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Quantum Computing and the G-77

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Introduction

Governments across the world are launching quantum computing initiatives and investing heavily in quantum computing research and development (R&D). When considering the United Nations Group of 77 (G-77) – the intergovernmental organisation of 135 (self-described) developing countries within the United Nations – quantum computing policy discussions are often focused on China, India, and Singapore. Yet quantum computing activity is underway in a wider range of G-77 states, from Brazil to South Africa.

The tremendous investment and interest in quantum computing can overshadow its current reality: it is still a nascent technology. While researchers pursue a variety of R&D approaches, we are still years away from a fault-tolerant quantum computer with sufficient quantum bits (qubits) for commercial applications at scale. It is important to note that quantum computing is not a pure hardware problem. 'Quantum advantage', when quantum computers outperform classical computers, will require both quantum computers – a hardware challenge – and quantum algorithms. Any discussion of operational quantum computers relies on two assumptions: future technical breakthroughs, and relevant application areas.

Shor's algorithm, a quantum algorithm that would break factor-based encryption, is one of the clearest applications for quantum computing, contributing to a deeply securitised international landscape and fears of quantum decryption and 'Q-Day' – the day quantum computers will break encryption. Yet quantum computing researchers have posited that quantum computers could be used for positive applications far sooner than they could break encryption.[1]

Policy and governance discussions on quantum computing are often driven by national security concerns, creating the risk that securitisation will further entrench existing divides along geopolitical and development lines, and limit the potential for globally equitable and positive applications. Meanwhile, G-77 states advocate for a greater role in international technology governance, including with quantum technologies. From the G-77[2] to UNESCO, these states have expressed the need for open, equitable scientific collaboration and technology governance mechanisms. In November 2023, UNESCO adopted a proposal to declare 2025 the international year of quantum science and technology, an effort led primarily by G-77 states.[3]

Ultimately, governments and researchers from the G-77 are already engaging with quantum computing and are important stakeholders in a technology that will likely have global opportunities and ramifications. This report focuses on G-77 states with some level of quantum computing activity.

- Section 1 groups G-77 states based on modalities of quantum computing access.
- Section 2 offers brief case studies of the three G-77 states developing sovereign quantum computer capabilities: China, India, and Singapore. It focuses on how these states shape geopolitics relevant across the G-77.
- Section 3 provides analysis and emerging trends on quantum cloud computing access and the G-77.
- Section 4 discusses additional characteristics and insights from case studies, especially for 'cloud access' states.

- Section 5 provides preliminary recommendations for interventions and further areas of work.

This work is not intended to be conclusive. Rather, we hope it spurs further research; in-depth, country-expert led analysis; and supports broader activity on globally equitable quantum computing.

The report was commissioned by the Research Group on the Law and Governance of Quantum Technologies at the University of Amsterdam, established with the support of Quantum Delta NL's Action Line 4 and the Centre for Quantum & Society (CQS).

Methodology

This report relied on desk research and supplementary expert interviews. It was scoped to focus on ongoing or planned quantum computing activity within the G-77.

The G-77
This report engages primarily with state-based analysis and uses the United Nations Group of 77 (G-77)'s 135-member list[4] of countries as the basis of the term 'G-77 states'.[1] China is included in the list, although it is not a full G-77 member and in political discussion and analysis is often referenced separately as the 'G-77 and China'.

We selected this approach due to the G-77's role and importance as an organising bloc that represents and advocates for developing economies within the United Nations (UN) system. For example, the G-77 and China make regular submissions on more equitable trade and development with UN Trade and Development (UNCTAD), most recently in Geneva.[5] Other submissions range from climate change[6] to the UN's digital future initiative, the global digital compact.[7]

The terms 'developing economies' and 'Global South' are embedded in the history, goals and mission of the G-77, and we engage with this terminology where relevant. As underscored in the G-77's most recent summit, the group plays a "critical role in providing the Global South with the means to articulate our shared vision, promote our interests and enhance our joint negotiating capacity within the United Nations system."[8] Ultimately, the role of the G-77 in technology governance conversations cannot be removed from the group's origins in decolonisation movements nor from the impact of colonisation on current-day geopolitics and material inter-dependencies, including technology development. This perspective informs the report.

Ongoing or Planned Quantum Technology Activity
The report is focused on G-77 states that satisfy at least one of the following criteria.

