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GESDA Diplomatic Forum
Quantum for All Initiative
Geneva Science and Diplomacy Anticipator

OQI
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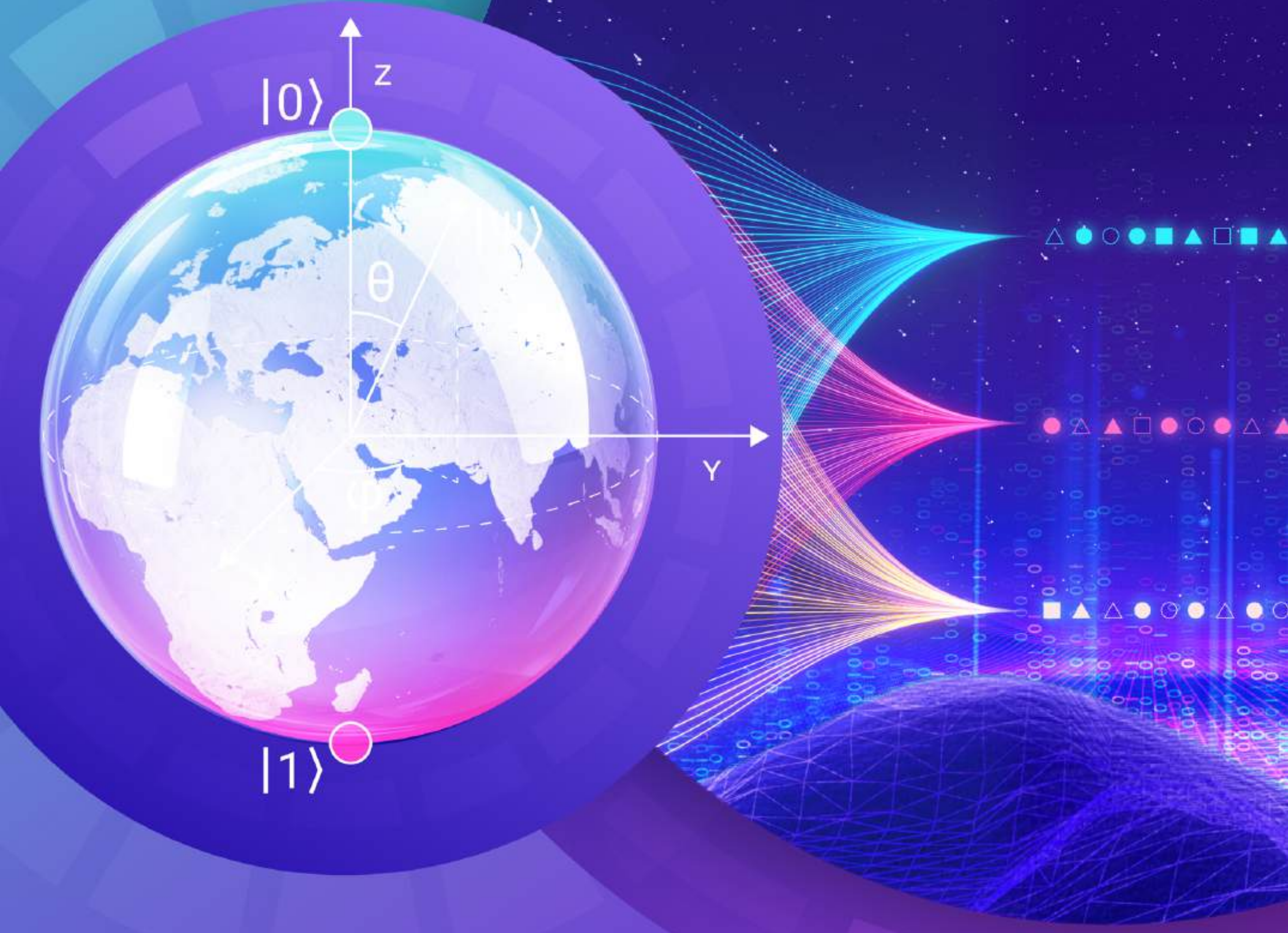

Intelligence Report on Quantum Diplomacy in Action 2025-2026

Third Edition • Geneva • October • 2025

Foreword

The development of quantum technologies, particularly quantum computing, continues to accelerate toward what experts describe as *fault-tolerant quantum computing (FTQC)*, in other words machines that can correct errors and operate reliably despite the noise inherent to quantum systems. Such systems would be capable of addressing problems far beyond the reach of classical computers. This opens a whole new set of possibilities for the future of humanity.

Against this backdrop, the relevance of multistakeholder platforms to maximize new opportunities for sustainable and inclusive solutions remains paramount. Notwithstanding, decision makers are faced with the risk of a widening *quantum divide*, where access to resources, infrastructure, knowledge and expertise is unevenly distributed, amplifying the current digital divide. Such disparities threaten to deepen existing inequalities while concentrating benefits in a few regions. Multistakeholder platforms have the agility to advance early practices of quantum technologies governance and to foster capacity building remain crucial in ensuring that the benefits of emerging technologies are shared inclusively.

In this year's *Intelligence Report for Quantum Diplomacy in Action*, we are delighted to highlight the strategic partnerships with UN specialized agencies, working closely with GESDA and the Open Quantum Institute (OQI) to foster a deepened understanding of the implications of quantum computing across diverse domains.

These collaborations represent an important step towards co-creating a vision for a shared governance of emerging technologies as it illustrates how science anticipation and anticipatory governance can help bridge divides and ensure that quantum technologies serve the common good. This year's intelligence report identifies both promise as well as urgency. Beyond the need to close the widening quantum divide, among the opportunities presented are the potential to use quantum computing to address growing global challenges such as climate resilience, water management, food security, and human health. The report discusses the impact of quantum computing on the future of labour and highlights opportunities for action. At the same time, the report reminds us of pressing risks at stake – particularly in the domain of cybersecurity, where urgent international coordination is needed to address vulnerabilities of existing cryptographic systems.

We would like to express our gratitude to all the partners, experts, and contributors whose insights and commitment have enriched this edition. In this sense, anticipating the future also means that we will continue to expand collective initiatives in anticipatory governance of quantum computing, capacity building and the development of use cases and applications for the benefit of all. This iteration of the Intelligence Report serves also as a call to keep momentum, building on the innovative partnerships generated during the *International Year of Quantum Science and Technology* and reflected in the annexed **Call to Action.** Indeed, the choices we make today will determine whether quantum computing becomes a source of greater division or a driver of inclusive global progress. It is in this spirit that we commend this report to policymakers, scholars, and practitioners alike, as an invitation to dialogue, co-creation and action.

Alexandre Fasel
State Secretary - Federal Department of Foreign Affairs Switzerland

Enrico Letta
Chair of GESDA's Diplomacy Forum

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1. A Point of Departure for Quantum Computing

Quantum computers represent a complete change of paradigm in the way that computation is practiced. Some key takeaways about how the technology works:

Quantum computing, like other quantum technologies (e.g., quantum sensing, quantum communication), leverages quantum phenomena, such as superposition and entanglement, creating an entirely novel mechanism for encoding information. Quantum information is stored and processed in “qubits” that operate in a different capacity than “bits,” their classical equivalent. That holds the promise for unprecedent performance improvements with specific computational problems.[1]

The exact nature of these computational problems is not yet well identified. However, there is a consensus in the scientific community that quantum computing would hold an advantage over classical computing to accelerate discoveries in material science and chemistry, since this involves the simulation of quantum behavior of matter. With steady, rapid progress, quantum computers may outperform classical computers in real-world applications by the end of this decade. To reach this critical milestone, significant research and development is needed to produce larger-scale, reliable quantum computing devices.

1.1 Technology maturity

Quantum computing is a multifaceted reality, with the potential to be ready at scale within the next decade.

It should be noted that quantum computing technology is still under development as hardware modalities are tested. Many large companies are developing superconducting qubits, while others pursue alternative promising modalities of qubits based on trapped ions, cold atoms, photonics, silicon, and diamonds. Each of these hardware modalities has pros and cons and it is too early to tell which approach will perform the best.

While advancements in a pre-fault-tolerant era have been recently reported, quantum computers are still performing on a small scale and are unreliable.[2] Further technological development is needed to reach quantum advantage: outperforming conventional computing in terms of execution, speed, accuracy, or energy efficiency when handling real-world relevant problems.

The aim is to create an adequate number of reliable qubits. Researchers expect that it will require thousands, if not millions, of qubits to solve useful tasks – depending on the type of hardware. Quantum properties are highly sensitive to environmental disturbances. Error-correction protocols are being investigated to ensure that quantum processors become more resilient and stable over a long period of time.

While hardware is essential, the implementation of quantum algorithms within the hardware is what will unlock the full potential of quantum systems. As part of the development and testing phase, quantum algorithms today can be implemented on simulators and emulators, which reproduce the quantum properties of quantum computers on classical devices at relatively small-scale. These allow the performance of small-scale, proof-of-concept simulations for practical applications, accelerating the exploration of valid use cases. Simulators and emulators may play an important role in bridging the gap that will remain until quantum hardware becomes available at scale, a milestone that may take another decade to achieve.

Because quantum computers operate in a fundamentally different manner than classical computers, traditional algorithms are not directly transferable to quantum computing. As a result, quantum algorithms are being developed to perform computational tasks, such as quantum simulation and factorization, as well as quantum-inspired optimization and machine learning.

1 Cf. Annex I.
2 Kim, Y., Eddins, A., Anand, S. et al. 2023.Evidence for the utility of quantum computing before fault tolerance. Nature 618, 500–505: https://doi.org/10.1038/s41586-023-06096-3.

1.2 How quantum and AI will work together

Artificial intelligence (AI) has so far enabled disruptive applications. From efficient analysis and predictive tasks on large datasets to "recommendation" systems and chatbots, AI's rapid adoption across a spectrum of industries is broadening. Combining classical machine learning (ML) - which is a subset of AI - with quantum computing is, unsurprisingly, a field of growing expectations and hype. The intersection of AI and quantum is still a nascent field, and the effort is at the research and development level. Quantum machine learning, for example, accounts for less than 1% of total machine learning research publications.

The interplay of machine learning and quantum computing can be summarized in three categories:

- **Using classical machine learning to develop quantum computers:** Already in use today, classical machine learning can help to improve experimental control of quantum computers and reduce hardware errors, construct quantum circuits, and simulate the result of quantum computations.[3]

- **Quantum-inspired machine learning:** Research on quantum computing has inspired the exploration of new techniques and theoretical insights benefiting classical machine learning.

- **Quantum machine learning:** Industry and academic researchers are exploring ways of using classical machine learning techniques on quantum computers. Currently, much of their research focuses on using existing small-scale quantum computers jointly with classical computers (so called "hybrid computing") to identify potential benefits. Quantum computers also offer some benefits for learning from quantum data (data that itself originates from quantum sensors for instance). **One major challenge is the efficient input and output of classical data to and from quantum data.** It is still too early today to predict if this hybrid approach could realize a quantum advantage for practical applications (i.e. outperforming classical computing), even with future fault-tolerant quantum computing.

Classical machine learning already benefits the development of quantum computers. Despite the early stage of this research field, the intersection of AI and quantum offers possible new avenues that can benefit from more direct collaboration between experts in different disciplines. As the field matures, a transdisciplinary approach should learn from AI governance principles and adapt them to this emerging field at the cross-section of AI and quantum computing.[4]

1.3 Economic maturity

Quantum computing already carries significant economic weight, and is being leveraged as an innovation accelerator in many sectors critical to the world's major economies.

The timeline to bring quantum computing to full maturity is relatively long compared to other technology development cycles, so its development requires sustained, significant long-term investment.

[3] See for example Liao, H., Wang, D., Iskandar Sitdikov, Salcedo, C., Seif, A., & Zlatko Minev. 03/05/2024. Machine Learning for Practical Quantum Error Mitigation. IBM Research: https://research.ibm.com/publications/machine-learning-for-practical-quantum-error-mitigation (accessed 16 August 2024); Q-CTRL. 02/08/2024. Making sense of quantum noise with machine learning. Q-Ctrl.com; Q-CTRL. https://q-ctrl.com/case-study/making-sense-of-quantum-noise-with-machine-learning (accessed 16 August 2024); Zeng, Y., Zhou, Z., Rinaldi, E., Gneiting, C., & Nori, F. 2023. Approximate Autonomous Quantum Error Correction with Reinforcement Learning. Physical Review Letters, 131(5) https://doi.org/10.1103/physrevlett.131.050601 (accessed 16 August 2024).

[4] Schuld, M., & Petruccione, F. 2021. Machine Learning with Quantum Computers. In Quantum science and technology. Springer. https://doi.org/10.1007/978-3-030-83098-4 (accessed 29 August 2024).

Governments are key drivers behind quantum R&D. Nations have committed $40 billion to quantum computing, sensing, and communication as of mid 2024, with most of the pledged spending concentrated in North America, the Asia-Pacific region and Europe.[5]

Private investment into quantum technology companies (including quantum computing, sensing, and communication) slowed in 2023 ($1.7bn in 2023, down from $2.3bn in 2022 and $2.33bn in 2021), accompanied by a shift towards more established companies that were founded at least five years earlier.[6]

The quantum computing market (revenue earned by quantum hardware and software vendors) is estimated at $870 million in 2024. Forecasts estimate this market could reach $5 billion by 2030.

Among the first end-users to test quantum computing are the financial, pharmaceutical, energy and automotive industries. Their expectation from quantum computing is that they will gain the ability to generate new revenue, profits, or cost savings. Estimates of the added economic value are complex, but some experts' forecasts put the amount at $180 billion by 2030.

1.4 Policy responses and current investments

A growing number of countries are adopting quantum strategies to affirm their sovereignty and competitiveness, while multilateral governance remains nascent.

As of August 2024, at least 29 countries had some form of quantum national initiative or strategy with public funding.23 The United Kingdom enacted the first one in 2014 and renewed it for ten years in 2023. The United States followed with its adoption of a national approach in 2018.[7]

Key common themes include more support for R&D (foundational and applied research); development of a quantum workforce (education and upskilling programs); preparing future users in the likely fields of application; resilience of the value chain (securing the supply of enabling components and technologies); national security considerations; and international cooperation (in connection with all the above themes, and with standardization that supports national interests).

Where they differ usually involves the level of financial support and funding mechanism. **A key differentiator is whether a country aims to develop a sovereign infrastructure or competitively rely on the private sector.** The focus can also differ as to priorities among quantum technologies (computing, communication, or sensing) depending on the local expertise; their scope (quantum specific, or quantum as part of deep technology strategies); main drivers (research, industry or government); and the modality of their implementation (top-down or bottom-up approaches) and the stage of development.

Most national strategies support the establishment of national industry consortia to foster ecosystem coordination, fast-track technology transfers, and an acceleration in the industrialization of sovereign quantum technologies. Quantum industry consortia include QED-C in the U.S., QIC in Canada, QuIC in Europe, and Q-STAR in Japan.

International cooperation on R&D efforts remain mostly at the bilateral level. Some examples of **bilateral agreements** can be found among the United States, Switzerland, Australia, United Kingdom, and Germany.

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[5] McKinsey Digital, Bogobowicz, M., Dutta, K., Gschwendtner, M., Heid, A., Issler, M., Mohrg, N., Soller, H., Zemmel, R., & Zhang, A. 2024. Steady progress in approaching the quantum advantage. https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20in sights/steady%20progress%20in%20approaching%20the%20quantum%20advantage/steadyprogress-in-approaching-the-quantum-advantage.pdf (page 4)(accessed 27 July 2024); World Economic Forum, IBM, & SandBoxAQ. 2024. Quantum Economy Footprint. (page 8) https://www3.weforum.org/docs/WEF_Quantum_Economy_Blueprint_2024.pdf (accessed 27 July 2024).

[6] Michael Bogobowicz et al., Steady Progress in Approaching the Quantum Advantage, McKinsey & Company, April 24, 2024, https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/steady-progress-in-approaching-the-quantum-advantage.

[7] CIFAR. 2021. A Quantum Revolution: Report on Global Policies for Quantum Technology, https://cifar.ca/wp-content/uploads/2021/05/QuantumReport-EN-May2021.pdf (accessed 26 July 2024); complemented by GESDA data

Multilateral initiatives are nascent at the international level. Closed groups are emerging among like-minded countries that align their roadmaps and discuss internal cooperation. For instance, in May 2022, representatives of 12 countries attended a roundtable meeting on 'Pursuing Quantum Information Together' in Washington, D.C. One outcome was the creation of the Entanglement Exchange, a portal for highlighting international exchange opportunities for students, postdocs, and researchers in quantum information science (QIS). This first roundtable was followed by additional meetings, including in September 2024 on 'Multilateral Dialogue on Quantum'. The working group is now composed of 13 countries.[8]

[8] Entanglement Exchange, https://entanglementexchange.org/ (accessed 02 August 2024).

