethical frameworks before deployment (Biamonte *et al.*, 2019; Coenen *et al.*, 2022; Balarabe, 2025).

Governments are continually under pressure and must adapt effectively to maintain resilience and position. At the same time, they should manage "the new speed of politics and the politics of speed" to ensure equity and sustainability (Floridi, 2023). The quantum governance literature emphasises the urgency of developing comprehensive legal-ethical frameworks that address unique quantum challenges, including cryptographic vulnerabilities, privacy implications of quantum communication systems and the potential for quantum-enhanced surveillance capabilities (Hoofnagle and Garfinkel, 2022; van Daalen, 2024).

## 3. Methods

The methodological approach adopted in this research addresses the challenges posed by studying quantum technology policy in an emerging and rapidly evolving field.

Firstly, the innovative nature of quantum technology governance suggests an exploratory approach due to considerable variation in policy document formats, scope and developmental stages across different national contexts (Lukoseviciene, 2025). Traditional comparative policy analysis methods, which depend on standardised data collection tools,

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may be insufficient depending on the current stage of national quantum strategies (Marchant *et al.*, 2024). Secondly, the decision to incorporate evaluation criteria from the Organisation for Economic Co-operation and Development (OECD) and the World Economic Forum (WEF) is driven by the need to gather insights and evidence that are technically grounded, as an established assessment framework in quantum governance is not yet available (Perrier, 2022). Thirdly, the systematic document analysis method enables the review of available strategic documents, recognising that quantum technology policy development occurs within diverse institutional frameworks, regulatory environments and political systems. The qualitative approach is particularly suitable given the strategic and often classified nature of quantum technology development, where quantitative indicators may be absent or deliberately unavailable due to national security concerns (OECD, 2025). The primary focus of this analysis is on countries' national strategies that have outlined roadmaps towards quantum technology autonomy.

### *3.1 Data collection*

The national strategy documents were considered the main sources for analysis. When unavailable, the data were supplemented with information from official government websites. To include China in the research, secondary sources based on academic papers were used, as no official strategy document in English has yet been identified. A structured evaluation grid was used to analyse the national strategy documents. This grid incorporated several criteria and sub-criteria based on established frameworks from reputable organisations, such as the OECD Report "Applying Evaluation Criteria Thoughtfully" (2021) and the WEF "Quantum Economy Blueprint" (2024). Criteria focused on relevance, coherence, effectiveness, efficiency, governance quality and impact, as detailed in Table 1. Each sub-criterion was scored on a scale from 1 (low) to 3 (high).

To close the evaluation process, the researchers who conducted individual assessments then participated in discussions during regular meetings to reach a shared evaluation. The analysis was further enhanced by incorporating strategic documents on postquantum cybersecurity. This integration, subject to the availability of relevant documentation, aimed to offer a comprehensive review. In particular, a substantial portion of the information used in this analysis was obtained from the official websites of various governments, including dedicated websites (US case).

## 4. Data analysis and results

QC's transformative capabilities have garnered global government attention over the past decade, attracting consistent public investments and associated national strategies since around 2015. A total of 16 countries have been identified as having a declared national QC strategy. Generally, sovereign interests in quantum technologies have driven comprehensive national programmes that reflect geopolitical priorities and ambitions for technological sovereignty. These initiatives often take the form of multi-year funding commitments, collaborative research frameworks and specialised educational programmes aimed at developing the necessary expertise within domestic scientific communities. united nations educational, scientific and cultural organization (UNESCO) has designated 2025 as the International Year of Quantum Science and Technology (IYQ) to help raise public awareness of the importance and impact of quantum science and its applications in all aspects of life. The year of QC will witness an evolving landscape of QC, and nations around the world are adopting diverse strategic approaches to seize the opportunities and address the threats posed by this transformative technology. A particularly urgent concern across national agendas is

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**Table 1.** Criteria adopted for the analysis

| ID | Criterion | Sub-criterion | Source | Description |
|---|---|---|---|---|
| 1 | Relevance | 1.1 Alignment with national goals | OECD (2021) | The Sub-criterion assesses the degree to which the quantum strategy aligns with overarching national objectives, such as economic growth and technological leadership. A high score reflects a strategy that articulates clear contributions of quantum initiatives to national goals |
| | | 1.2 Transition to quantum-safe cryptography | WEF (2024), NIST (2022) | The Sub-criterion evaluates the strategic plans for transitioning existing cryptographic systems to quantum-safe alternatives. A comprehensive roadmap for implementing post-quantum cryptography across critical infrastructure earns a high score |
| 2 | Coherence | 2.1 Integration with existing policies (e.g. AI policy) | OECD (2021) | The Sub-criterion examines the extent to which the quantum strategy integrates with existing science and technology policies. A high score is awarded to strategies that complement and build upon existing initiatives coherently |
| | | 2.2 Stakeholder engagement | WEF (2024) | The Sub-criterion evaluates the involvement of key stakeholders in the development of the quantum strategy Strategies developed through extensive consultation with industry, academia and civil society receive high scores |
| 3 | Effectiveness | 3.1 Achievement of goals | OECD (2021) | The Sub-criterion evaluates the presence and quality of measurement frameworks and indicators designed to track progress towards quantum capability objectives. Given the emerging nature of quantum technologies and strategies, the focus is on assessing whether robust monitoring mechanisms are in place, rather than actual achievement of targets |
| | | 3.2 Research-private sector collaboration | WEF (2024) | The Sub-criterion assesses initiatives that foster collaboration between research institutions and private companies in the development of quantum technologies. Strategies with well-funded joint R&D programmes receive high scores |