- **National Quantum Strategy.** A national government has announced a coordinated strategy on quantum technologies, which includes specific activities, objectives, and a funding commitment.
- **Building a Quantum Computer.** A national government supports the development of a sovereign quantum computer.

[1] Notably, the G-77 excludes East Asian economies including Japan, South Korea, and Taiwan; emerging markets such as Turkey; and those within Eastern Europe.

- **Global or Regional Quantum Initiative(s).** There is country representation in a global or regional quantum technology initiative. This includes individuals who participate in a personal capacity.
- **Public-Private Partnership(s).** A national government has announced a private sector partnership involving access to and/or the development of quantum technology in its country.
- **Academic Activity.** A country has academic initiatives or networks on quantum technology, or academic research within a university on quantum technology that is supported or funded by its national government.

A full list of countries and activity findings are available in the annex.

Quantum Technologies
For scoping reasons, this report and the typology put forward to open up perspectives on the G-77 is focused primarily on quantum computing, a new form of computing based on quantum bits (qubits). Additionally, some references and insights (Section 4) are offered related to other quantum technologies than computing: quantum sensing (sensors that apply quantum physics for more miniscule measurements of physical matter) and quantum communications (systems that transmit information using quantum states).
In instances where more than one technology is under consideration or it is unclear to which technology is being referred, we use the umbrella term 'quantum technologies'.

Quantum computing is still an R&D technology with limited present-day capabilities. There is tremendous uncertainty around the timeline for its development, the research and manufacturing pathway to build a fault-tolerant quantum computer with sufficient qubits for 'quantum advantage', and the development of quantum algorithms that can offer quantum advantage. This report grounds its analysis in existing activity but applies this to a 'medium to long-term' future with operational quantum computers. However, there is still a possibility that such breakthroughs will not be achieved.

Limitations:

- **Desk Research**

We relied on public materials for desk research, and conducted search primarily in English, with supplementary review in Spanish and Portuguese. Given the linguistic diversity across the G-77, this did not produce a comprehensive catalogue of quantum computing activity. This was not a goal for this report, although it is offered as recommendation for future activity.

We reference a wide variety of sources in this report, from academic materials to press releases and blog posts. Given the nascent nature of technology analysis and coverage, it was not possible to restrict our source materials to those published by traditional or academic outlets. Where possible, we sought to cross-reference findings.

- **Securitisation**

This report acknowledges the backdrop of securitisation but does not apply a securitisation lens to its analysis. As such, it includes G-77 initiatives focused on post-quantum cryptography and quantum key distribution but does not expand on the national security implications of quantum decryption and does not primarily treat quantum computers as a security asset. This approach leads to a limited treatment of the U.S.-China quantum 'arms race' (including U.S. restrictions of the sale of high-performance computing chips to China and sanctions focused on quantum computing) and of Iran. The latter is included in the annex but excluded from the body of our report due to its unique national security considerations and diplomatic relations, and the difficulties in verifying ongoing domestic activity.