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Quantum and the Digital Divide

Intelligence Report on Quantum Diplomacy in Action 2025-2026

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2. Quantum and the Digital Divide[9]

2.1 Introduction

While quantum computing applications and hardware developments are advancing at a fast pace with steady progress made by academic groups and industry, these advancements are geographically concentrated. As access to quantum computing is very financially resource-intensive, a geographic concentration of research and development efforts risks exacerbating the quantum divide. This in turn, can have negative implications for the development of quantum ecosystem, i.e. research and industry using and profiting from the scientific and economic benefits of quantum computing.

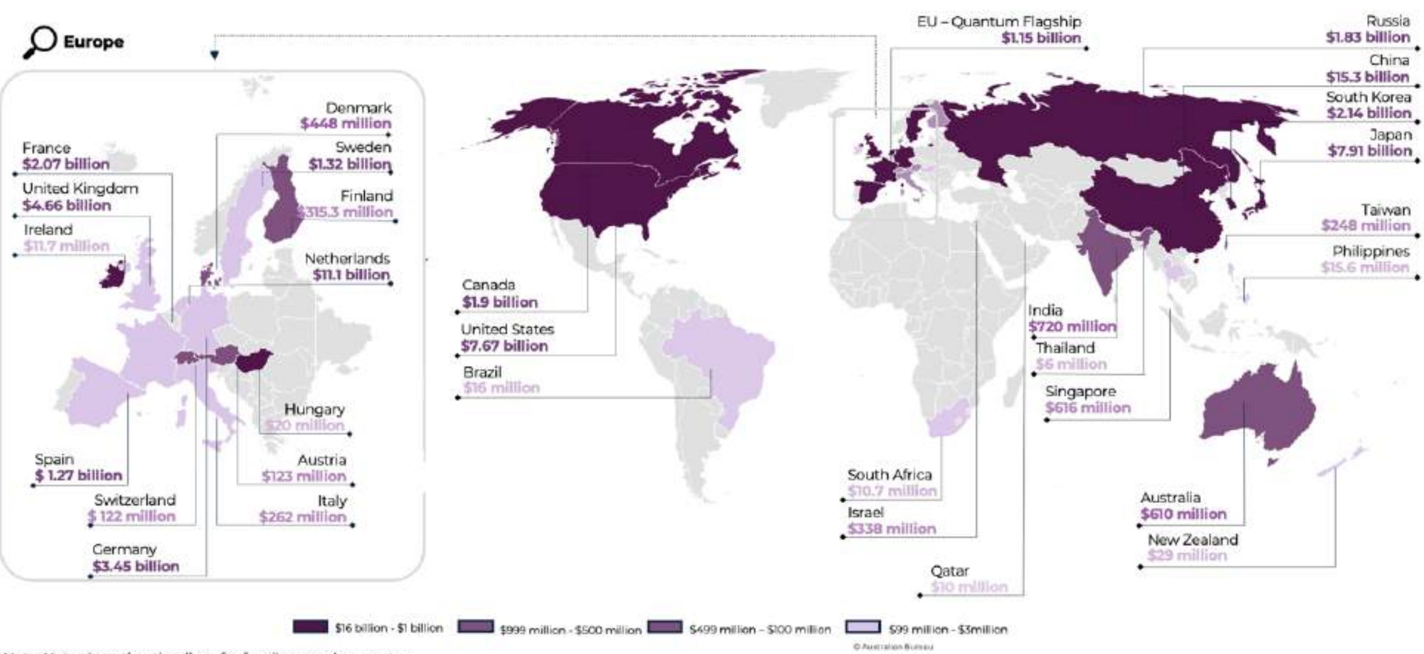
In the following, we discuss the implications of a quantum divide as well as possible mitigation strategies. Key themes are the need for anticipatory governance and how equity of access, capacity building, governance, and SDG-relevant -use cases can contribute to mitigating the risk of a further widening quantum divide.

2.2 Risks of a Widening Digital Divide in the Quantum-Powered Digital Economy

The risk of a global quantum divide becomes apparent when looking at the state of investments into quantum technologies. As the map below shows, the majority of investments are made in countries and regions that are already leading in terms of digital infrastructures and digital economies.

State of Quantum technology investments July 2025

Quantum Technologies Initiative Investments by State and Coalition (July, 2025)



Note: Not exhaustive; timelines for funding vary by country.
Sources: "Overview of Quantum Initiatives Worldwide 2025", QURECA, 9 July 2025, https://www.qureca.com/quantum-initiatives-worldwide/#qatar

The investment concentration in quantum technologies, allows inferring that quantum computing R&D - and thereby future innovation – is concentrated in a handful of nations and large corporations. Hence, wider participation in shaping the innovation happening in quantum computing and its application areas is limited. This situation could have the effect that regional and local needs are not being addressed and opportunities for prosperity not being seized. This

[9] This chapter has been written by Amal Kasry (UNESCO), Jing Zhao (UNESCO), Catherine Lefebvre (GESDA/OQI), Audrey Himmer (OQI), Marieke Hood (GESDA), Tim Smith (OQI), Mira Wolf-Bauwens (GESDA). The information and views set out in this article are those of the authors and do not necessarily reflect the official opinion of the Institution.

geographic imbalance can also lead to an opportunity bias in terms of the applications for which quantum computing is considered. By focusing on applications that respond to needs of highly advanced industry, potentially more widely impactful applications that would address the SDGs, for example, are not prioritized. SDG-relevant use cases, however, often are the use cases that are of greatest relevant and with significant expertise in 'quantum-underserved' regions. These underserved-regions might not have the 'quantum' expertise, but they do have the domain expertise, and they are the ones that are most often directly affected by global challenges, with the most vulnerable population. Thus, they would greatly benefit from new solutions leveraging emerging technologies, such as quantum computing, if these solutions were applied to global challenges (e.g. SDG-relevant). Thus, the quantum divide could be one of the reasons why little attention is given to noncommercial but high-impact use cases in areas of health, climate, food security.

The challenge of this divide also expands to global governance processes. While it is important to ensure that they are inclusive, partaking in these processes also requires exposure to quantum computing or its applications in order to meaningfully contribute. While it is not a requirement that each country becomes a leading expert with the technology, knowledge about the implications for one's own economy or research landscape is critical to ensure that those interests, connected challenges and multifold perspectives are reflected in global governance processes.

Currently, quantum capacity building faces multiple structural barriers. The most immediate structural barrier facing quantum practitioners worldwide is the fundamental deficit in research infrastructure. Preliminary findings from *UNESCO's Global Survey on Quantum Science and Technology* data indicate that 181 participants, representing 31.9% of all respondents, reported that their research institutions entirely lacked any quantum facilities.[10] This profound lack of basic resources serves as a major impediment to establishing foundational research programs.

Even when accounting for mitigation strategies such as access to shared experimental equipment through collaborative institutions or the use of cloud-based quantum computing platforms, the resource gap remains critical. A significant portion of the community—127 respondents, or 21.6% of the total - still reported being 'unable to access the necessary facilities'. This finding is particularly revealing - **it demonstrates that current efforts to democratize access through digital platforms and traditional academic cooperation models are insufficient or** unreliable for overcoming the underlying infrastructure deficit.

The distribution of available facilities further underscores this inequity. Globally, institutions reporting possession of specialized quantum infrastructure are rare: 22.3% reported having quantum computing research facilities, 16.8% had quantum communication infrastructure, and 16% were equipped with quantum sensing apparatus. These facilities encompass advanced resources such as superconducting quantum computers, ion traps, photonic platforms, and high-performance computing (HPC) for algorithm validation.

The geographical distribution, as implied by survey feedback, shows that nations with institutions reporting direct access predominantly cluster in the Global North. The Global South, conversely, exhibits a greater prevalence of data gaps, absence of access, or reliance on indirect accessibility. This asymmetrical arrangement creates a technological dependence trap. **High concentration of facilities in developed nations means that research in developing and underserved regions often relies entirely on infrastructure controlled by foreign entities**. This dependency restricts the scope of locally defined research, limits sovereign control over data, and often fails to provide the stable, continuous access required for long-term capacity building.

Figure 1 illustrates the distribution across nations of institutions reporting direct access to quantum facilities, indirect access, or no access at all within the Global Survey data. Countries lacking sufficient information are marked in grey. Nations with direct access and willingness to participate in the survey, predominantly cluster in the Global North, whereas the Global South exhibits greater prevalence of data gaps, absence of access, or reliance on indirect accessibility.

[10] A. Kasry et al., UNESCO Global Survey on the Research Status and Infrastructure in Quantum Science and Technology (forthcoming)

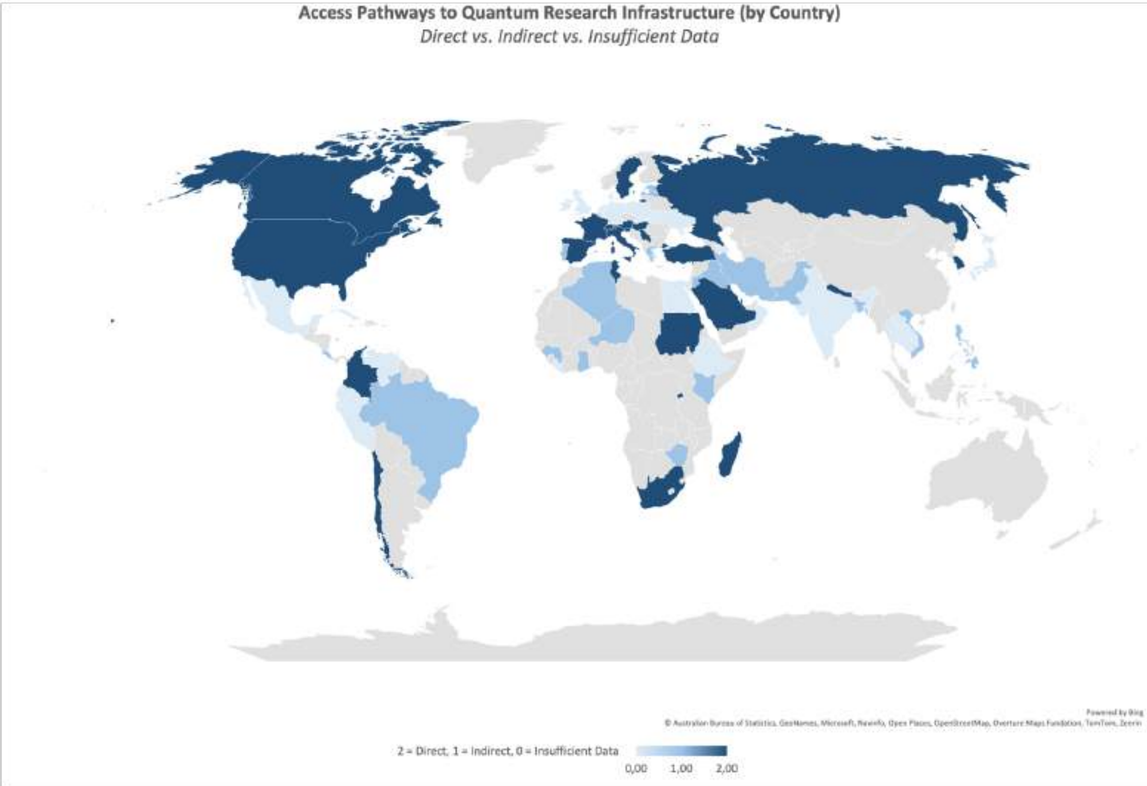


Figure 1. Access Pathways to Quantum Research Infrastructures (by country) facilities

Beyond structural resource gaps, talent shortages present a more acute challenge. Only 16% of respondents reported *net talent inflows* within their countries. This low figure implies that 84% of surveyed countries are experiencing either stagnation or a net **outflow of quantum expertise (brain drain)**. The reasons are evident in the feedback from young researchers, who universally identified inadequate funding and unstable career progression as their primary obstacles. In underserved countries, the challenge of limited career development opportunities was even more pronounced than in the broader Global South. This confirms that policy emphasis must shift from simply training researchers to retaining them by establishing viable local career pathways and strengthening domestic research conditions. Talent shortages are further exacerbated by persistent gender disparities. Female respondents constituted only 26.9% of the survey population. , The core barriers cited by women, including a lack of role models and mentors, challenges in balancing work and life, and underrepresentation in senior or decision-making positions, indicate that the root of the problem lies in institutional and cultural inertia, rather than a simple lack of education. Addressing these issues requires interventions far beyond enrollment targets. Institutional cultures must be transformed through family-friendly policies and proactive promotion of women into leadership roles. Failure to integrate and retain the full talent pool inherent in the population will inevitably perpetuate the global talent shortage.

Policy frameworks do little to offset the talent shortage challenges: As countries define their national quantum strategies, very few of them are from underserved geographies. At the global level, national quantum strategies (NQS) remain concentrated in advanced economies. The United States (National Quantum Initiative), China, the United Kingdom, and Germany have each committed multi-billion-dollar investments in computing, communications, and talent development. These strategies not only demonstrate strong national commitment but also provide a foundation for attracting international partnerships, mobilizing resources, and retaining skilled researchers.

A smaller group of emerging economies has also begun to define strategic pathways: India launched a National Mission on Quantum Technologies[11]; Brazil is developing a draft Quantum Roadmap; Uruguay integrated post-quantum cryptography measures into its National Cybersecurity Strategy[12]; The Department of Science and Innovation in South Africa launched the Quantum Technology–Driven Research and Innovation Framework, which gave rise to the South African Quantum Technologies Initiative (SA QuTI); and Singapore continues to operate a robust Quantum Engineering Programme[13].

By contrast, most countries in Sub-Saharan Africa, large parts of Latin America, and much of Asia still lack dedicated national strategies. This absence reflects both a shortage of local expertise and enduring deficits in basic digital infrastructure. Without clear strategies, it is difficult for these regions to set development goals, allocate resources effectively, or integrate quantum technology into broader sustainable development agendas.

Survey findings further underline these needs. As shown in Figure 2, respondents universally cited funding as the most urgent area of policy support, with particularly acute calls from underserved countries. Infrastructure was also identified as a critical priority in some regions, reflecting different stages of quantum science and technology development. Together, these findings highlight the need for targeted, tiered policy support to prevent the "quantum divide" from deepening and to ensure more inclusive participation in the global quantum ecosystem.

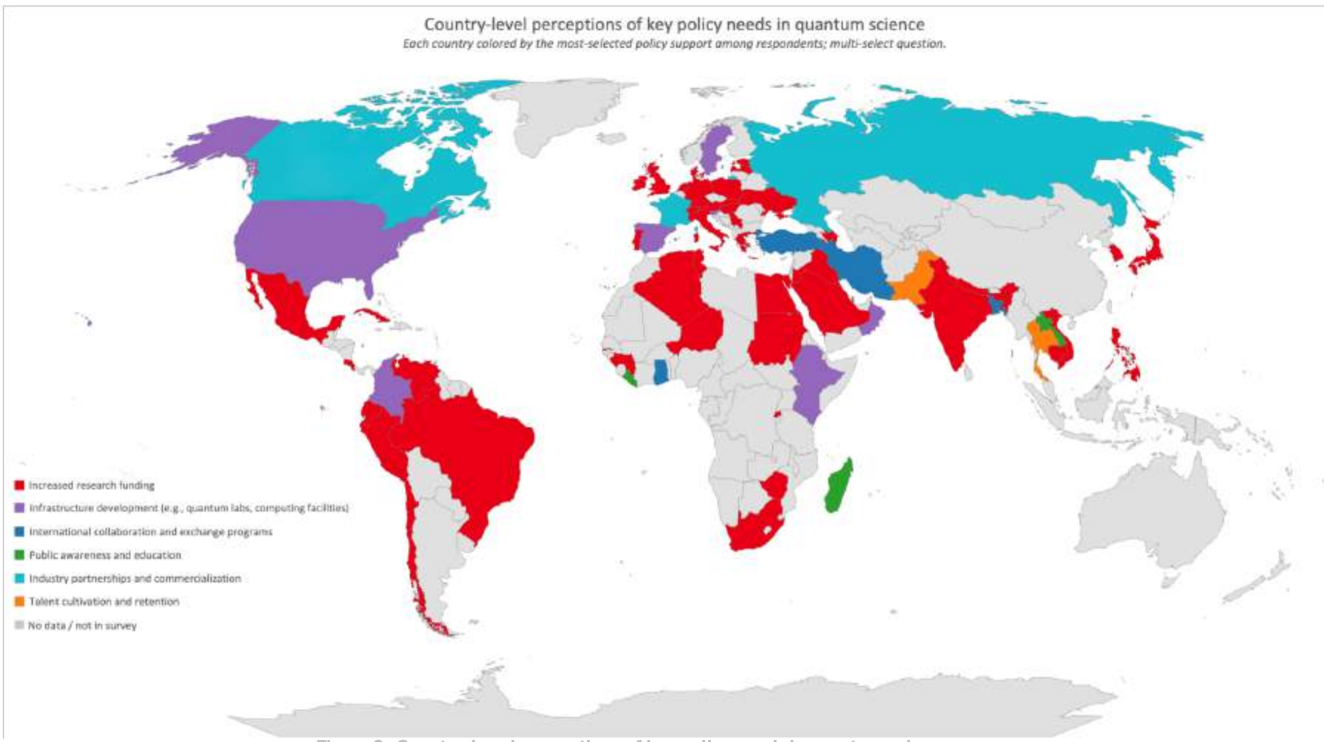


Figure 2. Country-Level perceptions of key policy needs in quantum science.