(*continued*)

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**Table 1.** Continued

| ID | Criterion | Sub-criterion | Source | Description |
|---|---|---|---|---|
| 4 | Efficiency | 4.1 Resource allocation | OECD (2021) | The Sub-criterion evaluates the effectiveness of resource allocation within the quantum strategy. Strategies prioritising investments in areas with the greatest potential impact are rated highly |
| | | 4.2 Commercialisation strategies | WEF (2024) | The Sub-criterion assesses the strategies aimed at facilitating the transition from research breakthroughs to commercial applications. Strategies with targeted support for quantum startups and technology transfer initiatives score highly |
| 5 | Governance | 5.1 Governance structure | OECD (2021) | The Sub-criterion examines the governance structure, coordination mechanisms and decision-making processes defined in the national strategy. Strategies with clear roles and responsibilities for implementation and monitoring receive high scores |
| 6 | Impact | 6.1 Workforce development initiatives | WEF (2024) | The Sub-criterion evaluates programmes aimed at developing a skilled workforce capable of engaging with quantum technologies. Strategies with comprehensive education and training initiatives across various expertise levels earn high scores |
| | | 6.2 Economic growth | OECD (2021) | The Sub-criterion assesses the broader economic benefits derived from the national quantum strategy, including job creation and innovation growth. Strategies demonstrating significant contributions to economic development receive high scores |
| | | 6.3 Societal benefits | WEF (2024) | The Sub-criterion evaluates the societal impacts of quantum initiatives, such as improvements in public services and health-care outcomes. Strategies prioritising applications with the greatest potential societal benefits score highly |

**Note(s):** research and development (R&D)
**Source(s):** Authors' own work, links accessed on December 2024–July 2025

the quantum threat to cybersecurity, which has prompted various response strategies among different countries.

Countries pursuing sovereign QC capabilities, such as (not an exhaustive list) the USA (Raymer and Monroe, 2019), China (Omaar and Makaryan, 2024; Cricchio, 2024), Canada (Sussman *et al.*, 2019; Csenkey and Graver, 2024), India (Chakraborty *et al.*, 2024), Russia (Fedorov *et al.*, 2019) and Australia (Roberson and White, 2019), have implemented comprehensive national strategies supported by substantial public investments. China's quantum technology programme is arguably the most financially robust government initiative globally, with declared public investments exceeding $15 billion, a figure that likely underestimates total expenditure when considering classified defence research. This financial commitment reflects Beijing's strategic calculus regarding quantum science as both an economic catalyst and a national security imperative, affirming China as a country that adopts a strategy of technological leadership, similar to its approach in aerospace technology, through selective integration into global industrial networks, development of domestic technological capabilities in key areas and recognising the importance of balancing domestic production with international collaboration to achieve technological and economic goals (Karwowski *et al.*, 2024). China's 14th Five-Year Plan (2021–2025) (The Central Commission for Cybersecurity and Information, 2022) explicitly positions quantum information science (QIS) among its highest technological priorities. This formal elevation within state planning documents signifies an institutional recognition of the transformative potential of quantum technologies across civilian economic sectors and military applications.

China has become a leader in developing quantum communication infrastructure, creating a network that links Beijing and Shanghai, through which data are reportedly transmitted with complete security.

Furthermore, China is working on cutting-edge quantum communication satellites, the Micius Satellite project, for quantum science experiments. The USA released its national quantum strategy in 2018. It launched legislative initiatives that envisage a coordinated approach at the federal level to improve research and development in quantum technology for economic and national security purposes. For example, the USA has stressed the importance of advancing the standardisation of quantum-safe cryptography protocols, which involves developing new algorithms resistant to hacking, including those that can withstand attacks from supercomputers. Global tech companies such as IBM and Google are emerging leaders in hardware and software research in quantum technology, providing quantum capabilities via their cloud platforms. Additionally, the National Quantum Initiative allocates funding to support QIS research and development, as well as to tackle a broad range of quantum challenges, including workforce development and industry engagement (https://quantum2025.org/about/).