- **Typology**

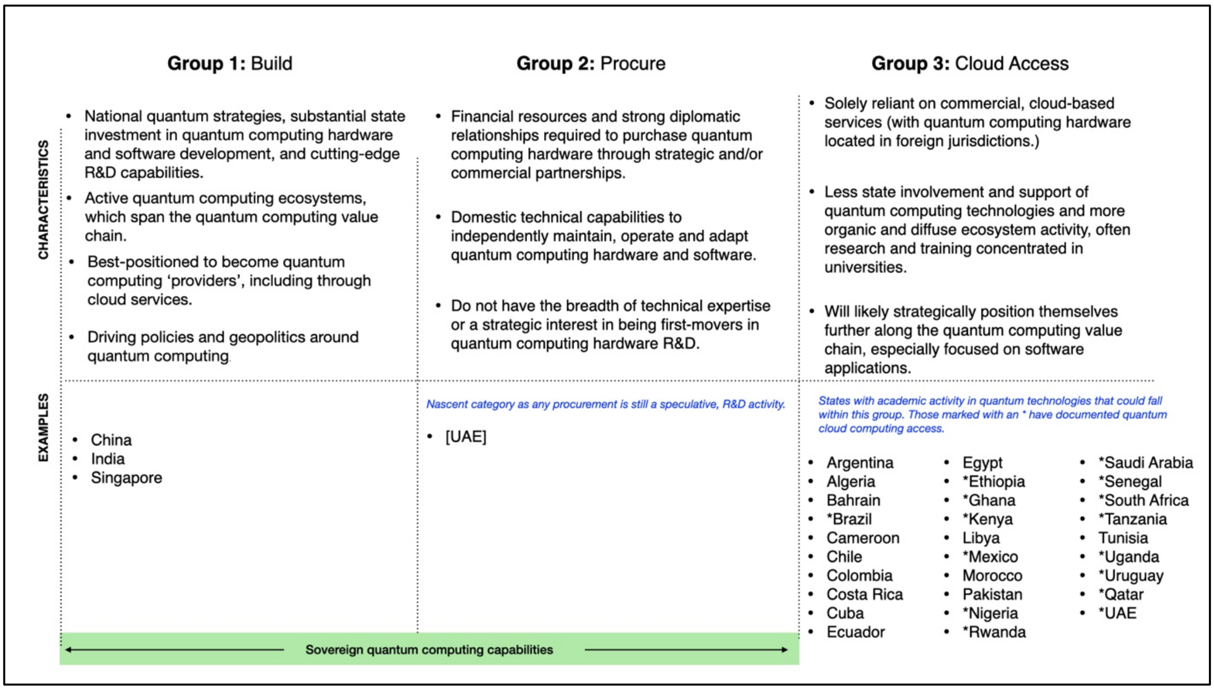
We offer a preliminary typology based on how G-77 states access or are likely to gain access to advanced quantum computing. This is intended to facilitate a more nuanced conversation on quantum computing and G-77 states, which often focuses solely on China, India, and Singapore. As with any grouping of countries with such distinct domestic politics, economies, geopolitics, and histories, we risk over-generalisation. There are also supplementary categorisations that can support nuanced discussion of geopolitical dynamics. For example, the World Bank categorises world economies by four income groups (which in turn, impacts international lending mechanisms). This report engages briefly with these categories, as well.[9]

The typology also summarises country-level dynamics, which can aggregate industry, state, and academic stakeholders. Finally, quantum computing will likely have implications for all states, regardless of whether they access and apply the technology directly. We offer some recommendations to extend our analysis in Section 5.

As mentioned, the report and typology are not intended to be conclusive. We hope it supports further work, which could include alternate or even diverging typologies.

1. Typology of G-77 states

We propose groups of G-77 states based on three modalities of quantum computing access: build; procure; and cloud access.



Group 1: Build

States within this category are looking to be first or early movers in developing sovereign quantum computing capabilities. They have national quantum technology strategies and have mobilised public investment to support academics and researchers. These also have the most active quantum computing ecosystems, with activity that spans the quantum computing value chain, from R&D focused on quantum computing hardware to use of cloud computing for commercial applications.

- In the **near term** (while quantum computing is still an R&D technology), these states will shape and respond to geopolitical dynamics around quantum computing development, especially with the US and EU. Much of the current discourse on the G-77 and quantum computing focuses on these states.

- In the **medium to long term** (assuming technology maturity), these states are best positioned to establish themselves as quantum computing 'providers'. They will have the most freedom to develop a national agenda for quantum computing, including for military and national security purposes, to develop or support commercial cloud offerings, and to set terms for international quantum computing access and cooperation.

At this point in technology development, it is important to note that building a 'sovereign' quantum computer still requires international co-operation for supply chain and knowledge transfer. Even China, which is moving towards supply chain self–sufficiency, likely relies on Japan for e-beam lithography.[10] In the medium to long term, the capital investment and expertise requirements to develop quantum computers will be more clearly specified. While such requirements will still pose substantial barriers to entry, they will be less experimental and will shift emphasis from research and development to knowledge transfer and supply chain access. Based on supply chains, sanctions, and export control regimes, more states may enter this group of states or alternatively, be pushed out.

In Section 2, we analyse the 'Build' group using current examples and case studies. China is a clear example of 'Build' state. India and Singapore are included as 'Build' states as well, although they have some characteristics of 'Procure' states.

Group 2: Procure

These states will pursue sovereign quantum computers by procuring hardware and software through strategic or commercial partnerships. States within this category will have financial resources and strong diplomatic relationships with quantum computing 'providers' but will not have relevant or sufficiently mature domestic technical expertise across the quantum computing stack, especially in quantum computing hardware.