Finally, the **global quantum community remains fragmented: nearly 60% of researchers are not yet part of international collaborations, restricting knowledge exchange and the co-development of solutions.** This fragmentation is reinforced by systemic barriers. Geopolitical and regulatory frictions, particularly export controls on critical quantum components, limit access to

[11] National Quantum Mission (NQM) | Department Of Science & Technology, 2023, https://dst.gov.in/national-quantum-mission-nqm.
[12] Estrategia Nacional de Ciberseguridad del Uruguay 2024 – 2030. Agencia De Gobierno Electrónico Y Sociedad De La Información Y Del Conocimiento, n.d., https://www.gub.uy/agencia-gobierno-electronico-sociedad-informacion-conocimiento/comunicacion/publicaciones/estrategia-nacional-ciberseguridad-del-uruguay-2024-2030/estrategia.
[13] QEP - National Quantum Office, National Quantum Office, n.d., https://nqo.sg/programmes/qep/

essential research tools. Financial asymmetries further disadvantage researchers in underserved regions, who struggle to secure mobility funding, equipment, or cloud access and are often confined to peripheral roles in international projects. Administrative hurdles such as visa regimes, intellectual property rules, and complex data-sharing requirements add further exclusion, especially for institutions with limited managerial capacity.

Interviews from UNESCO's Global Survey also illustrate the human dimension of these challenges. A director of a physics research institute in Africa noted that **many institutions in his region face two intertwined barriers: first, a lack of awareness and understanding of quantum technologies and how to engage with them; and second, the absence of sufficient talent to generate initial results, which leaves their institutions too fragile to establish meaningful collaborations, despite active efforts to connect with regional and international partners**. These findings collectively reveal how gaps in infrastructure accessibility, talent reserves, policy frameworks, and international cooperation intertwine and mutually reinforce: facility shortages impede local talent cultivation and retention; talent shortages weaken policy formulation and implementation capabilities; policy gaps lead to inefficient resource allocation and reduced international collaboration opportunities, ultimately creating a development impasse that is difficult to overcome. Unless this cycle is systematically addressed through global collaborative action, quantum technology risks not becoming a global public good but instead exacerbating technology-related inequalities between nations. This could leave numerous regions persistently excluded from the benefits of the quantum revolution. Based on this survey, UNESCO and other institutions propose targeted actions, calling on the international community to jointly forge a more inclusive and sustainable pathway for quantum technology development.

2.3 Mitigation Strategies

The divides identified are serious and mutually reinforcing. To address the divide some global efforts are undertaken and there is great opportunity to scale these.

One of them is the International Year of Quantum Science and Technology (IYQ 2025), which has shown that awareness of this divide can be addressed through collective action. The IYQ 2025 raised global awareness, sparked both institutional initiatives and grassroots engagement, and demonstrated the potential of quantum science to inspire inclusive participation. With over 1400 events and activities happening across the world, the IYQ has already turned exclusion into a global conversation on access, capacity, and responsibility.

Sustaining this momentum requires moving from awareness to long-term strategy. Three priorities are emerging as essential to address the divides. **Advancing quantum education and strengthening institutional and human capacity** will help integrate quantum science into skills development, foster inclusive ecosystems through regional and international cooperation, and provide open-access learning resources for women, youth, and underserved regions. This can include, for example, providing access to educational resources on widely accessible platforms in different languages.[14] **Building sustainable quantum infrastructure and enabling resource sharing** is critical to expand equitable access to facilities, create enabling environments for long-term investment, and support collaborative innovation platforms. Such initiatives exists in the realm of classical computing (e.g. through the work of GIGA) and are starting for quantum computing (e.g. through the access pillar of the Open Quantum Institute).[15] **Strengthening international cooperation through science diplomacy will** ensure that multi-stakeholder dialogues, with strong participation from the underserved geographies, lead to responsible frameworks for research, technology transfer, and international standards.

UNESCO has already piloted initiatives that align with these directions. **The Global Survey on Quantum Research and Infrastructure**, with nearly 600 responses from 81 countries, provides a comprehensive mapping of disparities and establishes the evidence base for future policy design. **The Quantum Coding Course for Women Scientists in Africa** created a new entry point for female researchers to gain hands-on skills, supported by mentorship and networks. The **art and science exhibition at the IYQ opening ceremony attracted strong attention and public**

[14] See Quantum Course, n.d. https://www.quantum-course.com.
[15] See Giga, n.d., https://giga.global and Open Quantum Institute, n.d., https://open-quantum-institute.cern.

interest, demonstrating the power of cultural platforms to communicate complex science and promising innovation in **Quantum and STEM education.** These pilots represent not isolated projects but a **strategic exploration of how quantum science can be embedded across educational, cultural, and policy ecosystems,** highlighting UNESCO's leading role in convening inclusive and imaginative approaches.

Looking ahead, the challenge is to consolidate these diverse efforts into a sustained and structured global framework. Building on the momentum of IYQ, the foundations can now be laid for a long-term global initiative that ensures quantum science evolves as a driver of inclusivity and sustainable development.

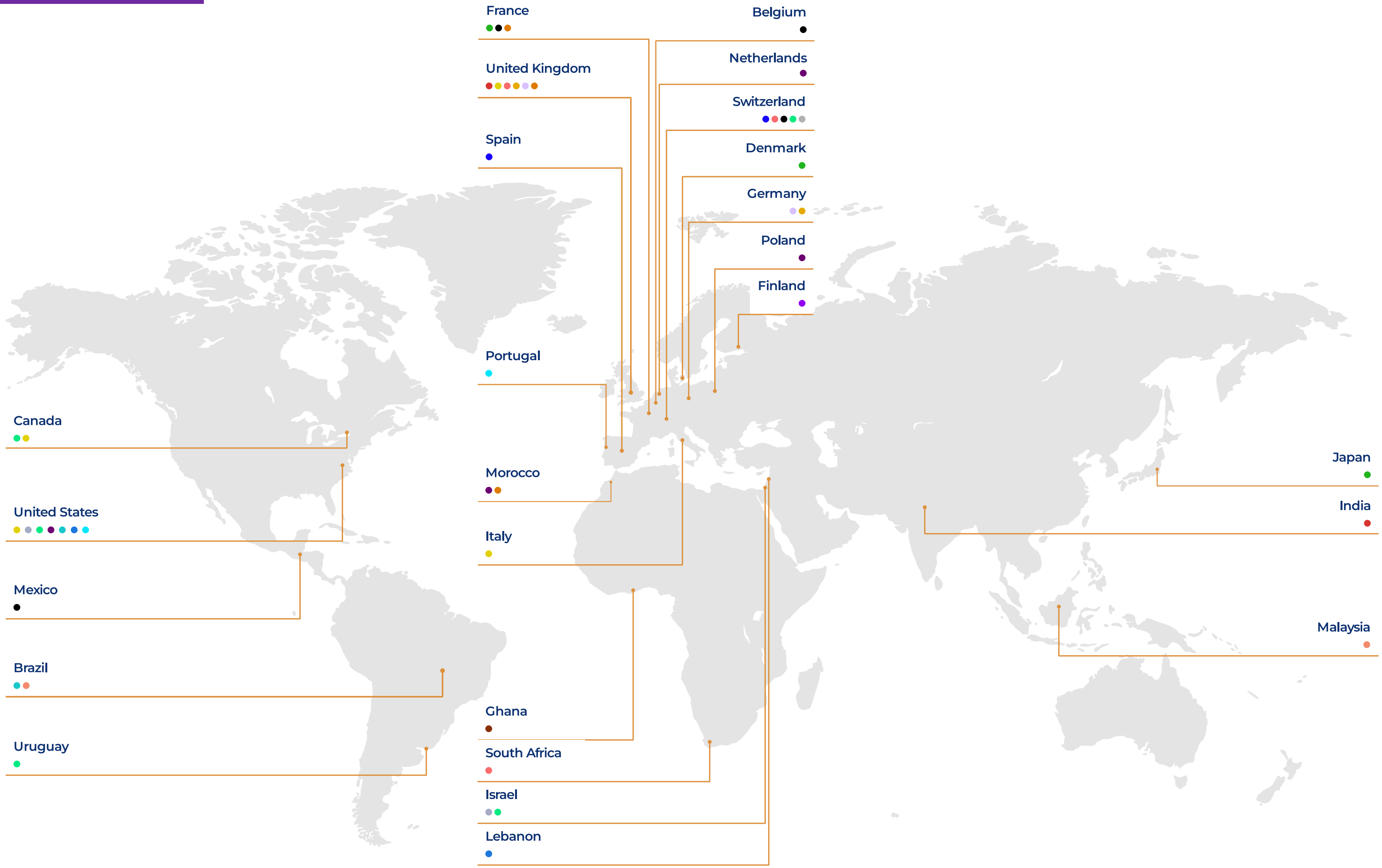
Another effort to address the divide is the **Open Quantum Institute (OQI)**. For example, the OQI is addressing the capacity building cap through its dedicated capacity building pillar. **Since the launch of the OQI 380+ participants + 320 certificates of pre-hackathon training by QWorld, providing students with key skills in quantum computing were delivered**.[16] It is important to note that hackathons are a learning journey for the students where they acquire competence, experience and network in quantum computing. These efforts are designed to be sustainable by connecting students with potential employers. Furthermore, host institutions are supported in making sure the event has government officials represented and can be connected to other local events and discussions regarding quantum computing strategies. Regional hackathon events provide an **opportunity for countries to share experiences and learn from each other in developing their respective approaches on how to take advantage of the opportunities quantum computing might afford**. These events can lead to the formation of new alliances and ecosystem cooperation. As they are primarily taking places in quantum-underserved-regions, they can potentially work to mitigating the quantum divide by creating new strong quantum alliances and respectively quantum hubs around which quantum economies can develop.

The OQI is also actively working on quantum computing applications addressing the SDGs. As we have seen above, working on SDG-related quantum applications is also seen as an key way of mitigating the quantum divide. **OQI supports the development of SDG use cases, bringing together diverse teams of experts from all around the world and providing technical and project management support to progress use cases from ideation to proof-of-concept, which could lead to implementation on today's quantum devices, with cloud access donated by leading quantum providers**. To ensure a successful collaboration, multidisciplinarity is key between the academic, private sector, NGOs, IGOs and experts with strong quantum computing algorithms-, classical computing-, domain-specific, impact- and SDG-specific expertise. For example, such use cases focus on **SDG 3 (Good Health and Well Being) exploring how quantum computing could accelerate the discovery of new antibiotics**; on SDG. 6 (Clean Water and Sanitation) by improving water management with the optimization of placement of water leak detectors in urban water distribution networks or with modelling groundwater resources access and distribution; on SDG 13 (Climate Action), by enhancing weather and climate forecasting models. A full overview of the OQI use case portfolio can be found below.

Not only is addressing these types of problems of great relevance, in quantum-underserved regions, OQI contributes to grow a global and diverse community of practice and foster collaboration to rigorously work together in leveraging quantum computing potentials for the SDGs. It is thereby shaping up to be a promising way to mitigate the quantum divide.

[16] https://qworld.net/oqi-hackathon-course/

OQI Use Cases Portfolio



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- Last-mile Food Delivery
- Nutritious Food Production
- Plant Genomic

- Accelerating Novel Antimicrobial Discovery
- Predicting Gastrointestinal Cancer
- Women's Healthcare
- Drug Metabolism

- Water Leak Detection
- Eliminating "Forever Chemicals" from Water Sources
- Molecular Docking to Clean up Pollution
- Water Resource Management

- Smart Grid Management
- Layout of Turbines in a Wind Farm

- Illegal Mining
- Coated Fertilizer Design

- Carbon Capture
- Carbon Reduction
- Flood Risk Assessment
- Weather and Climate Forecasting

2.4 Outlook - Mitigating the Quantum Divide

To close the quantum divide, bold, sustained, and inclusive action is needed across multiple fronts. Key strategies include **establishing institutional mechanisms such as the Open Quantum Institute (OQI) to catalyse collaborative innovation and inclusive participation**; promoting awareness and international collaboration (e.g. through the IYQ 2025); ensuring **equitable access to quantum infrastructure and training through global and regional initiatives**; and aligning research with SDG-oriented use cases to unlock quantum's benefits for all. Capacity-building - particularly for women, early-career researchers, and institutions in more diverse regions - must be prioritized alongside policies that encourage resource sharing, mentorship, and open knowledge exchange.

Open-access platforms, investment in enabling digital infrastructure, and inclusive education programs can further help democratize quantum technologies. **At the same time, participation in international governance and standard-setting processes must be broadened to ensure equitable shaping of the quantum future.** While existing initiatives like IYQ and OQI have laid strong foundations, the road ahead requires a sustained, multi-stakeholder commitment.

Looking ahead it needs to be ensured that these programs and initiatives are sustainable beyond 2026 and that e.g. applications are expanded to further SDGs and broader regions. A continuous monitoring of inclusive impact metrics also is required. Building a globally inclusive quantum ecosystem is not only a matter of fairness -it is a strategic imperative for shaping a more just, innovative, and sustainable digital era.

gesda
GESDA Diplomatic Forum
Quantum for All Initiative
Geneva Science and Diplomacy Anticipator

Quantum and the Future of Labour

Intelligence Report on Quantum Diplomacy in Action 2025-2026

OQI Open Quantum Institute

ITC International Training Centre

3. Quantum and the Future of Labour[17]

When drawing on experts' insights into the potential exposure and opportunities of occupations related to quantum computing, it seems that it is not only about the jobs created directly through the quantum computing industry, but more importantly jobs that are indirectly impacted by it. The challenge and opportunity alike is related to the timelines - it takes time to upskill- and the vast variety of domains impacted by QC.

From an economic and policy planning standpoint, a potential future of work where quantum technologies paired with AI, robotics, and automation accelerate task complexity beyond classical computing limits is worth anticipating for today. After all, the seemingly overnight global enrapture with generative AI technology followed the release of a user-friendly, experimental chatbot guaranteeing easy access to hundreds of millions of users. If scale of accessibility and applicability generate global conversations, there may never have been a better time to become quantum ready, thereby anticipating an incoming wave of technological disruption.

In this brief, following up from the ITCILO report on *Quantum Technologies and the Future of Learning*, we take 2030 as primary time horizon for proposed solutions and action, equally mindful of ILO *Decent Work Agenda* and priorities of the ITCILO. Together, we offer preliminary considerations of issues lying at the intersection between quantum computing and the future of work, bring forth pointers for the development of a quantum-ready workforce, and suggest governance, equity, and policy considerations for further reflection and research.

Key considerations are: which sectors will be most affected, how value chains could evolve due to quantum in these sectors, how the quantum maturity point will coincide with other inflection points.

3.1 Quantum and the Future of Labor

Quantum computing could exponentially accelerate problem-solving capacity in chemical simulation and machine learning. When combined with other technological advances, such as AI, robotics, and automation, quantum computing may enable entirely new classes of tasks beyond current computational limits. Convergence could produce cascading effects, such as faster drug discovery or new materials.[18] In fact, some convergence is necessary in order to reap the benefits of quantum computing as quantum computing will be integrated in high-performance computing workflows.[19]

Implications of this computational revolution on the workforce might extend beyond technical fields to domains where decision-making, creativity, and system oversight are core.