These nations are developing complete quantum ecosystems that encompass hardware development, software innovation, research and commercial applications. This reflects a strategic understanding that quantum sovereignty is crucial to national security and economic competitiveness.

A second category of nations, exemplified by the United Arab Emirates, is seeking quantum capabilities through strategic partnerships and commercial acquisitions rather than domestic development. The UAE's collaboration with Global Big Tech and quantum startups illustrates how nations with significant financial resources but limited technical expertise can access quantum technology: a pragmatic balance between achieving quantum capabilities and resource constraints. The third approach, adopted by nations such as South Africa (Forbes *et al.*, 2021), relies exclusively on cloud-based QC services provided by established quantum technology leaders. These countries focus on developing software capabilities and

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applications rather than competing in hardware development. This strategy allows them to participate in the quantum revolution while minimising infrastructure investments but is substantially dependent on third parties in the quantum scenario.

The EU has adopted a hybrid approach that combines elements of sovereign development with strategic partnerships. Through initiatives such as the Quantum Flagship programme (2018) and Europe, the EU is working to develop quantum capabilities while ensuring cryptographic resilience across member states (Riedel *et al.*, 2019). As part of its overarching digital transformation strategy, the Digital Decade, the EU aims to be at the forefront of digital transformation cutting edge of quantum capabilities by 2030. The European Quantum Communication Infrastructure Initiative aims to safeguard sensitive data and critical infrastructure by using quantum communication technologies to establish a terrestrial fibre network connecting strategic sites and providing secure connectivity via satellites (infrastructure for resilience, interconnectivity and security by satellite (IRIS)). With its nearly €7bn public investment in quantum, the EU ranks second only to China. Recognising the strategic value and dual-use nature (civilian and military) of quantum technologies, the Commission has identified them as critical for the EU's economic security, as they are considered the most sensitive and immediate risks related to technology security and technology leakage. In March 2024, 21 Member States committed to making Europe the "quantum valley" of the world by signing the European Declaration on Quantum Technologies (De Luca and Reichert, 2024). The EU collaborates internationally on quantum technology, for instance, with Canada, Japan, South Korea and the USA. Simultaneously, many EU countries, including Germany, the Netherlands, France, Finland, Ireland and the UK (Knight and Walmsley, 2019), are investing and planning a quantum roadmap to develop their internal capabilities. Japan's strategy exemplifies a balanced approach, combining domestic research and development with international collaboration, particularly in the fields of quantum cryptography and communications. The Japanese Government has prioritised quantum-resistant cryptography while investing in internal QC capabilities (Yamamoto *et al.*, 2019). Regardless of their chosen approach, nations universally acknowledge the quantum threat to current cryptographic systems, inspiring many initiatives in PQC and QKD. The US National Institute of Standards and Technology (NIST) has been leading the development of PQC standards, with many nations actively participating in this process.

This research focusses on nations that have developed formal national quantum strategies and explicitly aim to achieve quantum supremacy and technological sovereignty through targeted action programmes rather than merely allocating public or private investments.

Based on the research, Tables 2 and 3 provide a list of countries and documents that are publicly available and analysed. Although the analysis provides an assessment of the national quantum strategies published by various countries, it is essential to recognise that the existence of published material does not mean that all ongoing initiatives are covered.

Russia has an active quantum strategy (Fedorov *et al.*, 2019); however, no officially published material was available for inclusion in the analysis. Similarly, for China, the researchers were unable to find official government documents in English. Instead, they relied on public announcements and secondary sources, such as academic papers, to inform the evaluation, as well as a national strategy translated into English (The Central Commission for Cybersecurity and Information, 2022). Despite this constraint, the analysis recognises the importance of China's quantum strategy and its potential impact, given the country's technological progress and stated ambitions to lead in this field. The final selection of the strategic documents analysed is reported in Table 2 and the cybersecurity strategy or policy document analysed is reported in Table 3.

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**Table 2.** Country and strategic government quantum documents