Currently, the United Arab Emirates is the one possible example of a 'Procure' state. Abu Dhabi's Quantum Research Center will construct a quantum computer in collaboration with the Spanish start-up, Qilimanjaro.[11] The Center's chief researcher has said: "There will be a dramatic difference between the countries that own the technology and the ones that depend on the technology. The Emirates, like Singapore or Israel, [countries] of comparable sizes, cannot depend fully on allies. They have to develop their own technological strategies and they have to be sovereign. That is fundamental."[12]

- In the **near term**, this category is the least developed, as the technology is still preliminary, and there are few commercial providers. Any hardware that is currently sold or licensed is intended to support research, education and training, and lay a pathway for future sovereign quantum computing.

- In the **medium to long term**, this is likely the pathway for most states to develop sovereign quantum computers (within provider-specified conditions and restrictions). These states will be able to 'leapfrog' research and development investment and specialised quantum computing hardware expertise, although they will still require experts who are able inspect, maintain, and adapt such systems, and support those who conduct fundamental and applied research. However, this group of states will be especially vulnerable to export control and sanctions regimes.

As this is a nascent category reliant on future supply chains, it is not analysed further in this report. However as mentioned, India and Singapore have specific dynamics – such as reliance on strategic partnerships – that could lead to 'Procure' categorisation. This is explored in the India and Singapore case studies in Section 2.

Group 3: Cloud Access

Commercial cloud services can supplement sovereign quantum computer activity and help engage a wider range of academic and commercial entities with the technology. However, in states without sovereign quantum computer initiatives, commercial cloud services are the only access point for the technology. States within this group are solely reliant on commercial, cloud-based quantum computing with hardware located in foreign jurisdictions.

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While states with sovereign quantum computers initiatives can be characterised as having 'top down' or 'vertically integrated' quantum computing strategies – as is often the case with single, capital-intensive technologies that require substantial coordination and financing – those that rely on cloud computing access typically have diffuse quantum computing activity with less government involvement. Such activity is often housed within universities, driven by academics or university departments with expertise in specific aspects of quantum computing.

'Cloud Access' states will likely position themselves further along the quantum computing value chain. For example, South Africa's quantum computing strategy does not focus on the hardware itself, as it cannot compete in terms of capital investment; rather, it will focus on leveraging its capabilities in software development.[13]

- In the **near term**, there will be a continuation of the current trends. This will be the largest group of G-77 states. They will engage with exploratory quantum cloud computing services through U.S-based commercial providers unless they are subject to access restrictions.

- In the **medium or long term**, quantum cloud computing may become essential infrastructure. However, the nature of the access will depend on cloud 'providers', including whether they are commercial or government entities, and how they are impacted by export control and sanctions regimes.

This group is explored at length in Section 3 and 4.

2. In Focus: 'Build' states – China, India, and Singapore

Overview: Domestic Quantum Computing Activity

- Case Study: China

China has committed $15.3 billion in public funds to quantum technology development.[14] It is the leading investor in quantum technologies globally; the next nation by public investment is the U.S. with $3.7 billion. China's strategy is focused on developing quantum communications, computers, simulators, and precision measurement technology.[15] Among its achievements is the country's latest 72-qubit quantum computer, 'Wukong', developed in 2023.[16] China has also built 'Micius', the world's first satellite capable of quantum-key distribution.[17] Additionally, China has reportedly begun producing dilution refrigerators needed for superconducting quantum computing.[18]

Chinese academics are the biggest contributors to quantum-relevant publications, and over half of all quantum technology patents are granted to Chinese researchers.[19,20] China's public investment appears to focus on Chinese research institutions.[21] The Chinese Academy of Sciences (CAS), a national research institute, plays a particularly important role in quantum development. In 2014, it launched its Center for Excellence in Quantum Information and Quantum Physics, which has made significant advances in quantum physics.[22] The University of Science and Technology of China (USTC), which is part of CAS, was the first university to award doctorates in quantum science and technology in China[23] and is where Pan Jianwei – known by some as the 'Father of Quantum'[24] – is based. Pan's USTC team worked on the 66-quibit Zuchongzhi 2 which, until Wukong, was China's most advanced quantum computer.[25]