Shifting Value Chains

As we have seen before, quantum-enhanced capabilities could radically restructure existing industries (e.g., material science, pharmaceuticals, energy, manufacturing). As a result, supply chains may be reconfigured around entities with access to quantum tools, creating new dependencies and asymmetries. In turn, this could also imply that knowledge-intensive sectors centred around quantum-relevant problems (healthcare, material discovery, chemical sector) may centralize around quantum hubs and thereby concentrating economic value or reinforcing existing hubs. Examples of this can be seen in the US where the Cleveland Clinic has acquired a quantum system in order to strengthen its computational capacities but also to train a new generation of computational scientist, and healthcare and life sciences professionals in using this

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[17] This chapter has been written by Carlotta Clivio (ICT ILO), Andreas Klemmer (ICT ILO), Sher Verick (ILO), Marieke Hood (GESDA), Catherine Lefebvre (GESDA/OQI), Maricela Munroz (GESDA), Marianne Schoerling (GESDA), Mira Wolf-Bauwens (GESDA). The information and views set out in this article are those of the authors and do not necessarily reflect the official opinion of the institution.

[18] The Quantum Revolution in Pharma, 08/25/2025, https://www.mckinsey.com/industries/life-sciences/our-insights/the-quantum-revolution-in-pharma-faster-smarter-and-more-precise

[19] Lanes et al, A Framework for Quantum Advantage, June 27, 2025, arXiv, https://arxiv.org/abs/2506.20658

new computational tool for their work and research.[20] This can create demand for new skills in certain areas or movement of skilled-labour.

While the development of quantum computing is going as per industry projections, and is still in its early stages, anticipatory governance and planning well for these potentials labour market shifts are important. In particular, as the projected timeline of quantum breakthroughs could align with critical inflection points in labor markets (automation adoption, AI maturity, demographic shifts).[21] For example, first breakthroughs with quantum computing are to be expected within the next 5 to 10 years. This time-scale coincides with AI reaching maturity in generative and decision-support functions, peak adoption of automation across routine tasks, demographic shifts, including aging populations and shrinking workforces in advanced economies. This confluence of labour market factors could amplify labor disruptions, intensifying both displacement risk and reskilling demand.

Hence, early alignment between education, training, and policy design is essential to avoid structural unemployment shocks.

3.2 Becoming Quantum-Ready

Aligning education, training, and policy design around quantum computing invites reflections on how to best support a service-sector workforce seeking to become quantum-ready. Here, we ask: in a future which is still speculative and pending quantum computing research and development breakthroughs occurring between 2030 and 2050, **what does a quantum-ready workforce look like?** What would it mean for it to be quantum-ready, and which skills should it possess to be considered as such? We attempt to draw a tentative picture of what the not-so-distant future may hold for a workforce that is equipped to maximize the benefits of quantum computing, while minimizing or eliminating potential risks associated with it.

A quantum-ready workforce is **quantum literate**. We take the definition of the European Competence Framework for Quantum Technologies (CFQT) identifying quantum literacy as the ability to describe fundamental quantum concepts by drawing on appropriate terminology and with underlying mathematical formalisms and representations.[22] A quantum literate workforce is one with knowledge of the application landscape for quantum technologies (computing, networks, sensors), market-ready use cases, expected technological development of quantum technologies across professional domains (e.g., pharmaceutical design, material science, chemistry), and with nuanced perspectives on the ethical implications of quantum adoption.

Quantum computing presents a credible, tangible threat to the entirety of the digital security infrastructures on which global systems currently operate. While a quantum-literate workforce may need to know its way around classic algorithms, a specific sub-demographic of the quantum-literate workforce may consider taking its skills one step further, choosing to specialize in **hybrid classical-quantum algorithm design.** For classic algorithm designers-turned-quantum architects, developing one such skill may coincide with being capable to speak the language of classical algorithms for them to interact with quantum algorithms and vice versa, thereby effectively bridging between two worlds. While considering that any industry-scale transition from classic computing to quantum will need to be just to leave no one behind. Thus, the envisioned pathway is less about upskilling and reskilling from classic to quantum algorithm design but a choice to adopt the new skill of quantum algorithm development. However, along the way, transferable skills will be learned that are useful beyond a career in quantum computing (such as computational complexity analysis).

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[20] Cleveland Clinic and IBM, Cleveland Clinic and IBM Unveil First Quantum Computer Dedicated to Healthcare Research, March 20, 2023, https://newsroom.clevelandclinic.org/2023/03/20/cleveland-clinic-and-ibm-unveil-first-quantum-computer-dedicated-to-healthcare-research

[21] International Labour Organization, Population ageing: alternative measures of dependency, 2023, https://researchrepository.ilo.org/esploro/outputs/encyclopediaEntry/Population-ageing-alternative-measures-of-dependency/995218898802676

[22] European Competence Framework for Quantum Technologies, QT Proficiency for the QT Literate Person (QT-literate business role, advocator, enthusiast), April 2025, 21.

A quantum-ready workforce also possesses **cross-disciplinary skillsets**. The nature of quantum computing demands of the quantum-aware enthusiast and the quantum policy practitioner alike to cultivate knowledge from across computer science, engineering, physics, and mathematics. As the quickest, most direct application of quantum computing in capacity development and the world of work may involve reliance on generative AI, fraternizing with AI applicability and data analytics may be central to any successive consideration on how to make quantum computing relevant across business and policy contexts.[23] A quantum-ready workforce may thus be expected to gain knowledge of the cross-disciplinary data which will need to be collected in the years preceding hardware breakthroughs in quantum computing, and to collect it, so as to have a chance of leveraging quantum computing to its full potential.

The ability to bridge between hard and soft skills will also be a must for a quantum-ready workforce, with special attention devoted to innovation, both as an individual competence and as part of a working culture.[24] Tracing patterns and creating connections across disciplines is now within reach for publicly accessible generative AI applications; yet, the production of entirely new knowledge on quantum computing and any creativity related to the application of quantum computing tools is bound to continue setting human intelligence apart from generative AI, especially if knowledge breakthroughs will continue to be co-generated, and knowledge co-constituted, grounded in interaction and exchange. There will thus be a need to back innovation not only with the other UN Quintet of Change skills of building modern data expertise, developing digital expertise and fostering strategic foresight; but also with critical thinking, teamwork, communication, and with organization-wide commitments to continuous learning.

The training of a quantum-ready workforce invites for a **reimagining of learning, capacity development and skills development**. To this end, mindful of its mandate within the ILO as a safe space for experimentation for innovative capacity development solutions that accelerate social development, the ITCILO has been working on the codification of an emerging technology taxonomy which may guide capacity development providers and support institutions in their understanding of quantum computing applications and their potential relevance. The taxonomy serves as reference for professionals navigating the world of quantum computing, especially from a pedagogical and instructional design perspective. Seen in tandem with the CFQT, the taxonomy may further support instructional designers in implementing training initiatives to achieve quantum awareness (requiring a few learning hours at least, a few learning days at most), quantum literacy (requiring weeks at least, months at most), and quantum proficiency (requiring years at least, years of training combined with years of experience at most).

[23] Percy, C. and Tyrrell, M., Quantum Technologies and the Future of Learning, 2025, https://www.itcilo.org/quantum-technologies-and-future-learning.

[24] European Competence Framework for Quantum Technologies, Certification Scheme for QT Proficiency: area (I), Focus on the underlying concepts (quantum physics etc.), 04/2025, 10.

Table 1: ICT ILO Quantum relevance matrix[25]

Emerging technologies in infrastructure domains	
Energy — **Metrics:** energy produced per unit cost, distribution distance per unit cost, energy sustainability measures etc. — **Technology drivers:** renewable energy (solar, wind, hydro, incl. space-based solar), energy storage (batteries, supercapacitors), smart grids, hydrogen fuel cells, fusion, carbon capture, circular economy, green algorithms, etc.	**Compute** — **Metrics:** FLOPs-equivalent per unit cost, data storage per unit cost, data retrieval speeds etc. — **Technology drivers:** digital algorithm progress, transistor miniaturisation (e.g. via nanotechnologies), retrieval algorithms, superconductors, data infrastructure technologies, neuromorphic computers, DNA data storage, quantum computing hardware etc.
Materials — **Metrics:** number of unique materials/physical functions we can construct, cost for bespoke construction, ability to intervene in existing physical systems etc. — **Technology drivers:** atomic/molecular science, protein engineering, smart materials, nanotechnology, 3D & 4D printing/additive manufacturing, advanced composites, metamaterials, biomimetic materials, elastocalorics, quantum materials, etc.	**Connectivity** — **Metrics:** reliable GB/second per unit cost/energy, population connectivity coverage ratios, number of items connected to the Internet, latency, etc. — **Technology drivers:** 6G and successor technologies, fiber optic cables, infrastructure build-out, protocols and standards, high altitude platform stations, LEO satellite constellations, quantum networking etc.

[25] Percy, C. and Tyrrell, M., Quantum Technologies and the Future of Learning, 2025.

Emerging technologies in application domains

AI & ML
- Natural Language Processing
- Computer Vision
- Predictive Analytics
- Robotic Process Automation
- Agentic AI
- Generative AI / LLMs
- AI TRiSM / AI alignment
- Explainable AI
- Quantum AI/ML algorithms

AR & VR
- Mixed Reality
- Extended Reality
- Remote Assistance & Collaboration
- Training and Simulation
- Haptic interfaces
- Holography for communication

Cybersecurity
- Threat Intelligence
- Zero Trust Security / ZKPs
- Cyber Resilience
- Identity and Access
- Management
- Cybersecurity mesh architecture
- Disinformation security
- Homomorphic encryption
- Quantum cryptography

Distributed Ledgers
- Blockchain
- Cryptocurrencies
- Smart Contracts
- Decentralized Finance
- Supply Chain Management

Sensors & Internet of Things
- Industrial IoT
- Smart Homes
- Wearables
- Connected Vehicles
- Environmental/machine sensors
- VLEO satellites
- Spatial computing
- Quantum metrology

Biotechnology
- Bioinformatics
- Gene editing, incl. CRISPR
- Synthetic biology / bioprinting
- Adult stem cells
- mRNA therapeutics
- Fluxomics
- Personalised 'omics medicine
- Cellular programming
- Quantum biotechnology

Cloud & Edge Computing
- Infrastructure as a Service
- Platform as a Service
- Software as a Service
- Serverless Computing
- Fog Computing
- Edge AI / AI as a service
- Real-Time Data Processing
- IoT Edge
- GitOps / Infrastructure as computing

Advanced Robotics
- Collaborative Robots
- Autonomous Mobile Robots/
- Vehicles
- Drone Technology/Swarm robotics
- Robotics Process Automation
- Soft robotics
- Self-organising, self-healing robotics
- Space manufacturing
- Reconfigurable/intelligent surfaces

Simulation
- Digital twins
- Predictive Maintenance
- Product Lifecycle Management
- Smart Cities and Infrastructure
- Virtual prototyping
- Quantum simulation

Neurotechnology
- Neuroimaging and Brain Mapping
- Brain-Computer Interfaces (BCI)
- Neurostimulation/
- Neuromodulation
- Neural Prosthetics
- Neural Data Analysis
- Neuro-pharmacology/-modulators

Space & Transport
- Nuclear space propulsion
- Hypersonics
- Ion propulsion
- On-orbit maintenance
- Next-gen satellites
- Reusable rockets

While thinking about the implications of the introduction of quantum to capacity development and the world of work, there'll be a need to make room for a variety of inputs and perspectives across countries, regions of the world, underrepresented demographics and marginalized groups. If not inclusive by design, **quantum readiness will look different** depending on which region of the world, which demographic, and which professions will start probing into the usefulness, usability and applicability of quantum computing. At the individual level, a concrete step in the direction of minimizing or eliminating potential differences may be for professionals to become **quantum aware**: i.e. to become acquainted with foundational quantum concepts and terminology away from mathematical complexity. This, notwithstanding any real or perceived distance from quantum computing and its applications. This situation presents an opportunity for an anticipatory approach, where early self-reflection of e.g. a nation's workforce structure allows identifying quantum labour potentials.

Infrastructural deficits across world regions (and the high-income country-situatedness of quantum technology equipment) may also play a role in diversifying the content of conversations surrounding quantum readiness. Any truly global conversation around quantum is expected to move beyond research and development communities hosted in high-income countries or upper-middle income countries to include knowledge communities from **developing countries in the lower-middle income to least developing country categories.** As a result of ongoing transnational dialogue, even quantum partnership building may take different forms (e.g., technology transfers, ensuring equitable access to quantum infrastructure): these, however, will continue having to be grounded in each country's needs and ambitions surrounding the use of quantum technologies and the leveraging of their potential.

3.3 Governance, Equity, and Policy Considerations

For conversations around quantum-readiness to mature, quantum technology development and its introduction into the world of work should be inclusive by design. If the future of emerging technologies remains strongly about people, about decent work, and about values, this is a future which ILO constituents and institutional partners can support by negotiating a future of decent work that works for all.

The work of emerging or already established **multi-stakeholder quantum governance bodies** (inclusive of policymakers, educators, industry representatives and civil society organizations) could benefit from embracing the ILO approach to the advancement of social justice for decent work through human-centred technology. Entities operating at the intersection of creating decent work opportunities and understanding the potential impact of emerging technologies on the world of work may find renewed strength in exchanging and interacting with ILO constituents and institutional partners, carrying out future foresight exercises for policy scenarios where human labour leverages quantum technologies to achieve results of unprecedented scale and precision.

Current ethical reflection in this domain often focuses on responsible adoption and quantum literacy. To increase the likeliness for success of these approaches, intertwining them with established responsible innovation practices and anticipatory science diplomacy paradigms could be beneficial. For instance, this would involve bringing voices from the social sciences and humanities—ethicists, sociologists, anthropologist—into early anticipation processes, so that considerations of fairness, human agency, and equity are part of governance design before quantum technologies reach scale.

Grounding quantum technologies conversations in **South-South and Triangular Cooperation approaches** will also enable said multi-stakeholder quantum governance bodies to bridge unintended infrastructural and digital divides, should they create rifts across different world regions and demographic groups. Fostering openness and South-South or Triangular Cooperation dialogue across will enable global quantum stakeholders to more effectively anticipate future quantum breakthroughs together.

Multi-stakeholder quantum governance bodies may also centre their mandate around the **coordination of quantum literacy strategies**, the design of workforce transition programmes for communities requesting one, and relevant capacity development frameworks. Moving in one such direction may prevent excessive reliance on any one particular framework that is not taking into account the quantum aspirations of developing economies, the capacity development needs of marginalised groups, and the pedagogical inputs of communities of practice geographically distant from where the highest-end quantum technology equipment is located. Part of research and development funding, when and if available internationally, may be devoted in support of the crafting of inclusive quantum pedagogies, while South-South and Triangular cooperation agreements may constitute the pillars of international cooperation propelling quantum forward.

Global competition around quantum leadership raises risks of uneven workforce impacts between countries and regions. Hence, proactive quantum literacy strategies will be key in preventing the widening of a quantum divide.[26]

On inclusive quantum pedagogies: multi-regional knowledge sharing workshops, future foresight events and pilot labs are some of the **"targeted support" means** which may enable institutions to incorporate quantum technologies into learning and capacity development ahead of infrastructure breakthroughs and widespread commercialization.

A critical next step is to embed equity and inclusivity at the core of anticipatory governance mechanisms by ensuring that the tripartite dialogue between governments, employers, and talent' organisations is complemented by the voices of civil society, academia, and industry. In doing so, governance processes can better anticipate distributional effects and ensure that the transformation of work brought by quantum technologies advances decent work, social justice, and opportunities for all. The ITCILO and GESDA are ideally placed to act as incubators where conversations about inclusive quantum pedagogies happen – for the future of the world of work in general, and for learning and reciprocal capacity development in particular.

3.4 Conclusion & Forward Path

Quantum computing is likely to have a transformational impact on certain sectors of the labour market. In very specific sectors such as pharmaceutical design, material science and chemistry, the impact might even be disruptive. Hence, anticipating workforce impacts now prevents reactive responses that lag technological adoption. Regulation and governance frameworks must address the opportunities afforded by the development of quantum computing but also labor equity and distributional effects. It is a unique time that allows for anticipatory and pro-active governance in order to ensure that workforce adaptation matches the speed of technological diffusion, rather than trailing behind it.

[26] For details on the Quantum Divide, please see the first chapter of the Intelligence Report on Quantum Diplomacy In Action 2025-2026.

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Quantum and Global Security

Intelligence Report on Quantum Diplomacy in Action 2025-2026

OQI Open Quantum Institute
UNIDIR United Nations Institute for Disarmament Research

4. Quantum and Global Security[27]

Quantum security spans multiple dimensions, from the future resilience of cryptographic systems to broader implications for national security and technological competition. Recent technical advances confirm that roadmaps for the development of fault-tolerant quantum computers are on track. This increases the urgency to implement mitigation measures for the potential disruption of quantum computing to cryptography while simultaneously creating a clear potential for innovation and international cooperation.