| Country | National strategy title | Publication year | Entity of issue | Link to document |
|---|---|---|---|---|
| Australia | National Quantum Strategy: Building a Thriving Future with Australia's Quantum Advantage | 2023 | Department of Industry, Science and Resources | www.industry.gov.au/sites/default/files/2023-05/national-quantum-strategy.pdf |
| Canada | Canada's National: Quantum Strategy | 2022 | Government of Canada | https://ised-isde.canada.ca/site/national-quantum-strategy/sites/default/files/attachments/2022/NQS-SQN-eng.pdf |
| China | *No available published official government documents in english, the analysis is based on the secondary sources detailed and a translation of policies of stanford university* (DIGICHINA) | | | Cricchio, J., 2024<br>Jeroen Groenewegen-Lau and Antonia Hmaidi, 2024<br>The 14th Five-Year Plan for National Informatisation. Stanford Cyber Policy Center 616 Jane Stanford Way Stanford, CA 94305– 6055 USA DIGICHINA https://digichina.stanford.edu/work/translation-14th-five-year-plan-for-national-informatization-dec-2021/ |
| Denmark | Strategy for Quantum Technology Part 1 – World-Class Research and Innovation<br>Strategy for Quantum Technology Part 2 – Commercialisation, Security and International Cooperation | 2023 | Ministry of Higher Education and Science | https://ufm.dk/en/publications/2023/files/strategy-for-quantum-technology.pdf<br>www.eng.em.dk/Media/638315714019915522/National%20Strategy%20for%20Quantum%20Technology.pdf |
| France | France National Quantum Strategy | 2023 | Minister of Higher Education and Research | www.lavoix.eu/wp-content/uploads/France-strategy-1.pdf |
| Finland | Finnish Quantum Agenda | 2023 | Finnish Quantum Agenda Working Group (academics and | https://instituteq.fi/wp-content/uploads/2023/02/FQA-February-2023.pdf |

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**Table 2.** Continued

| Country | National strategy title | Publication year | Entity of issue | Link to document |
|---|---|---|---|---|
| Germany | Roadmap Quantencomputing by VDI Technology Center GmbH, published in 2021 Action Plan for Quantum Technologies by the German Federal Government (Handlungskonzept Quantentechnologien der Bundesregierung), published April 2023 https://qbn.world/wp-content/uploads/2023/04/Action-Plan-Quantum-Technologies-by-German-Government-2023-2026.pdf | 2021 e 2023 | | https://dserver.bundestag.de/btd/20/066/2006610.pdf www.quantentechnologien.de/fileadmin/public/Redaktion/Dokumente/PDF/Publikationen/Roadmap-Quantencomputing-bf-C1.pdf |
| India | National Quantum Mission (NQM) | 2023 | Department of Science and Technology | https://dst.gov.in/national-uantumissionqm https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1917888 www.psa.gov.in/mission/national-uantumission/26 https://psa.gov.in/CMS/web/sites/default/files/psa_custom_files/VIGYAN%20DHARA_Final%20Version%201_0.pdf |
| Ireland | Quantum 2030A National Quantum Technologies Strategy for Ireland Putting Ireland in a quantum super position | 2023 | Department of Further and Higher Education, Research, Innovation and Science | www.gov.ie/en/publication/126b4-quantum-2030-a-national-quantum-technologies-strategy-for-ireland/ |
| Japan | Strategy of Quantum Future industry development | 2023 | Secretariat of Science, Technology And innovation policy, cabinet office | www8.cao.go.jp/cstp/english/strategy_r08.pdf Yamamoto, Y., Sasaki, M. and Takesue, H. (2019), "Quantum information science and technology in Japan", Quantum Science and Technology, Vol. 4 No. 2, 020502. https://doi.org/10.1088/2058-9565/ab0077 |

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**Table 2.** Continued

| Country | National strategy title | Publication year | Entity of issue | Link to document |
|---|---|---|---|---|
| The Netherlands | National Agenda for Quantum Technology | 2019 | Quantum Delta | https://qutech.nl/wp-content/uploads/2019/09/NAQT-2019-EN.pdf<br>https://quantumdelta.nl/ |
| Singapore | Singapore National Quantum Strategy | 2024 | National Quantum Office (NQO), hosted in the agency for science technology and research (a*STAR) | https://nqo.sg/nqs/<br>https://nqo.sg/wp-content/uploads/2024/06/Media-Factsheet_NQO_National-Quantum-Strategy_27-May-clean-1.pdf |
| Korea | Korea's National Quantum Strategy | 2023 | Ministry of Science and ICT | https://quantuminkorea.org/initiatives/<br>https://quantuminkorea.org/wp-content/uploads/2024/06/Koreas-National-Quantum-Strategy-2023_c.pdf |
| Sweden | Swedish Quantum Agenda | 2023 | The Swedish Research Council, Vinnova, WACQT | www.vinnova.se/globalassets/bilder/publikationer/the-swedish-quantum-agenda.pdf?cb=20230328130156 |
| UK | National Quantum Strategy | 2023 | Department of science, Innovation and Technology | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1142942/national_quantum_strategy.pdf |
| USA | National Strategic Overview for Quantum Information Systems and Related Documents | 2018 | Subcommittee on Quantum Information Science (Committee on Science) | www.quantum.gov/strategy/ |