China's private sector has been active in quantum computing, although this activity appears to be closely integrated with government research activity. In 2022, Baidu announced its first superconducting quantum computer 'Qian Shi', along with a platform providing access to quantum hardware.[26] Tencent has a quantum lab researching enterprise use cases for quantum simulations and algorithms.[27] Origin Quantum, the Chinese company behind Wukong, is aiming to develop a 1,000 qubit computer by 2025.[28] Finally, CAS and Alibaba have set up a lab providing quantum computing services via the cloud, and its membership appears to consist mainly of Chinese universities.[29]

- Case Study: India

India's national quantum mission, approved by its cabinet in April 2023, allocates $730 million in funding to quantum technologies between 2023-2031.[30] While this is a substantial sum – second only to China's investment when considering G-77 states – it is smaller than India's other technology program investments, such as the $1.3 billion annual allocation for space exploration and $10 billion commitment in subsidies for semiconductor chip manufacturing.[31]

India's quantum initiative is focused on four application areas: Quantum Computing and Simulations, Quantum Communications, Quantum Sensing and Metrology, and Quantum Material and Devices. Each vertical will be coordinated by a hub that will encourage a corresponding ecosystem with international cooperation, industry links, start-ups and workforce and talent development.[32] For example, future quantum activities pursued by the Centre for Development of Advanced Computing, a government R&D organization, will be in line with India's national strategy.[33]

India ranks highly in academic contributions to quantum-relevant publications, and number of universities with quantum technology research programs.[34] Leading Indian universities with quantum technology degree programs include the Indian Institute of Science, Indian Institute of Technology Jodhpur, and the Indian Institute of Technology Madras.[35] All of these institutions have partnered with IBM for quantum computing cloud access and training.[36]

In India, large private companies are experimenting with quantum computing applications. Infosys has launched its Quantum Living Labs, which offers quantum-based solutions to clients for a range of use cases across different industries.[37] Tata Consultancy Services has partnered with the Indian Institute of Technology Tirupati to provide industry internships in quantum computing.[38] There are a growing number of quantum computing start-ups, as well. For example, QpiAI has developed a platform for room-temperature qubit control capable of running large ML models.[39]

- Case Study: Singapore

Singapore has an estimated $138 million public investment in quantum technologies.[40] In May 2022, it announced its strategy on quantum, which supports three national platforms with ~ $17.09 million[41] in funding: the National Quantum Computing Hub, the National Quantum Fabless Foundry, and the National Quantum Safe Network.[42]

The country's quantum computing efforts rely heavily on its research institutions and networks. In 2018, the Singaporean government launched the Quantum Engineering Programme (QEP) to support research in quantum technology across the country.[43] Based at the National University of Singapore, the QEP coordinates the work of the three national platforms with support from the National Research Foundation. This includes working with private sector organisations; in 2021 the QEP announced its collaboration with AWS to develop quantum communication and quantum computing technologies.[44]

The National Quantum Computing Hub will lead Singapore's development of quantum computing hardware, and applications in fields including finance, supply chain and chemistry.[45] In addition, the Hub will host Singapore's quantum computer and provide direct access to companies and government agencies. It will also provide education and training.

Singapore features some noteworthy start-up and private investment activity. Horizon Quantum Computing, a Singaporean start-up developing quantum algorithms, recently raised $18.1 million in a Series A funding.[46] Another example is S-Fifteen Instruments, a spin-off from the Centre for Quantum Technologies, which applies photonic quantum technologies for secure communications.[47] In April 2023 IQM Quantum, a leading European quantum computing hardware company, opened an office in Singapore aiming to take advantage of the country's talent pool and build public-private partnerships.[48]

Insights

- Relationships with the U.S., especially tense China-U.S. relations, shape global quantum computing geopolitics.

The U.S. has pursued aggressive trade and sanctions policies towards China, including through restrictions on semiconductors used for high-performance computing, and by expanding its sanctions list to target quantum computing efforts that support China's military applications.[49] A full analysis of U.S.-China relations is out of scope for this report. However, these dynamics underpin China's isolated approach to quantum computing research and development, its levels of investment, and interest in supply-chain self-sufficiency.