Through its Innovations Dialogue 'Quantum Technologies and their implications for International Peace and Security' held in 2024, UNIDIR has identified several critical implications of quantum technologies for international peace and security that demand attention from policy makers and diplomacy leaders. Key take-aways include:[28]

— **Quantum technologies at a crossroads:** Quantum technologies are poised to revolutionize fields such as computation, secure communications and sensing, offering unprecedented potential to address global challenges. However, they also present risks such as destabilizing cryptographic systems, amplifying inequalities and worsening geopolitical tensions.

— **A multilateral call for governance:** Governance frameworks are critical for managing the dual-use nature of quantum technologies. Proactive governance must balance innovation, regulation and security to foster equitable and responsible development. Learning from past experiences with artificial intelligence (AI) is paramount to avoid fragmentation and delays in governance.

— **Capacity-building and equity:** Ensuring equitable access to quantum technologies has emerged as a central theme. The risk of a quantum "digital divide" is evident and necessitates prompt mitigation through capacity-building initiatives, particularly in the Global South. The proposed models, which aim to democratize quantum innovation, include regional quantum hubs and remote access to quantum research tools.

— **Multi-stakeholder collaboration:** Effective governance requires inclusive and structured dialogue among governments, industry leaders, scientists and civil society. Institutions such as the Open Quantum Institute (OQI) foster collaboration among diverse stakeholders and aligning quantum advancements with the Sustainable Development Goals (SDGs).

— **Strategic and ethical considerations:** Quantum technologies have several ethical and security implication, including the need for frameworks to manage potential misuse and address the ethical dilemmas posed by dual-use applications. International collaboration is essential to secure critical supply chains, develop global standards and mitigate the risks of technological monopolies.

[27] This chapter has been written by Giacomo Persi Paoli (UNIDIR), Fabiana Da Pieve (European Commission), Ele Donegan (GESDA/Yale University), Bruno Huttner (IDQuantique), Marieke Hood (GESDA), Amal Kasry (UNESCO), Federica du Pasquier (GESDA), Catherine Lefebvre (GESDA/OQI), Maricela Munroz (GESDA), Jessica Pan (Sandbox AQ), Kelly Richdale (Sandbox AQ), Catherine Simondi (IDQuantique), Tim Smith (OQI), Julian van Velzen (Capgemini), Mira Wolf-Bauwens (GESDA). The information and views set out in this article are those of the authors and do not necessarily reflect the official opinion of the institution.

[28] Dongyoun Cho, 2024 Innovations Dialogue: Quantum Technologies and Their Implications for International Peace and Security, 2024, https://unidir.org/publication/2024-innovations-dialogue-quantum-technologies-and-their-implications-for-international-peace-and-security/.

Supporting UNIDIR's analysis on the importance of collaboration to address the multiple use nature of quantum computing, the Stockholm International Peace Research Institute identifies quantum computing's diverse military applications that require attention of policy makers and diplomacy leaders:

- "Quantum computing offers long-term military potential in areas such as cryptanalysis and materials science. […] In materials science it could enable the simulation and optimization of advanced materials, including stealth coatings and resilient armour. Quantum computing also supports complex optimization tasks, including satellite tasking, mission logistics, coordination of uncrewed aerial vehicles (UAVs) and battlefield navigation. Quantum computing may assist with situational awareness analysis and decision making, and it may power future forms of quantum artificial intelligence (AI). In addition, quantum simulation capabilities are expected to support chemical and biological modelling, including the behaviour of hazardous agents in chemical, biological, radiological and nuclear (CBRN) scenarios."[5]

Despite the growing recognition of the importance of Quantum technologies, no dedicated multilateral process in the context of international peace and security currently exists to address them.[29]

However, quantum computing has been explicitly referenced in two existing frameworks. First, the **Wassenaar Arrangement** on Export Controls proposed quantum computing controls as early as 2019, but a nation's vetoes blocked multilateral agreement in 2022-2024, leading at least eight countries to implement harmonized unilateral quantum export controls (34-qubit threshold, cryogenic systems) outside the multilateral framework—a "Wassenaar minus one" approach that the December 2024 Plenary implicitly acknowledged.[30]

Second, the **Open-ended Working Group on security of and in the use of information and communications technologies 2021-2025 (OEWG)** provided the most explicit multilateral recognition of quantum technologies in the context of international peace and security, with its July 2025 Final Report acknowledging quantum computing's potential security implications and highlighting "the need to advance the development and deployment of, and prepare for the migration to post-quantum cryptographic solutions."[31]

Beyond explicit mentions of quantum, several existing frameworks offer relevant models that could inspire governance efforts for quantum technologies. The **Chemical Weapons Convention** provides a comprehensive dual-use technology architecture, including technologically neutral general purpose criteria, and Scientific Advisory Board establishing temporary working groups on emerging technologies (as demonstrated with AI in 2025)[32]. The **Biological Weapons Convention** demonstrates how technologically neutral language can remain valid across decades of change, offering lessons on balancing security with peaceful research protection. The **OEWG's successor mechanism**—the permanent Global Mechanism beginning March 2026 with dedicated thematic groups—provides the most immediate forum for quantum security discussions.[33]

The primary lesson is that while export controls may remain the primary actionable response to dual-use technology threats, consensus-based regimes face structural vulnerabilities when single states can veto updates, creating mismatches between decision cycles and technology diffusion

[29] See, for example, the Chair's Summary of the United Nations Disarmament Commission Working Group II: United Nations Office for Disarmament Affairs, General Assembly First Committee – Seventy-Ninth Session (2024), 2024, https://meetings.unoda.org/meeting/75662/documents

[30] Wassenaar Arrangement, Statement Issued by the Plenary Chair on 2024 Outcomes, 12/5/2024, https://www.wassenaar.org/app/uploads/2024/12/Chair-Statement-2024-Outcomes.pdf. Also see: CSIS, Rethinking the Wassenaar Minus One Strategy, December 5, 2024, https://www.csis.org/analysis/rethinking-wassenaar-minus-one-strategy.

[31] UN Open-Ended Working Group on ICT Security, Final Report, Document A/AC.292/2025/CRP.1, 07/11/2025, para. 26, https://dig.watch/resource/oewg-report-2021-2025

[32] https://www.opcw.org/media-centre/featured-topics/aichallenge

[33] Digital Watch Observatory, OEWG 2021-2025 adopts its Final Report,07/11/2025, https://dig.watch/updates/oewg-2021-2025-adopts-its-final-report

and leading to fragmentation of efforts. For quantum technologies, at least in the short term, governance will likely evolve through hybrid approaches: plurilateral export control coordination, norms development, quantum-specific technical advisory mechanisms, and capacity-building initiatives—rather than a single comprehensive multilateral instrument.

While the above security implications require sustained attention and multilateral coordination, the most concrete and near-term challenge posed by quantum computing lies in its capacity to break current encryption schemes. This cryptographic vulnerability is also an area where actionable solutions can be implemented today by migrating to quantum-safe solutions. In the following, we will deep-dive in the state of technical solutions, roadmaps and timelines for this migration.

4.1 The Quantum Threat to Cryptography

The most clearly defined threat by quantum computing is that to widely used cryptographic schemes, namely the Rivest-Shamir-Adleman (RSA) algorithm and Elliptic Curve Cryptography (ECC).[34] Such schemes rely on complex mathematical problems that are exceptionally difficult to solve by classical computers - it would only be possible for them to do so in billions of years – such as factoring large numbers and solving the discrete algorithm problem. However, due to the formulation of Shor's algorithm[35] , quantum computers with sufficiently advanced power will be able to solve such mathematical problems in reasonable time, threatening our secure communications, data at rest, and tasks requiring authentication and digital signatures.

Harvest-now-decrypt-later

While it is impossible to precisely predict when a cryptographically-relevant quantum computer (CRQC) will be available, **the threat to public-key cryptography, and in particular to confidentiality, is a concern already now, due to the so-called 'harvest-now-decrypt-later' attacks**, where malicious actors may be storing encrypted data and communications already now and decrypt them in the future when a CRQC will be available.

There is a growing concern, from different sectors, around the 'harvest-now-decrypt-later' threat from different sectors where long term confidentiality is important. Affected sectors one might think of more are as finance, telecommunications, healthcare but also diplomatic communications or classified national security information.

These concerns also extend to personal privacy, such as for health records, and thus it is not just a threat to national security, but a matter of individuals' human rights to privacy.

When?

The materialisation of the quantum threat can be estimated using the timeline of CRQC. When a CRQC will have been produced, actors with access to such advanced quantum capabilities will gain the power to break current public-key encryption. This will pose a security risk to actors lagging the move to quantum-resilient security solutions - such as post-quantum-cryptography (PQC), exacerbating digital asymmetries and potentially weakening international cyber stability.[36]

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[34] Michal Krelina, Military and Security Dimensions of Quantum Technologies, July 2025, https://www.sipri.org/sites/default/files/2025-07/0725_military_and_security_dimensions_of_quantum_technologies_0.pdf

[35] Note that while one often speaks of Shor's algorithm, in principle these are two algorithms, or one could see it as one with two different implementations. Classiq, Shor's Algorithm Explained, July 19, 2022, https://www.classiq.io/insights/shors-algorithm-explained.

[36] OECD, A Quantum Technologies Policy Primer. OECD Digital Economy Papers, No. 371, 2025, https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/01/a-quantum-technologies-policy-primer_bdac5544/fd1153c3-en.pdf See also, CETQAP, Pakistan's 1st Quantum Computer Made by CETQAP (Centre of Excellence for Technology Quantum and AI), January 1, 2025, https://www.thecetqap.com/quantum-computer-pakistans-1st-quantum-computer-made-by-cetqap-centre-of-excellence-for-technology-quantum-and-ai/

Hence, all states should act now to become quantum-resilient by investing and implementing their transition to PQC.[37]

While the threat to authentication and digital signatures is not of immediate concern, the path for protecting such cryptographic task is even more complex, since we use such signatures in many ways in our networks and applications. The consequences a CRQC decrypting our communications (and eventually also attacking schemes for other cryptographic tasks), the so-called Q-day, would be catastrophic, as it would potentially destabilise the economic, societal and political status of a nation or of entire regions. Fortunately, protection measures against such an attack **are already available now**.

4.2 The Response – Opportunities for Action

The threat of CRQC is clear. Fortunately, the solutions and responses are also clear. There is one technical solution that is already available now.

Post-Quantum Cryptography (PQC):

PQC is a new public-key cryptography based on mathematical problems which are conceived to be difficult to be solved even by quantum computers. While it is a software-based solution, for certain sectors, it implies the development of accelerators, or even new systems-on-chip design. This means that the transition to PQC is not just about the software stack, there is a need for updating system chips and devices themselves. Lack of such actions would create supply chain risks. A harmonized transition to PQC across different institutions will be essential for protecting confidentiality, authentication and integrity of communication and data, and privacy. PQC algorithms are available today and four of them have been standardized by NIST in 2024. As we will see below, regulators across the globe are in different stages of mandating migration to PQC algorithms.

The rapid standardization of Post-Quantum Cryptography (PQC) algorithms in 2024 marked a significant milestone, with vendors swiftly integrating these new standards into OpenSSL, TLS, HSMs, and other foundational products. Yet, the discovery of side-channel vulnerabilities in Falcon - after years of global scrutiny - serves as a stark reminder: cryptographic algorithms, no matter how robust today, may face unforeseen threats tomorrow.

In an environment where advances in quantum computing, new attack vectors, or emergent vulnerabilities can render cryptographic schemes obsolete overnight, crypto agility is not a luxury - is a necessity. **Crypto agility refers to the capacity of organisations and systems to rapidly switch between cryptographic algorithms in response to evolving threats or the emergence of new standards, all while maintaining operational continuity**. This is not a one-time transition, but an ongoing commitment to flexibility and resilience as the threat landscape and standards continue to evolve.

The migration to quantum-safe solutions presents a unique opportunity to assess and enhance crypto agility across organisational systems. This process is multi-dimensional:

Information Agility: Organisations must improve visibility and information sharing regarding cryptographic assets—algorithms, protocols, certificates—across both IT and OT landscapes. This enables rapid identification of systems requiring upgrades or modifications and supports informed decision-making in response to new threats.

Process Agility: The definition and industrialisation of processes for cryptographic adoption and upgrade are essential. This includes clear identification of stakeholders, governance structures, and policies tailored to each system type, ensuring that transitions are systematic and repeatable.

System Agility: Systems should be engineered for modularity and updatability, minimizing disruption during cryptographic transitions. Legacy systems may present unique challenges, but

[37] PQC is indeed largely software-based, however unfortunately in certain sectors it will require also the development of new chips and to change the design of the Systems-on-Chips.

all systems should strive for architectures that facilitate swift algorithm changes with minimal operational impact.

To operationalise crypto agility, organisations should prioritize several key actions:

- **Maintain a live cryptographic inventory:** Comprehensive knowledge of which algorithms, keys, and certificates are in use—and their locations—is foundational for effective risk management and transition planning.

- **Automate key and certificate management:** Manual processes are insufficient in the face of rapidly evolving threats. Automation ensures timely updates and reduces human error.

- **Design modular, update-ready systems:** Avoid hard-coded cryptography. Employ configuration files and CI/CD pipelines to enable rapid, large-scale updates.

- **Rotate keys regularly:** Annual key rotation should be the minimum standard; automated, policy-driven rotation is preferable to ensure ongoing security.

- **Ultimately, crypto agility is about future-proofing security architectures.** As quantum threats mature and new vulnerabilities emerge, only organisations with agile cryptographic infrastructures will be able to respond swiftly and effectively protecting data, privacy, and strategic stability in an unpredictable digital landscape.

Timelines for Implementation

Regardless of this exact date in the future, as we have seen, the threat to encrypted information exists today because – as we have seen - any malevolent actor can collect and store currently encrypted data, only to break it when CRQC become available (and accessible).

Different countries have published recommendations of varying degree. For more details, please see the appendix. Experts estimate that it will "take about 5 to 10 years" in an optimistic view, to fully migrate all relevant systems to PQC and recommend the following adoption milestones.10

In order to understand the time, it takes to adopt PQC, we are looking at one example. In this case, based on the recommendation of the EU.[38]

Example timeline for PQC Adoption - EU[39]

— Stage 1: By end of 2026

- Perform an inventory assessment of most critical assets that are vulnerable to attacks.
- Identify and educate stakeholders, perform risk assessments, create national awareness campaigns, and develop national timelines and implementation plans.
- Establish PQC transition planning and individual national transition roadmap. Plan and pilot migration of high-risk use cases to prepare to migrate most critical and vulnerable assets.

— Stage 2: By end of 2030

- Complete migration to PQC for high-risk uses cases.
- Plan and pilot migration for medium-risk use cases.
- Set software and firmware upgrades to be quantum-safe by default and adopt certification schemes that support a quantum-safe upgrade path.

38 Please note that there are different national and regional guidelines and it is adviseable to consider the guidance for one's specific region or country. It can also be noted, that the fragmentatisation of guidelines itself is a challenge but it would take us too far to discuss this here.

[39] European Commission, A Coordinated Implementation Roadmap for the Transition to Post-Quantum Cryptography, 06/ 16/ 2025, https://digital-strategy.ec.europa.eu/en/library/coordinated-implementation-roadmap-transition-post-quantum-cryptography

— Stage 3: By end of 2035
  - Full migration for high and medium risk cases.

For the sole key agreement task, serving symmetric cryptography, another potential solution is quantum key-distribution (QKD), which holds promises for implementing this task with informatic theoretic security, meaning a security that is not bounded to the (quantum) computing capabilities of the adversary.

Quantum Key Distribution (QKD):

QKD employs the principles of quantum mechanics to enable secure agreement of a symmetric key between parties. The strong, inherent security of QKD lies in the fact that any attempt to intercept or measure, during transmission, the quantum states of the beam transmitted in first place to agree on the key will inevitably disturb such states, alerting the communicating parties to potential eavesdropping. Indeed, by leveraging quantum principles, QKD ensures that any unauthorized access introduces detectable anomalies. This allows two parties to share a secure random secret key, with the agreement process being quantum-safe. The key can then be used for encrypting and decrypting messages via symmetric cyphers. Thus, the whole process of key agreement and encryption attains different levels of security according to the symmetric cyphers used, and depending on this it can still potentially offering theoretically unbreakable security. QKD can provide a valuable testbed for advancing quantum technologies and fostering collaboration in the quantum domain.