**Source(s):** Authors' own work, links accessed on December 2024–July 2025

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**Table 3.** Country and cybersecurity in quantum official documents

| Country | Document title | Publication date | Entity of issue | Document link |
|---|---|---|---|---|
| Australia | *Planning for Post-Quantum Cryptography* | 2022<br>2023 | Australian Signal Directorate | www.cyber.gov.au/sites/default/files/2023-08/PROTECT%20-20Planning%20for%20Post-Quantum%20Cryptography%20%28August%202023%29.pdf |
| Canada | *Canadian National Quantum-Readiness*<br>*Best Practices and Guidelines* | 2023 | Quantum-Readiness Working Group (QRWG) of the Canadian Forum For Digital Infrastructure Resilience (CFDIR) | https://ised-isde.canada.ca/site/spectrum-management-telecommunications/sites/default/files/attachments/2023/cfdir-quantum-readiness-best-practices-v03.pdf |
| Denmark | *Quantum-Related Cybersecurity in Denmark* | 2022 | The Niels Bohr Institute, DTU Physics, DTU Electro, KMD, IBM, Danish Chamber of Commerce | https://digitallead.dk/files/Innovation/Cyberboost%20-20Quantum%20related%20cyber%20security.pdf |
| France | *Post Quantum Criptography* | 2024 | Banque de France | www.banque-france.fr/system/files/2024-11/BDFxMAS%20report%20final.pdf |
| | *ANSSI Views on the Post-Quantum Cryptography Transition (2023 follow-up)* | 2023 | ANSSI | https://cyber.gouv.fr/sites/default/files/document/follow_up_position_paper_on_post_quantum_cryptography.pdf |
| Finland | *Post-Quantum Cryptography Finland (various publications)* | 2020 | Australian Signal Directorate | www.pqc.fi/ |
| Germany | Weber, Valentin and Maria Pericàs Riera. *How Germany Can Improve Its Standing in Post-Quantum Cryptography*. DGAP Policy Brief 25 (2024). German Council on Foreign Relations. November 2024. https://doi.org/10.60823/DGAP-24-41434-en | 2024 | German Council on Foreign Relations. | https://dgap.org/en/research/publications/how-Germany-can-improve-its-standing-post-quantum-cryptography |

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**Table 3.** Continued

| Country | Document title | Publication date | Entity of issue | Document link |
|---|---|---|---|---|
| India | *Technical Report Migration to Post Quantum Cryptography* | 2025 | Telecommunication Engineering Centre, Department of Telecommunications Ministry of Communication Government of India | www.tec.gov.in/pdf/TR/Final%20technical%20report%20on%20migration%20to%20PQC%2028-03-25.pdf |
| Japan | *Recent Trends on Research and Development of Quantum Computers and Standardisation of Post-Quantum Cryptography* | 2021 | Japan National Bank Government of Japan | www.imes.boj.or.jp/research/papers/english/21-E-05.pdf https://project.inria.fr/FranceJapanICST/files/2021/01/UEDA_FranceJapanWS0225-1.pdf |
| The Netherlands | *Netherlands Cybersecurity Strategy 2022–2028* | 2022–2024 | National Cyber Security Centrum | Guidelines for Quantum-Safe Transport Layer Encryption, National Cybersecurity Center, July 2022: [NL-2022] ThePQC Migration Handbook, TNO, CWI, AIVD (Netherlands National Communications Security Agency), Dec 2023 [AIVD-2023] Make your organisation quantum secure, May 2024. National Cybersecurity Center [NL-2024] |
| Singapore | *The Singapore Cybersecurity Strategy* MAS/TCRS/2024/01: Advisory on Addressing the Cybersecurity Risks Associated with Quantum | 2024 | Cyber Security Agency of Singapore | www.csa.gov.sg/resources/publications/guidelines-and-companion-guide-on-securing-ai-systems |
| UK | Next steps in preparing for post-quantum cryptography | 2024 | National Cybersecurity Center | www.ncsc.gov.uk/whitepaper/next-steps-preparing-for-post-quantum-cryptography |
| USA | Post Quantum Cryptography Homeland Security *Preparing for Post-Quantum Cryptography* | 2021–2025 | United States Government | www.dhs.gov/quantum www.dhs.gov/sites/default/files/publications/post-quantum_cryptography_infographic_october_2021_508.pdf |

**Source(s):** Authors' own creation based on publicly accessible online resources

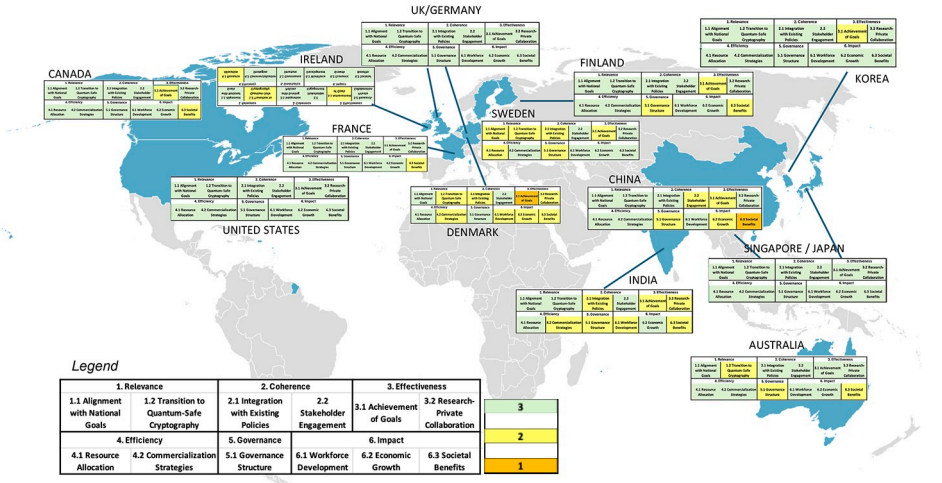


**Figure 1.** Quantum strategy assessment
**Source:** Authors' own work

The findings highlight similarities and differences between countries based on established evaluative criteria (Table 1), with key patterns shown in Figure 1.

### *4.1 Global landscape of national quantum strategies*

Based on research conducted up to December 2024, 16 nations have officially published quantum strategies, a modest number considering UNESCO's designation of 2025 as the International Year of Quantum Science and Technology and the associated financial investments registered. Most countries have published their strategies recently in 2023 and 2024, while the USA established a dedicated governmental quantum infrastructure in 2018. The US strategic foresight appears to follow a trajectory similar to the evolution of AI. Research ministries, scientific authorities and academic institutions are the primary authors of national strategies based on the stage of development of the technology. Several countries have formulated complementary PQC strategies through financial regulatory bodies and cybersecurity agencies, as exemplified by Singapore, Japan and France, highlighting the importance of proactive QC measures to prevent cybersecurity threats.

### *4.2 Evaluative analysis*

Countries actively developing quantum strategies generally demonstrate strong awareness of technological importance (Criterion 1), strategic alignment with larger national policies (Sub- criterion 2.1), comprehensive stakeholder engagement (Sub-criterion 2.2) and effective public–private collaboration frameworks (Sub-criterion 3.2). These strategy documents typically outline clear resource allocation priorities (Sub-criterion 4.1), advanced pathways for commercialisation (Sub-criterion 4.2), dedicated initiatives for skill development (Sub-criterion 6.1) and explicit acknowledgement of economic growth potential (Sub-criterion 6.2).

However, substantial variations emerge regarding governance structures (Sub-criterion 5.1), with relatively few countries establishing dedicated implementation bodies. More concerning is the general absence of precise measurement frameworks (Sub-criterion 3.1),

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granular adoption roadmaps and articulation of societal benefits beyond economic considerations (Sub-criterion 6.3).

*4.3 Alignment with national goals (Sub-criterion 1.1)*

Almost all the strategies examined demonstrate substantive alignment with broader national economic and technological objectives. Fifteen countries have received the highest evaluation (3) (see Figure 1). These documents explicitly connect quantum initiatives with overarching national priorities. Australia's strategy reports QC as a mechanism to "modernise our economy, enhance our society, support national interests, and create high-paying jobs for future generations". Similarly, Canada's framework aims to "amplify Canada's significant strength in quantum research; grow Canadian quantum technologies, companies and talent; and solidify global leadership in quantum science and its commercialisation". Sweden received a moderate assessment (2), as its approach establishes foundations for future strategic development rather than articulating immediate national objectives.

*4.4 Quantum safe cryptographic transition (Sub-criterion 1.2)*

A total of 12 nations have established comprehensive cryptographic transition frameworks and received the highest evaluations (3). Canada's strategy exemplifies this approach, establishing "ensuring privacy and cybersecurity for Canadians in a quantum-enabled world through a national quantum-secure communications network and post-quantum cryptography initiative" as a core mission. Australia, Denmark, Ireland and Sweden received moderate evaluations (2), acknowledging cryptographic vulnerability without developing detailed transition roadmaps.

*4.5 Policy integration (Sub-criterion 2.1)*

Most countries achieved the highest (3) evaluations of the integration of quantum frameworks within existing scientific and technological policy architectures. Germany's strategy exemplifies comprehensive integration across its Digital Strategy, Research and Innovation Strategy and Federal IT Security Research Framework. Denmark and Sweden received moderate evaluations (2) due to limited articulation of policy integration mechanisms.

*4.6 Stakeholder engagement (Sub-criterion 2.2)*

Most of the nations demonstrated extensive consultation processes involving industrial partners, academic institutions and civil society, receiving the highest evaluations (3). Denmark's approach included "close dialogue with the other parties in the interministerial quantum secretariat" alongside substantial input from "universities, research institutions, organisations, and private and public research funding foundations". China received a moderate assessment (2) due to limited transparency with respect to stakeholder consultation mechanisms.