That said, the claimed security of QKD still much depends on operating in controlled environments: devices must not be compromised, and the hardware and software implementing QKD must be free of side-channel leaks or backdoors. While this is true for any implementations of cryptography, for QKD it is one of the crucial aspects that prevents large adoption, given the high costs for its deployment (starting from the very emitters and detectors, the trusted nodes that serve as relay between two relatively distant users, sometimes dedicated fiber links ...). The low key rate achieved by QKD is also an impediment for large scale adoption in different domains, especially for reasons of business continuity. Moreover, QKD addresses only the agreement of keys, whereas PQC provides a broader, software-based solution for securing a wide range of cryptographic functions without new physical infrastructure.

From a standards perspective, PQC remains the most practical and widely deployable pathway for achieving cryptographic resilience in the near and medium term. QKD may play a complementary role in certain high-security or research-driven contexts, but it is not a replacement for the adoption of PQC across critical systems. For example, researchers at SIPRI noted that the conversation around how to best prepare for the Q-day has "never been PQC or QKD" but rather that QKD (a quantum hardware tool) may complement PQC (a classical software tool) when long-term confidentiality and post-compromise security are required, while PQC alone will be necessary across the broader digital landscape.16 Since PQC and QKD have different attack vectors, their combination constitutes Cryptographic Defence-in-Depth (CDD), leveraging multiple layers of cryptographic techniques to mitigate the risks of relying on a single solution. Cryptographic defence-in-depth enhances security by limiting the effects of breaches, ensuring critical systems remain protected even if one layer of security fails. CDD may also be achieved through use of PQC and (current) symmetric key encryption, based on symmetric cyphers that will still stay safe for very long time.

The space for action is clear, so are the timelines for implementation. Given the risk, it is paramount to take this opportunity for action seriously and do so in a timely manner.

4.3 Institutional Recommendations and Processes

In response to these risks, initial governance mechanisms and recommendations have been issues. Notably by the EU and US with individual countries to follow.[40]

[40] For a comprehensive list of national recommendations on Quantum Security, see Annex IV.

Recommendations Across National and International Policy Initiatives

While national and international policy initiatives have different nuances, reflecting their local context, it is important to note that they converge on a set of practical recommendations. As a first step, organizations are urged to conduct a comprehensive inventory of cryptographic assets and assess risks, with particular attention to information requiring long-term confidentiality to mitigate 'harvest-now, decrypt-later' attacks, mentioned above.[41] Migration should be staged and prioritized, with the most sensitive systems addressed first and aligned with system lifecycle upgrades rather than through wholesale replacements.[42] During this transition, bodies recommend deploying crypto agile approaches. This ensures resilience while standards mature, and implementations are tested. At the same time, stakeholders should align closely with national and international standards bodies, such as the U.S. National Institute of Standards and Technology (NIST) PQC standardization process, the European Union's EuroQCI initiative, or Japan's CRYPTREC recommendations, while mandating certified implementations. Systems should be designed with cryptographic agility to enable seamless replacement of algorithms when new guidance emerges.[43]

Quantum Key Distribution (QKD) is viewed as a complementary, rather than universal, solution. It is recommended primarily for highly sensitive communication links where physical-layer trust can be guaranteed (e.g., backbone infrastructure and government channels). European strategies (e.g., the European Quantum Internet Alliance and ProtectEU Strategy) highlight QKD's role in securing critical infrastructures but stress the need for integration, interoperability, and certification frameworks.[44]

Across all initiatives, emphasis is placed on strengthening key management and supply chains, ensuring firmware and device lifecycle processes are quantum-resilient, and vetting vendors for trustworthiness. Finally, governments recommend investment in R&D pilots, workforce development, and international coordination. Multilateral frameworks such as NATO's Quantum Technologies Strategy, the G7's 'Quantum-Ready Alliance' vision, and the AUKUS call for collaboration on secure standards, supply chains, and testbeds.[45]

Standardisation

To increase the adoption and interoperability of quantum safe algorithms now and future QKD applications, different standardization bodies have begun the respective processes. Examples of these include ISO who have three working groups looking at quantum random number generators (QRNG) (IEC/ISO JTC 3/AHG 6) that can be important for security related applications as well as standards for quantum secure communications (IEC/ISO JTC 3/AHG 4).[46] The International Electrotechnical Commission (IEC) has set up a working group to coordinate with the Institute of Electrical and Electronics Engineers (IEEE) and International Telecommunication Union (ITU) to work on standard for different quantum-related sensors, including QRNG and quantum communication. IEEE also has different efforts, among which one on *Recommended Practice for*

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[41] Government of India, National Mission on Quantum Technologies and Applications (New Delhi: Ministry of Science and Technology, 2020); National Centre for Quantum Computing, "Strategic Roadmap" (Islamabad: Government of Pakistan, 2021).

[42] HM Government, National Quantum Strategy (London: Department for Science, Innovation and Technology, 2023); U.S. Congress, National Quantum Initiative Act, Pub. L. No. 115-368 (2018).
[43] National Institute of Standards and Technology (NIST), Post-Quantum Cryptography Standardization Process (Gaithersburg, MD: U.S. Department of Commerce, 2016–2024); European Commission, EuroQCI: European Quantum Communication Infrastructure (Brussels: European Union, 2021); Cryptography Research and Evaluation Committees (CRYPTREC). Cryptographic Technology Guideline – Post-Quantum Cryptography, 2024 Edition (2024).

[44] European Quantum Internet Alliance (QIA), Strategic Roadmap (Amsterdam: Quantum Delta NL, 2021); European Commission, ProtectEU Strategy (Brussels: European Union, 2022).

[45] NATO, Quantum Technologies Strategy (Brussels: NATO Science & Technology Organization, 2022); G7, "Transatlantic Quantum Community Statement" (Elmau, Germany: G7 Summit, 2022); AUKUS, "Quantum Arrangement (AQuA)" (Canberra: Joint AUKUS Communiqué, 2021).

[46] International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC), IEC/ISO Joint Technical Committee 3: Quantum Technologies, 2024, https://www.iso.org/committee/10138914.html

Post-Quantum Cryptography Migration.[47] Most notably among these efforts has been the National Institute of Standards (NIST) effort to standardise post-quantum cryptography algorithms.[48] Given the weight and influence of NIST, the NIST recommendation has been widely seen as authoritative.

4.4 Conclusion

Quantum computing offers transformative potential but also presents tangible risks to the confidentiality, authenticity and integrity of our digital communications and data. The primary concern remains the vulnerability of widely adopted public-key cryptographic systems to future quantum decryption. While the timeline for a cryptographically relevant quantum computer is uncertain, "harvest-now-decrypt-later" threats **make immediate action essential**. PQC provides a practical, deployable pathway, and implementing cryptographic agility will ensure resilience against both current and future threats. Complementary approaches, such as QKD, can enhance security in high-risk contexts but are not replacements for PQC. Overall, proactive transition, standardization, and coordinated governance offer the best opportunity to safeguard communication and data and strategic stability in the quantum era. UNIDIR emphasizes that preparing for a post-quantum world is not solely a technical challenge but also a matter of governance, stability, and international cooperation. In this context, **strengthening resilience through timely transition to PQC is a critical step, but broader efforts to manage the geopolitical and security dimensions of quantum innovation will also shape the global security environment**.

In the context of potential weaponization of the technology and other broader security implications, consensus-based mechanisms face structural vulnerabilities, especially when single states can veto recommendations made by many states. Consequently, decision cycles may be lagging technology diffusion -which then leads to fragmented efforts and heighten risks. For quantum technologies, at least in the short term, governance will likely evolve through hybrid approaches: plurilateral export control coordination, norms development, quantum-specific technical advisory mechanisms, best practices, and capacity-building initiatives—rather than a single comprehensive multilateral instrument. There is still an opportunity to foster a more anticipatory mindset and to develop complementary standardised measures, particularly through more flexible and agile multistakeholder platforms.

[47] IEEE Computer Society, Recommended Practice for Post-Quantum Cryptography Migration (P3172), May 13, 2022, https://standards.ieee.org/ieee/3172/10926/

[48] National Institute of Standards and Technology (NIST), NIST Releases First 3 Finalized Post-Quantum Encryption Standards, August 13, 2024, https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards

gesda

GESDA Diplomatic Forum
Quantum for All Initiative

Geneva Science and Diplomacy Anticipator

Quantum and a Framework for SDG Applications

Intelligence Report on Quantum Diplomacy in Action 2025-2026

OQI
Open Quantum Institute

5. Quantum and a Framework for SDG Applications[49]

While the international R&D quantum community is dedicating increasing effort to exploring where quantum computing could effectively be applied—with tremendous potential on economy and safety—the finding is unanimous: this is a hard endeavor. Determining the right set of problems that rigorously demonstrate potential advantage against conventional computing is complex. It requires not only a deep knowledge of quantum computing algorithms and their practical implementation on quantum devices, but it also requires a deep understanding of the problems to solve in their domain of applications and the current limitations of the most advanced conventional computing approaches.

OQI is taking on the additional challenge of exploring which types of applications would have a beneficial impact on society and our planet, ensuring an alignment with the UN agenda to accelerate the achievement of the SDGs and beyond, while minimizing the risk of anyone being left behind in the quantum revolution.

Over the past 3 years, OQI has defined a rigorous methodology to explore use cases relevant to the SDGs. To date, OQI has supported 19 use cases, providing technical and project management support to progress them from ideation to proof-of-concept. Such use cases focus, for instance, on SDG 3 (Good Health and Well Being) exploring how quantum computing could accelerate the discovery of new antibiotics or better understand drug metabolisms to limit side effects; on SDG 6 (Clean Water and Sanitation) by improving water management by optimizing the placement of water leak detectors in urban water distribution networks or with modeling groundwater resources to monitor climate change effects and contaminant breakthroughs; SDG 13 (Climate Action), by enhancing weather and climate forecasting models. A full overview of the OQI use case portfolio is available in Annex 1, with detailed descriptions in our yearly Use Case White Papers (2022[50], 2023[51], 2024[52], 2025[53]).

The key takeaways from our experience working with use case teams from all around the world on specific Global Challenges—where quantum computing could contribute to a novel solution—can be summarized across four key aspects: (1) multidisciplinarity, (2) multi-phase development, (3) access, (4) pathway to impact. These aspects are further developed below.

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[49] This chapter has been written by Catherine Lefebvre (GESDA/OQI), Philipp Kammerlander (OQI), Francesca Schiavello (OQI), Alexandra Bernasconi (OQI), Josua Rochat (OQI), Yacine Haddad (OQI/CERN), Tim Smith (OQI), Enrica Porcari (OQI/CERN), Marieke Hood (GESDA), Mira Wolf-Bauwens (GESDA).

[50] GESDA and Open Quantum Institute, Solution Idea: SDG Use Cases – GESDA / Open Quantum Institute, 10/ 10, 2022, https://open-quantum-institute.web.cern.ch/wp-content/uploads/2023/10/GESDA_OQI_Use-Cases_WhitePaper2022.pdf

[51] GESDA and Open Quantum Institute, White Paper 2023: WP1, October 2023, https://open-quantum-institute.web.cern.ch/wp-content/uploads/2023/10/GESDA_OQI_WP1-WhitePaper2023_final_versionPDF.pdf

[52] Open Quantum Institute, OQI White Paper 2024, December 2024, https://open-quantum-institute.cern/wp-content/uploads/2024/12/OQI_WhitePaper2024.pdf

[53] Available soon.

5.1 Key Aspects

5.1.1 Multidisciplinarity

OQI starts its exploration of use cases by first sourcing ideas from UN global challenges and priorities. This requires a close collaboration with IGOs and large NGOs, who play the role of the "problem-owners" or "end-users". Problems are selected according to their suitability for being addressed with quantum computing and the potential impact of the solution.

To advance an idea into a use case that would lead to a proof-of-concept, OQI brings together a multidisciplinary team of experts:

— **Quantum computing experts,** with deep knowledge of quantum algorithms and their practical implementation on quantum devices.

— **Classical computing experts,** with deep knowledge of state-of-the-art classical approaches and their current limitations with conventional supercomputing.

— **Domain experts,** with deep knowledge of the problem statement and its real-world applications.

— **Impact experts,** with deep knowledge of the relevant SDGs and the UN priorities, to ensure that solutions would maximize impact for humanity, especially for underserved geographies.

OQI actively serves as a matchmaker, providing a neutral platform that drives collaboration and knowledge exchange among these diverse experts. By leveraging the richness of multidisciplinarity perspectives and cultural backgrounds, OQI takes a central role in translating across different levels and domains. This bridging function embodies science diplomacy in action, which lies at the core of OQI's mission.

5.1.2 Multi-phase development

OQI supports the development of use cases in a multi-phase process, beginning with the identification of relevant SDG problems and leading them into proof-of-concepts. To guide this process, OQI has developed dedicated OQI use case guidelines that are available to support the use case exploration.[54]

— **Ideation.** This step focuses on clearly defining the problem statement in relation to the SDGs and assessing its suitability for quantum computing. The ideation step is sub-divided into 2 phases:

  - **Phase 0:** Initial selection of use case ideas

  - **Phase 1:** Refinement of selected ideas, with OQI support, into more concrete use cases that are then featured as contributions to the annually published OQI Use Case White Paper (c.f. Editions 2022[55], 2023[56], 2024[57], 2025[58]).

— **Proof-of-concept. In the context of OQI,** a proof-of-concept is a demonstration that quantum computing can solve a problem, either on current quantum hardware devices, within the Noisy Intermediate-Scale Quantum (NISQ) era, or in terms of future Fault-Tolerant Quantum Computing (FTQC) hardware. The proof-of-concept is sub-divided into 3 phases:

[54] Open Quantum Institute, Use Case Submission Guidelines, 07/2025.
[55] GESDA and Open Quantum Institute, Solution Idea: SDG Use Cases, 2022.
[56] GESDA and Open Quantum Institute, White Paper 2023, 2023.
[57] Open Quantum Institute, OQI White Paper 2024, 12, 2024.
[58] Available soon.

- **Phase 2:** Development of a full proposal, with OQI support. The problem must be representative of a real-world SDG problem, and it should follow a rigorous justification for quantum computing. This includes a benchmarking strategy against state-of-the-art classical approaches, with the aim of demonstrating a potential quantum advantage, at least in the FTQC context.

- **Phase 3:** Implementation on quantum simulators, if a small-scale implementation on today's quantum simulators available on the cloud is feasible and has the potential to lead to meaningful results.

- **Phase 4:** Implementation on quantum processing units (QPU) available on the cloud.

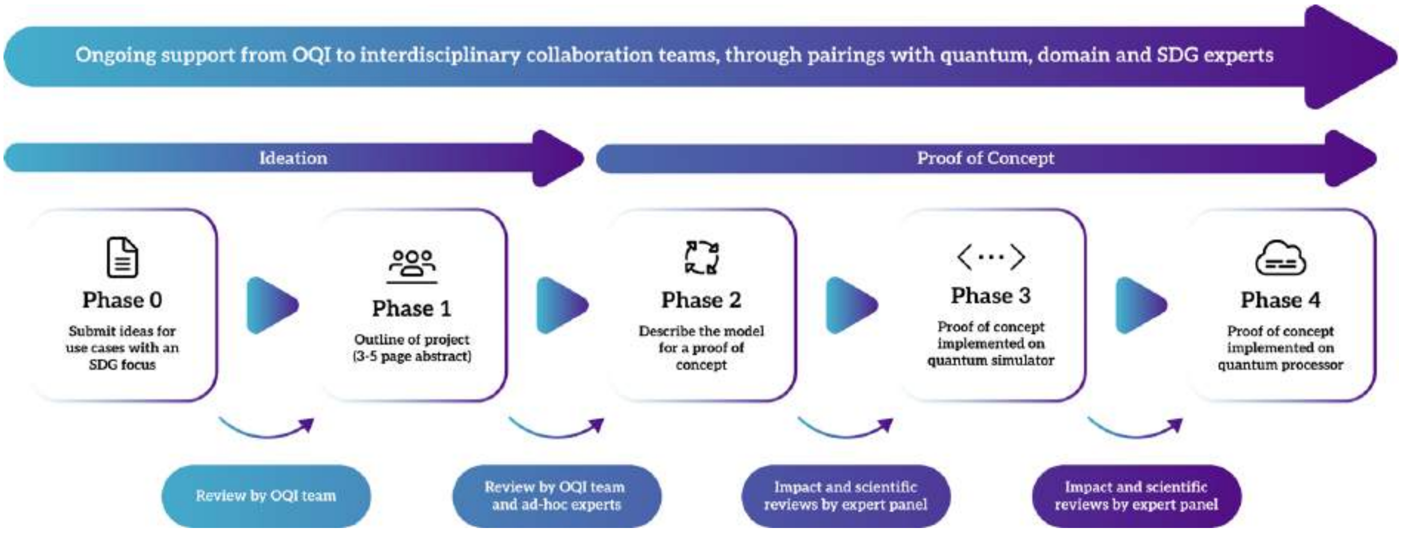


Figure 3. OQI Multi-phase use case development, from ideation to proof-of-concept.