*4.7 Performance measurement (Sub-criterion 3.1)*

France, Germany, Japan, the UK and the USA established sophisticated measurement frameworks with specific indicators to track progress towards the objectives of quantum capabilities, receiving the highest evaluations (3). Australia, Canada, Ireland, the Netherlands, Singapore and South Korea received moderate assessments (2), illustrating monitoring mechanisms without detailed performance metrics. China, Denmark, Finland,

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India and Sweden received lower assessments (1) due to the absence of specific performance evaluation frameworks.

*4.8 Research-Industry collaboration (Sub-criterion 3.2)*

Most countries have established joint research programmes based on academic-industrial partnerships, receiving the highest ratings (3). Germany's approach highlights collaborative innovation through dedicated hubs and competence networks. Denmark and India received moderate ratings (2) due to limited implementation details, despite recognising the importance of collaboration.

*4.9 Resource allocation (Sub-criterion 4.1)*

All countries examined, except Sweden, received the highest assessment (3) for prioritising investments in areas with the greatest potential impact. The UK's strategy exemplifies detailed resource allocation, committing "£100m for research hubs", "£70m for quantum missions" and "£25m for fellowships". Sweden received a moderate assessment (2), which identified funding requirements without providing detailed allocation across priority domains.

*4.10 Commercialisation frameworks (Sub-criterion 4.2)*

Most countries established targeted support mechanisms for quantum enterprises and technology transfer initiatives, receiving the highest evaluations (3). Canada's approach exemplifies comprehensive commercialisation support, accelerating "development, prototyping, and testing of strategic quantum products and services", supporting "innovative companies to help them grow and developing markets through government procurement. Denmark and India received moderate evaluations (2) due to the limited specificity of their implementation.

*4.11 Governance architecture (Sub-criterion 5.1)*

Most countries have established clear accountability frameworks for the implementation and monitoring of the strategy, receiving the highest assessments (3). Canada's governance structure includes a dedicated Advisory Council that provides strategic guidance, domain-specific working groups that develop implementation roadmaps and an interdepartmental committee that ensures coordination. Australia, China, Finland, India and Sweden received moderate assessments (2) due to limited articulation of governance mechanisms and decision-making frameworks.

*4.12 Workforce development (Sub-criterion 6.1)*

Most countries established comprehensive educational initiatives at various levels of expertise, receiving the highest assessments (3). France's QuanTEdu-France programme exemplifies this approach, involving 21 universities and targeting training for over 5,000 specialists across multiple domains. Denmark, China and India received moderate assessments (2) due to limited implementation specifics.

*4.13 Economic impact (Sub-criterion 6.2)*

All countries, except China and Denmark, received the highest evaluations (3) for articulating substantial economic development contributions through employment creation and acceleration of innovation. Australia's strategy projects that "quantum technologies could contribute

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$6.1 billion to GDP by 2045" while "directly employing 19,400 people". Due to limited quantitative projections, China and Denmark received moderate assessments (2).

*4.14 Societal benefits (Sub-criterion 6.3)*

Nine countries prioritised applications with significant social impact, receiving the highest assessments (3). Germany's approach articulates benefits across various domains, including climate research, health care, mobility and security. Australia, Canada, France, Finland and India received moderate assessments (2) due to limited prioritisation frameworks. China received a lower assessment (1) due to the insufficient information collected and available on the prioritisation of societal impact.

The final picture is shown in Figure 1.

Despite the relatively low number of published national strategies worldwide, many governments are adopting comprehensive approaches that foster collaboration between research and industry. The UK, the USA, Germany and Japan are notable for their clear governance structures and a strong focus on economic and societal benefits. The transition to PQC is a significant priority for governments to safeguard critical infrastructure, and most countries are developing long-term quantum-safe transition roadmaps. However, the assessment reflects the available official documentation, and due to the classified nature of cybersecurity, it is likely to be quite partial and incomplete.

## 5. Discussion

The analysis carried out has revealed various factors related to governmental strategies for developing QC technology. A common pattern emerges when comparing quantum strategy approaches with AI adoption. Countries with strong AI ecosystems and innovative technology strategies, such as the USA and China, have developed comprehensive, long-term, structured quantum plans. Foundational capabilities and innovation approaches are designed to create conditions and prerequisites to harness technological potentials for exponential growth. Therefore, early development can lead to significant advancements in the future. However, investment in emerging technologies offers advantages but may also widen the global technological gap (Acemoglu and Johnson, 2023; Ten Holter *et al.*, 2023), and the QC initiatives so far appear to be retracing the path. Another important factor is the participation of the private sector. The US private investments mainly support the QC strategy, and Big Tech companies lead in QC research. The risk of governments becoming codependent and the significant implications of this dynamic will require public sector managers to navigate the complex political economy relationships between governments and technology providers, while ensuring the responsible and effective deployment of these technologies for public benefit (Margetts and Dunleavy, 2024; Ten Holter *et al.*, 2023).