In such a multi-phase exploration of relevant and impactful use cases, it is natural that some use cases are concluded after the ideation or in the course of the proof-of-concept stages. To ensure the pipeline remains relevant, OQI engages world-renowned experts at every stage, aligning the work with both the current state and the evolving capacity of the technology. In practice, this may mean that if (i) a problem is highly relevant but cannot yet be addressed due to resource requirements or technological limitations or (ii) a quantum approach to a problem is recently shown by the scientific community to yield no meaningful results, making it unlikely to surpass classical methods, then such problems or approaches would not be continued for the moment with the support of OQI. Alternatively, a previously concluded use case could become reactivated as technology advances or new approaches emerge from the scientific community. Through this continuous review, OQI ensures that its use cases remain scientifically rigorous, socially impactful, and responsive to the latest progress and challenges in quantum computing.

At the proof-of-concept stage, the OQI scientific committee and the OQI impact committee are also involved to assess the quality of use cases. This evaluation is crucial to maintain scientific rigor and SDG-alignment, neutrality, and transparency. It is a key step to guide in the progress of the use cases and to ensure that today's scarce quantum computing resources are used for the implementation of the most feasible proof-of-concepts.

In support of exploring the most promising use cases, the OQI scientific committee works alongside the broader scientific community to build a compendium of problems that have identified promising prospects for a super-quadratic quantum advantage. This is an effort to rigorously define the "regimes of advantage", i.e. the conditions or constraints that must be satisfied for meaningful applications of quantum algorithms. This compendium is a critical tool that aims to serve not only the OQI community, but also the wider quantum community – academic and private sector – in the collective pursuit of quantum advantage.

OQI places a strong emphasis on openness. Outputs produced by OQare designed to be open source and to contribute to collective community knowledge. As such, the OQI methodology, tools, resources, codes, publications, etc developed with the support of OQI are to be open source.

5.1.3 Access

By promoting equitable, inclusive and global access, OQI brings the technology to the people who need it most. Therefore, OQI has secured access to state-of-the-art quantum computing devices for the relevant use cases. Such hardware access is often difficult to obtain, especially in underserved geographies, and is highly costly. To overcome this barrier, OQI partners with quantum providers, who abide by the values of impact and inclusivity by donating credits for the implementation of use cases on their quantum devices accessible via the cloud. OQI works hand-in-hand with quantum experts and the quantum providers to match the quantum approaches to the most suitable hardware, ensuring effective implementation and use of the resources through the following these steps:

- **Resources estimation** – Rigorous projection of the needs for (i) HPC simulation, (ii) current quantum computing hardware (NISQ) and/or (iii) scalable solution on future quantum platforms (FTQC).

- **HPC Simulation** – Testing and optimization of small-scale proof-of-concepts. From the simulation results, the feasibility for implementation on quantum hardware is reassessed.

- **QPU implementation** – Executing on suitable cloud-available quantum processors, depending on the type and size of the proof-of-concepts. The results of the implementation then inform a scaling assessment to evaluate the performance on future large-scale fault-tolerant quantum computers (FTQC).

5.1.4 Pathway to impact

While quantum computing technology is central to the exploration of use cases, the benefit for humanity of the solution is equally essential–and the raison d'être of OQI.

In collaboration with its impact committee, OQI has developed an impact anticipation framework to anticipate the benefits of use cases for the population, planet and prosperity once deployed in the real-world. Based on the Theory of Change, it maps the conditions and steps that would lead to the intended long-term impact. It ensures the engagement of relevant stakeholders and accounts for both risks and unintended consequences. It also maps the interlinkage between relevant SDGs, illustrating the multifaceted impact of a quantum computing use case.

This impact anticipation framework provides a timeline for real-world implementation, as well as a pathway to prepare the necessary conditions for when the technology will be available at scale and the quantum solution ready to be deployed. Small-scale pilot projects from the use cases, carried out with local communities who stand to benefit most, lay the foundations for building local capacity and infrastructure needed for sustainable adoption of the quantum-enabled solution.

5.1.5 Perspective

Quantum computing is still under development and there is steady progress on both the hardware–improving the performance and the reliability against noise–and the software–reducing the resources needed for implementation. Yet, as of today, there is no quantum solution deployed in the real-world that leads to a quantum advantage. The most promising path toward outperforming conventional computing and for leading to beneficial applications lies in quantum simulations, which model quantum systems at the nanoscale and below, where quantum effects are significant and relevant to physical, chemical and biological processes. This is of particular importance for pharmaceutical applications with the discovery of new drugs or better understanding of drug metabolism, for instance. Quantum computers are a natural fit for simulating quantum phenomena and could offer greater accuracy for modelling large quantum systems and exponential speedup over what is currently intractable on classical computers. However, today's quantum devices are not yet sufficiently reliable and scalable to perform quantum simulations for problems of a size that would enable practical, real-world applications. Tremendous effort in the scientific community is poured into reducing the timeline to reach these practical applications, leveraging for instance, quantum adjacent solutions as well as AI, to approach the problems differently or more efficiently.

Despite the low maturity of the technology, there is value today in anticipating the potential benefits of quantum computing for humanity. The multifaceted nature of quantum computing applications for the SDGs is complex. It requires a thorough exploration with deep alignment with the evolving state of the technology. OQI's role is to remain agile, integrating new findings that emerge from the scientific community and pushing the use case exploration as far as the technology allows.

What OQI is contributing today, even in enabling early access for small-scale proof-of-concepts, is to grow a global community of practice that efficiently explores the impact of quantum computing, contributing to the UN agenda, and that is adequately prepared for when quantum computers will be at scale.

Annex 3 features the portfolio of SDG use cases led by experts from all around the world, with the support of OQI.

6. Concluding Remarks: The Call to Action on Quantum Futures[59]

In this defining moment for science, innovation, and society, we - scientists, policymakers, industry leaders, and global citizens - unite under a shared vision to shape a future of quantum technologies that is in service of peace and security, prosperity and human rights. We stand at a historic inflection point, where quantum capabilities – once theoretical – are now transforming how we compute, communicate and sense the world. Whether these powers deepen divisions or serve the well-being of humanity and our planet -depends on choices we make today.

We recognize that quantum technologies must be developed with consideration for local and cultural contexts, ensuring that global innovation is enriched by the diversity of human experience. Our vision extends beyond human welfare to embrace the well-being of all living beings and the planet as a whole - reflecting the concept of planetarized humanity.

Throughout the **International Year of Quantum Science and Technology (IYQST),** thousands of people around the world have engaged with quantum technologies - exploring, learning, and imagining what the future of the second quantum revolution could mean for them and their communities.

As the IYQST draws to a close, building on the awareness raised and visions created, we call for coordinated global action to collectively advance Quantum Innovation that is purposeful, ethical, and responsible. As signatories to this call for action, we commit to:

— **Prioritizing quantum applications** that address the most urgent challenges of our time, placing human and planetary well-being at the center, and supporting this with robust, long-term funding for quantum research and development.

— **Upholding safety and security as core quantum** development principles, proactively mitigating misuse and minimizing risks.

— **Championing global, open, and interdisciplinary collaboration** on quantum technologies - embracing scientific and cultural diversity, fostering multistakeholder dialogue, and ensuring equitable access to quantum capabilities.

— **Developing global governance principles** for quantum technologies that that include diverse local and cultural contexts, recognizing that diverse perspectives are essential for inclusive and effective solutions.

— **Promoting sustainable quantum research and development practices** that minimize ecological and resource impacts.

— **Establishing quantum governance frameworks that are fit-for-purpose** - flexible, evidence-based, and practice-informed - to create the conditions for accelerated innovation and anticipatory global policy.

— **Integrate harmoniously with existing technological ecosystems**, enhancing performance and reducing systemic strain

We invite all stakeholders—governments, research institutions, industry leaders, parliamentarians, civil society organizations

[59] This call to action is based on a joint initiative started between Institut Quantique at Université de Sherbrooke, OQI and GESDA, with the intention for it to be taken up and carried forward by a wider community.

7. The Annexes

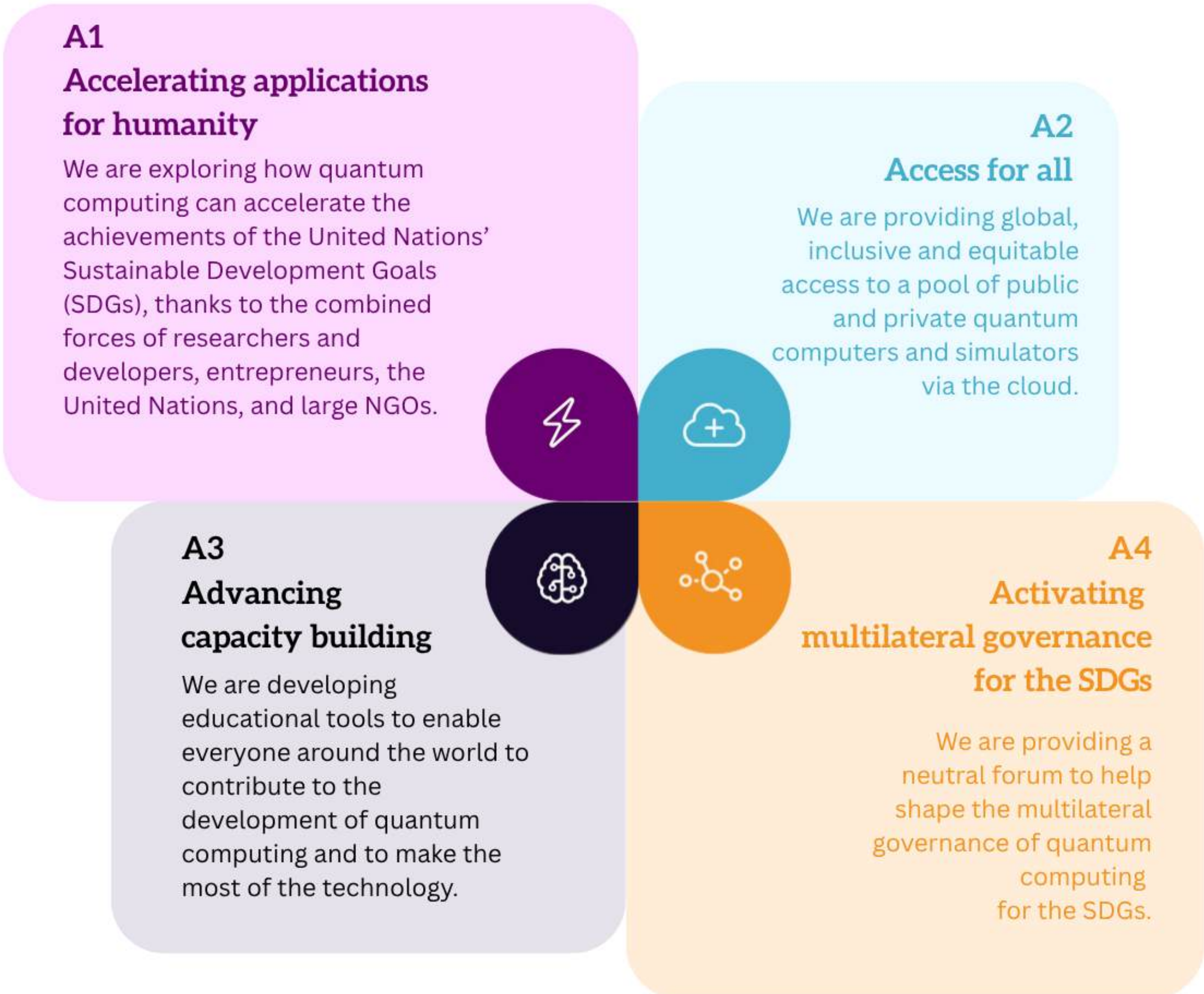
Annex I
The Open Quantum Institute, hosted at CERN, born at GESDA, supported by UBS

From the 40 emerging scientific topics covered by GESDA,[119] Quantum Technologies is the most advanced in the Anticipatory Situation Room (ASR) pipeline.[120] Quantum computing is identified as a technology with great transformative capability requiring a science and diplomacy mobilization to ensure global access and benefits. The related solution idea – the Open Quantum Institute (OQI) – reached the incubation phase in 2023.

In line with GESDA's core mission, the OQI is an anticipatory instrument. We are anticipating the moment when quantum computers will be ready at scale by reflecting now on their future impact on people, society and the planet, and by acting ahead of time to create the conditions for using them in the best interests of humanity. By acting now, we enable human agency and prepare the future multilateral governance so it will be ready when the technology can be effectively deployed.

Located in Geneva, the OQI is a multilateral governance initiative, born at GESDA, hosted at CERN, and supported by UBS for its pilot phase (2024-2026). The OQI promotes global and inclusive access to quantum computing and the development of applications for the benefit of all humanity. As a novel science diplomacy instrument, it brings together stakeholders in research, diplomacy, the private sector and philanthropy.

The OQI's mission is divided into four pillars:



Annex II
How Quantum Computing Works

How Quantum computing works

Quantum computers exploit quantum mechanics: the laws of physics that govern the behavior of matter at the tiniest of scales. Quantum mechanics defy all our intuitions about how the physical world operates. It is a world of probabilities rather than clear cause and effect, and it upends our understanding of time and space.

At the most basic level, all information in a classical computer is encoded as sequences of bits – 1s and 0s that represent flicking on and off tiny electrical switches known as 'transistors.' Qubits are the quantum equivalent of bits, but because they represent quantum systems rather than simple switches, they have unusual properties that classical bits don't share. That allows them to store and process much more information simultaneously.

The unusual properties of quantum computers stem from three main quantum effects:

Superposition

In a classical computer, bits exist as either 0s or 1s. They are like flipped coins that are either heads or tails. In a quantum computer, qubits, which are the fundamental information processing units, can exist as a complex combination of the two outcomes. Each outcome has a certain probability of being true. This state, known as superposition, can be maintained until the qubit is measured, at which point it will settle on one of the two values. Q Qubits in superposition are like coins spinning on their sides.[60]

Entanglement

When two quantum systems are entangled, changing the state of one instantaneously changes the state of the other, no matter the distance between them. This is what Einstein called "spooky action at a distance." Entanglement makes it possible to connect multiple qubits together so that all their fates are intertwined. The result is a single superposition of all the possible outcomes encoded in each individual qubit. Reading one of these qubits provides information about the states of the others, which means a quantum computer can process information exponentially faster than a classical one.

Interference

How qubits are linked up matters. The probabilities that govern the outcome of each qubit can interfere with those of its neighbors, amplifying or canceling the other one out. To go from all possible outcomes to the one that is the solution to a problem, a quantum algorithm is needed that carefully choreographs a pattern of interference that leads to the correct solution. There are several options for how to arrange the qubits. The most popular model involves organizing them into circuits, like in classical computers. These circuits are built from a sequence of operations on smaller subsets of qubits that together help to solve whatever problem the quantum computer has been set to take on.

[60] Amit Katwala, "Quantum Computing and Quantum Supremacy, Explained," WIRED UK, March 5, 2020, https://www.wired.co.uk/article/quantum-computing-explained

While this approach is common to most quantum computers under development today, the physical systems used to implement qubits can vary considerably. The leading modalities are[61]:

- **Superconductors**
  qubits encoded in electrical properties of a loop of superconducting wire.

- **Ion traps**
  qubits encoded in quantum states of an ion trapped by lasers.

- **Cold atoms**
  qubits encoded in quantum states of an atom trapped by lasers.

- **Silicon**
  qubits encoded in quantum states of electrons in a silicon chip.

- **Photonics**
  qubits encoded in quantum states of photons moving along circuits in silicon chips.

Researchers expect we will need thousands if not millions of qubits to build practical quantum computers that can solve a wide variety of useful tasks. That's partly because of the large number of qubits needed to encode bigger problems into the machine and to deal with the fragility of quantum systems, which makes qubits error prone. To get around this, quantum computers require error-correcting schemes to ensure that mistakes don't pile up too quickly and derail a computation. But to do this, up to 10,000 times as many qubits may be needed to run the error-correction code.

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[61] Boston Consulting Group (BCG), What Happens When 'If' Turns to 'When' in Quantum Computing, July 2021, https://web-assets.bcg.com/89/00/d2d074424a6ca820b1238e24ccc0/bcg-what-happens-when-if-turns-to-when-in-quantum-computing-jul-2021-r.pdf?utm_source=chatgpt.com

Annex III
OQI Use Case Repository

OPTIMISATION

Last-Mile Food Delivery

2 ZERO HUNGER

Quantum computing optimisation of the food supply chain, in particular in the route planning offood delivery in underserved regions impacted by climate change or other crises.

COQIT, HASSAN II UNIVERSITY OF CASABLANCA, INDIAN INSTITUTE OF TECHNOLOGY, QUANTUM AI FOUNDATION, TECHNICAL UNIVERSITY OF DELFT, UNIVERSITY OF MUMBAI, WORLD FOOD PROGRAM (WFP), YALE UNIVERSITY

MACHINE LEARNING

Plant Genomics

2 ZERO HUNGER

Quantum computing solution to improve wheat, corn and soy yield by targeted gene editing.

FOOD AND AGRICULTURE ORGANISATION (FAO), INARI, QUERA, VENTURUS

OPTIMISATION

Sustainable Food Production

2 ZERO HUNGER

Improving sustainability of global food systems by making them more resilient to climate change through a quantum optimisation solution to produce more nutritious food locally in less land.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE (EPFL), GLOBALE ALLIANCE FOR IMPROVED NUTRITION (GAIN), NATIONAL INSTITUTE FOR THEORETICAL AND COMPUTATIONAL SCIENCE (NITHECS), QUANTUM BASEL

MACHINE LEARNING

Accelerating Novel Antimicrobial Discovery

3 GOOD HEALTH AND WELL-BEING

Quantum machine learning solution to accelerate the antimicrobial discovery and lower resistance to drugs.

GLOBAL ANTIBIOTIC RESEARCH AND DEVELOPMENT PARTNERSHIP (GARDP), MCMASTER, QBRAID, UNIVERSITÀ DEGLI STUDI DI CAGLIARI

MACHINE LEARNING

Predicting Gastrointestinal Cancer

3 GOOD HEALTH AND WELL-BEING

Quantum machine learning solution to improve accuracy of gastrointestinal cancer diagnosis and speed up medical treatment and prevention.

UNIVERSITY OF COIMBRA, CENTRE FOR SOCIAL STUDIES, INTERNATIONAL AGENCY FOR RESEARCH ON CANCER (IARC)

QUANTUM SIMULATION

Women's Healthcare

3 GOOD HEALTH AND WELL-BEING

Quantum simulation of the molecular interaction of the biological targets and drugs involved in the treatment of endometriosis, perimenopause, and menopause.

UNIVERSAL QUANTUM

QUANTUM SIMULATION

Drug Metabolism Design

3 GOOD HEALTH AND WELL-BEING

Quantum simulation of electronic structures to understand metabolic processes of enzymes to reduce adverse drug reactions.

ALGORITHMIQ

QUANTUM SIMULATION

Eliminating 'Forever chemicals' from Water Sources

6 CLEAN WATER AND SANITATION

Quantum simulation of the decomposition of "forever chemicals" (Poly-fluoroalkyl substances, PFAS) for more efficient removal in water, limiting physiological and environmental harm.

QUANTUM SOUTH, SANDBOXAQ, UNHABITAT

MACHINE LEARNING

Molecular Docking to Clean Up Pollution

6 CLEAN WATER AND SANITATION

Quantum simulation and quantum machine learning solution to accurately model the chemical process of molecular docking involved in removing organic pollutants in water.

QUANDELA, QUNASYS, WORLD HEALTH ORGANISATION (WHO)

OPTIMISATION

Water Leak Detection

6 CLEAN WATER AND SANITATION

Quantum optimisation solution to optimally position sensors and detect water leaks in urban water systems.

PASQAL, QCLAVIS.IO, REPLY, UNHABITAT

LINEAR SYSTEMS OF EQUATIONS & PDEs

Water Resource Management

6 CLEAN WATER AND SANITATION

Quantum fluid dynamics solution to model aquifer systems, prevent and monitor contaminant breakthrough and assess impact of climate change on water reservoirs.

AMERICAN UNIVERSITY OF BEIRUT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)

OPTIMISATION

Layout of Turbines in a Wind Farm

7 AFFORDABLE AND CLEAN ENERGY

Quantum optimisation solution to efficiently layout turbines in a wind farm and maximise the power produced.

G. NARAYANAMMA INSTITUTE OF TECHNOLOGY, INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), UNIVERSITY OF PLYMOUTH

OPTIMISATION

Smart Grid Management

7 AFFORDABLE AND CLEAN ENERGY

Quantum optimisation solution to improve the management oflarge energy grids and efficiently distribute energy.

CLASSIQ, INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), WOLFRAM

QUANTUM SIMULATION

Coated Fertiliser Design

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Quantum simulation to optimise the nutrient release from coated fertilisers for sustainable agriculture.

UNIVERSITÉ DU LITTORAL CÔTE D'OPALE (ULCO), MOHAMMED VI POLYTECHNIC UNIVERSITY (UM6P), UNIVERSITY OF NOTTINGHAM

MACHINE LEARNING

Illegal Mining

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Quantum machine learning solution for monitoring illegal mining through satellite imagery and promoting environmental conservation, particularly in Ghana.

UNIVERSITY OF ENERGY AND NATURAL RESOURCES, UNIVERSITY OF EDUCATION, WINNEBA (GHANA)

MACHINE LEARNING

Carbon Capture

13 CLIMATE ACTION

Quantum machine learning solution to improve efficiency of catalysts involved in the chemical process of carbon capture.

QCENTROID, ETH ZURICH

QUANTUM SIMULATION

Carbon Reduction

13 CLIMATE ACTION

Quantum Computing simulation to reduce carbon dioxide (CO2) in the atmosphere by improving catalysis process responsible for the fixation of carbon on the surface of materials.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE (EPFL), ETH ZURICH, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC)

MACHINE LEARNING

Flood Risk Assessment

13 CLIMATE ACTION

Quantum machine learning solution to provide better accuracy in flood prediction and improve prevention mechanisms in regions at risk, particularly Malaysia.

MALAYSIA QUANTUM INFORMATION INITIATIVE, UNIVERSITI TEKNOLOGI PETRONAS, QUATI

LINEAR SYSTEMS OF EQUATIONS & PDEs

Weather and Climate Forecasting

Quantum fluid dynamics simulation to improve the reliability of weather and climate forecasts.

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS (ECMWF), PLANQC, UNIVERSITY OF OXFORD, WORLD METEOROLOGICAL ORGANISATION (WMO)

Annex IV
Current Quantum Technologies Initiatives addressing Peace and Security:
State and Coalition

Note while this table is comprehensive, it is not exhaustive

State	Initiative	Aims
Australia. [62]	National Quantum Strategy: Army's Quantum Technology Roadmap - Army Quantum Technology Challenge (AQTC) Army Research Centre: The Quantum Next Generation – Minesweeper Challenge 2023.	Annual technology challenge and flagship initiative designed to identify the "most disruptive and advantageous application of QT for the land domain." Initiative seeking to stimulate innovation in military and humanitarian applications of QT.
Brazil. [63]	FAPESP Quantum Technologies Initiative (QuTIa) Brazil-Vietnam Joint Committee on Science, Technology and Innovation	Mention of cybersecurity in initiative mission. Brazil is interested in establishing partnerships in areas such as quantum technologies.
Canada. [64]	North American Aerospace Defense Command (NORAD) Quantum-enabled defence capabilities R&D	Advance research on communications and networking, quantum enabled sensing such as radar and lidar, quantum-enabled alternative position, navigation and timing, and quantum computing mastery for exploration of new materials and medical countermeasures.
China. [65]	The 13th Five Year Special Plan for Science and Technology Military-Civil Fusion Development	Focus on quantum communication satellite systems and quantum sensing for stealth detection and navigation.

[62] Commonwealth of Australia, National Quantum Strategy Building a thriving future with Australia's quantum advantage. (2023). : https://www.industry.gov.au/sites/default/files/2023-05/national-quantum-strategy.pdf.

[63] Planalto. Department of Foreign Affairs (2025). Brazil, Vietnam strengthen partnerships during visit of President Lula, ministers to Asia. (online) : https://www.gov.br/planalto/en/latest-news/2025/04/brazil-vietnam-strengthen-partnerships-during-visit-of-president-lula-ministers-to-asia (Accessed 21 Jul. 2025). See also, Alisson, E. (2025) 'FAPESP aims to boost the development of quantum technologies in Brazil', Agência FAPESP, 15 January. : https://agencia.fapesp.br/fapesp-aims-to-boost-the-development-of-quantum-technologies-in-brazil/53685 (Accessed: 21 July 2025).

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Denmark. [66]	Collaborating with France on testing a quantum sensor	Quantum-based navigation in case of GPS disruptions.
France. [67]	Defence Quantum Strategy Defence Innovation Agency created of Defence Quantum Campus	Focus on quantum computing for military applications.
Germany. [68]	Quantum Technologies Conceptual Framework Federal Office for Information Security (BSI)	Focus on discovering the practical relevance of quantum computing, various applications in the areas of optimization, machine learning and simulation. BSI has published guidelines on QT and Quantum safe cryptography.
India. [69]	National Security Council Secretariat established the Quantum Lab at the Military College and announced the National Mission on Quantum Technologies and Applications (NM-QTA). The Defence Research and Development Organization (DRDO) opened the Quantum Technology Research Centre (QTRC)	Aims to develop sovereign quantum technologies for secure communication, sensing and post-quantum cryptography. Experiments focus on secure communications, timekeeping, sensing and advanced materials.
Israel. [70]	Defense Ministry Directorate of Defense Research and Development Innovation Authority (IAI) Established Quantum consortium and Quantum Computing Center and Quantum QHIPU lab	Prioritizing development of practical quantum computing applications. IAI mission is to stay "one step ahead of adversaries."
Japan. [71]	Defense Buildup Program (DBP) and Quantum Vision	Focus on quantum computing and communications. Focus on PQC and QKD.

[66] Weber, V. and Riera, M. (2025). Quantum Technologies Ranking Germany's Ambition and International Reputation POLICY BRIEF. (online) : https://dgap.org/system/files/article_pdfs/10_DGAP%20Policy%20Brief%202025_EN_Quantum_Tech_0.pdf.

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Pakistan. [72]	National Center for Quantum Computing The Centre of Excellence for Technology Quantum and Artificial Intelligence Pakistan (CETQAP)	Investment in quantum computing to maintain its strategic equilibrium and avoid the threat of Harvest Now Decrypt Later.
Philippines. [73]	Indo-Pacific Defense Industrial Base Collaboration Research and Development	References advancement of science and technology such as quantum biotechnology.
Republic of Korea. [74]	National Quantum Strategy: Defense Science and Technology Innovation Basic Plan	Expanding investment in quantum through military-private cooperation. Aims to develop world's top-class sensor technology, focusing on GPS-independent navigation technology with the Korean Positioning System (KPS).
Russia. [75]	Rostec: Policy on development of the forces and means of warfare through development of promising high technologies.	Improving information security tools and techniques through quantum computing.
Singapore. [76]	NRF Singapore launched the National Quantum Strategy and began partnership with Ministry of Defence (MINDEF)	Establishing a Quantum Sensing Centre to foster global collaboration and advanced research to realize quantum sensors as well as quantum computing and communication.
South Africa. [77]	South African Quantum Technologies Initiative (SA QuTI)	Worked with China on proving use of quantum for secure communication.
Spain. [78]	Established Quantum Communications Hub Spanish Quantum Technologies Strategy 2025-2030	Focus on convergence between AI and quantum, quantum communications and quantum sensing and metrology.

https://www.japan.go.jp/kizuna/2022/05/cutting_edge_of_quantum_technology.html.

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Switzerland. [79]	Swiss Quantum Initiative	Involvement in Horizon Europe.
Thailand. [80]	Quantum Technology Roadmap	Development in three focus areas of quantum computing and simulation, quantum communication and quantum metrology and sensing
United Kingdom. [81]	National Quantum Strategy: Investment in Technology Missions Fund with UK National Quantum Technologies Programme	Focus on quantum sensing applications to resilient capabilities in position, navigation and timing where traditional satellites cannot reach.
United States. [82]	National Quantum Initiative Act Defense Advanced Research Projects Agency (DARPA)'s Quantum Benchmarking Initiative (QBI) National Institute of Standards and Technology (NIST)	Collaboration with industry to determine if it is possible to build an industrially useful quantum computer much faster than conventional predictions Timeline for standardizing PQC algorithms.

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[81] United Kingdom Department for Science, Innovation & Technology (December 2023), https://www.gov.uk/government/publications/national-quantum-strategy/national-quantum-strategy-accessible-webpage#:~:text=,into%20defence%20applications%20of%20quantum

[82] United States Government, National Strategic Overview for Quantum Information Science (September 2018) https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf

Partnerships	Initiative	Aims
African Union.[83]	African Union High-Level Panel on Emerging Technologies (APET)	Focus on software development.
Arab League. [84]	Saudi Arabia Vision 2030	Focus on developing a quantum computer.
ASEAN. [85]	Various respective national strategies, no unified strategy	Intent on catching the second quantum revolution.
AUKUS. [86]	Quantum Arrangement (AQuA)	Aims to accelerate investments to deliver generation-after-next quantum military capabilities. There will be an initial focus on quantum technologies for positioning, navigation and timing.
BRICS. [87]	BRICS Framework Programme for Scientific, Technological and Innovation (STI)	Prioritized quantum technologies and computing as critical areas for collaborative research in 2020. In 2023, made progress in quantum communication links for BRICS countries.

[83] Justina Dugbazah et al. (2024). Harnessing Quantum Computing To Advance Health Solutions Across Africa | AUDA-NEPAD. [online] Nepad.org. Available at: https://www.nepad.org/blog/harnessing-quantum-computing-advance-health-solutions-across-africa.

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European Union.[88]	European Defense Fund: military focused quantum effort European Quantum Flagship – European Quantum Internet Alliance (QIA) European Commission: Quantum Europe Strategy ProtectEU Strategy – EuroQCI ReArrm Europe – European technological armament roadmap Space and Dual-Use Quantum Technologies (Security and Defence) Advanced-Disruptive and Emerging Quantum technologies for Defence (ADEQUADE) project	QUEST project focusing on quantum sensors and positioning QKD network development and PQC policies Focus on 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. Invest in quantum clocks, sensors and secure links for Galileo and IRIS, Launch initiatives for defence applications.
NATO.[89]	Quantum Technologies Strategy Defence Innovation Accelerator for the North Atlantic (DIANA) and NTAO innovation Fund (NIF) G7 Communiqué	Vision of a Quantum-Ready alliance by making cryptographic systems quantum-safe and developing improving navigation systems. Launched Transatlantic Quantum Community G7 countries looking to coordinate quantum supply chains and establishing a G7 observatory to track quantum-safe readiness.
SCO	No published unified strategy	

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Annex V
Call to Action.

This table specifies what this call to action implies for you, if you are a ...

Hardware Developer

Signing and committing to this call to action for you can entail:
- Making your best-in-class hardware accessible for societally beneficial research and development at no or very low cost.
- Fostering open-source development and public research and development collaborations where possible.
- Sharing knowledge about the technology you are developing with interdisciplinary audiences and the wider public.

Application Researchers and Developer

Signing and committing to this call to action for you can entail:
- Committing at least 10% of your research and development time to a societally and environmentally beneficial application.
- Developing open-source software or contributing to open-source libraries.
- Participating in international standardisation efforts.

Public Funding agency

Signing and committing to this call to action for you can entail:
- Committing to spend 10% of your funding budget on viable societally and environmentally beneficial quantum technology projects.
- Encouraging each funded project to have a societally beneficial component.
- Making a responsible technology assessment mandatory in funding applications.

Private Funding agency

Signing and committing to this call to action for you can entail :
- Committing to spend 10% of your funding budget on viable societally and environmentally beneficial quantum technology projects.

Policy maker

Signing and committing to this call to action for you can entail:
- Establishing soft governance mechanisms for responsible innovation in quantum technologies by 2030.
- Participating in international standardisation efforts.
- Establishing a public roadmap for quantum-safe transition.

Quantum Technology User

Signing and committing to this call to action for you can entail:
- Committing to the peaceful use of quantum technologies.
- Spending 10% of your research and development effort on societally beneficial applications.