The link between technological leadership and economic prosperity has become more evident in the modern global economy. An analysis of the EU-US productivity imbalance published in "The Future of European Competitiveness, EU, 2024" identifies the productivity gap between the EU and the USA, which emerged in the mid-1990s, as being directly related to Europe's limited capabilities during the first digital revolution. EU productivity growth has matched that of the US over the past two decades when excluding the technology sector. Technological leadership has become a primary driver of economic growth in major economies around the world. QC appears to be a new opportunity for the EU to establish technological sovereignty and a competitive edge. The emerging state of quantum development remains sufficiently open for Europe to secure a leadership position, provided it acts decisively and strategically (Riekeles, 2023).

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Another interesting consideration is that, although most national strategies are well integrated into the overall strategy framework and supported by specific funds and actions, measuring achievements appears to have been overlooked. Sophisticated governance structures are insufficient to prevent underestimating social benefits, equity versus economic growth and infrastructure defence (Roberson *et al.*, 2021). Although the difficulty of measuring the impacts of technologies, especially disruptive ones, has been acknowledged for some time, a measurement framework for assessing impacts and related consequences, both short- and long-term, still appears to be lacking, undermining efforts for anticipatory governance.

This outcome is closely tied to the common trend of prioritising technological sovereignty over wider societal benefits. To ensure that quantum technologies benefit the public, it is essential to expand participatory networks by including a more diverse range of social perspectives (Roberson *et al.*, 2021; Seskir *et al.*, 2023; Marchant *et al.*, 2024). Certainly, the current state of technological development does not permit a comprehensive vision to predict long-term impacts, which many other factors may influence. However, the competition and co-petition dynamics being created do not seem to be driven by potential social benefits, such as climate change and health, but rather by national defence and the threat of economic dependence or delay, derived from a reactive rather than proactive approach (Floridi, 2022).

## 6. Conclusions

The purpose of this study was to analyse official national strategies as of the start of 2025, the year officially designated by UNESCO as the IYQ. Currently, only 16 nations have published an official national strategy, with differing approaches. The potential of QC, particularly its exponential impact when combined with other technologies such as AI, remains largely underestimated overall, except in countries that have made technological innovation a key lever of power, including China and the USA.

### *6.1 Theoretical implication*

This research explores the emerging field of quantum governance and reviews the current status of national plans for quantum technology. A gap is apparent between the potential of transformative quantum tools and their inclusion in public policies. According to earlier studies on anticipatory governance, most countries have yet to fully develop their quantum governance strategies (Coenen *et al.*, 2022; Ten Holter *et al.*, 2023). The concept of responsible innovation provides a lens to analyse why these strategies primarily focus on economic and security issues, rather than addressing broader societal concerns and implications (Ten Holter *et al.*, 2023; Kop *et al.*, 2024). The results align with a governance model that emphasises the importance of being forward-thinking, adaptable and collaborative in dealing with new technologies (Marchant *et al.*, 2024). Many current strategies overlook the interdisciplinary approach, which involves integrating ethical, legal and social aspects into quantum research and development (Kop *et al.*, 2024).

### *6.2 Practical implications*

This research provides insights for policymakers and public officials. The effects of quantum technologies extend beyond the economy and require a path towards quantum resilience to protect a country's critical infrastructure. This path will require years of effort and investment, so governments should think ahead instead of just reacting. Our findings suggest that today's national strategies do not fully address the dual-use risks of quantum technologies, a concern that frequently appears in research (Blanchard *et al.*, 2024; Kop *et al.*, 2024). Governments need

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to establish robust frameworks that not only foster innovation but also manage risks, particularly regarding cybersecurity issues that impact current encryption methods and overall legal implications (Balarabe, 2025). Additionally, we identified a significant gap in public involvement and efforts to democratise quantum strategies (Seskir *et al.*, 2023).

Adapting existing digital governance models should open opportunities to explore new approaches that can coexist with current ones and develop alongside technological advancements in an adaptive rather than reactive way. This also considers the speed at which technologies permeate society once introduced to the market and their capacity to promote exponential innovation in combination with other innovations, such as AI (Floridi, 2022).

A broader perspective that incorporates societal challenges into quantum strategies, moving beyond limited commercial or military considerations, should form part of the core public management vision. Furthermore, as QC advances, longitudinal studies will be crucial to evaluate the effectiveness of national strategies and their impact on society and resilience.

### *6.3 Limitations*

The research carried out has several limitations.

Firstly, the research was based on declared sources and did not include interviews or data collection that involved direct comparisons with technology producers, government representatives or research institutions.

The dynamic nature of technology development roadmaps makes it challenging to perform a thorough analysis over time; instead, research may become obsolete in a relatively short period.

Finally, the qualitative nature of the document analysis, although supported by an analysis framework and four researchers who had the opportunity to compare their findings, cannot be entirely free of bias.

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