Meanwhile, India and Singapore – the two other sovereign quantum computer states within the G-77 – enjoy friendly relations with the U.S. India is especially close; the Indo-U.S. Quantum Coordination Mechanism establishes the basis for a future bilateral quantum agreement. Announced in June 2023, the Coordination Mechanism covers a range of activities to support U.S.-India research collaboration, including a $2 million grant program to support joint research and commercialisation of AI and quantum technologies. In addition, the two countries will work toward a comprehensive Quantum Information Science and Technology Agreement.[50] (The U.S. has such an agreement with the U.K., which includes promoting multidisciplinary research and potential jointly funded research opportunities, enabling a global market and supply chain for quantum technology research, and engaging stakeholders to grow a future marketplace).[51]

Singapore enjoys a strategic technology partnership with the U.S., which facilitates bilateral government, academic, and private sector exchange and information sharing on post-quantum cryptography.[52] In May 2023, the U.S. science envoy met with counterparts in Singapore to explore collaboration opportunities in quantum technology, including research partnerships between institutions and start-ups.[53] While Singapore is an active member of the G-77, it is often thought in relation to other groupings, including the Asia-Pacific Economic Cooperation (APEC) – which comprises 21 economies, including the U.S., Canada, and Japan – and the Association of Southeast Asian Nations (ASEAN), which comprises ten G-77 member states. Singapore was the only ASEAN member to join the Western sanction regime against Russia.[54] It is also one of the countries within the Indo-Pacific Economic Framework for Prosperity (IPEF),[55] the 2022 U.S. trade initiative widely viewed as Washington's effort to re-assert engagement in region and counter Beijing's influence. However, it continues to maintain friendly relations with Beijing, balancing between tense U.S.-China relations.

Both India and Singapore participate in U.S.-led scientific and industry fora. They enjoy membership in the Quantum Economic Development Consortium (QED-C), a consortium that aims to identify gaps in quantum technology, standards, and the workforce. (QED-C was established with support from NIST as part of the US' National Quantum Initiative Act).[56] In addition, India is the only G-77 member in the Chicago Quantum Exchange, a U.S.-based hub to advance science and engineering of quantum information, train the workforce, and drive the quantum economy. [57]

As can be seen, the U.S. facilitates India and Singapore's access to advanced quantum computing R&D and capabilities, likely reducing domestic expenditure on R&D. However, this could embed geopolitical dependencies, shifting India and Singapore to the 'Procure' category in the future. In addition, strategic partnerships with the U.S. may heighten risks around brain drain. (Brain drain is explored further in Section 4).

- China's relationships with G-77 states are often negotiated through the Belt and Road Initiative (BRI). As of now, quantum computing does not appear to be a BRI priority although this may shift, especially with respect to Pakistan.

The Belt and Road Initiative is China's (estimated) $1 trillion infrastructure development project, which has broadened the state's economic and political influence across Africa, Oceania, and Latin America. The Digital Silk Road (DSR), launched in 2015, is an increasingly important component of the BRI. The DSR focuses on the strengthening digital connectivity and cooperation with BRI participants.[58] It prioritises a number of frontier technologies, including quantum computing.[59] There is no public information available on DSR projects specific to quantum computing. (Other DSR initiatives include developing telecommunications networks in Egypt, implementing national facial recognition systems in Zimbabwe and creating electronic payment systems in Myanmar.[60]) BRI has come under criticism as a Chinese expansionist project, advancing the country's global dominance and entrapping poorer countries, including through long-term loans.[61] However, its proponents argue that BRI's agenda is developed through diverse bilateral interactions, and outcomes are shaped by mutual interests and agenda.[62] (The impacts of the BRI's impact on critical raw materials is discussed in Section 4).

A flagship BRI project is the China-Pakistan Economic Corridor (CPEC), an agreement for improved transportation and industrial cooperation, and increased trade and economic activity.[63] China's bilateral relationship with Pakistan has become especially important, and is understood to be a counterweight to India's close relationship with the U.S. Through CPEC, China and Pakistan launched the Science and Technology Centre, which will facilitate business by Chinese technology companies in special technology zones in Pakistan.[64] China is also a popular destination of study for Pakistani students, who often stay in the country after graduation.[65] Within Pakistan, stakeholders have called for closer collaboration with China on quantum computing.[66]

- BRICS has made initial forays into technology governance. Quantum computing may be on the bloc's 2024 agenda.

Both China and India play leadership roles in BRICS, a group of states comprising Brazil, Russia, India, China, and South Africa. The bloc is in process of expanding to Egypt, Ethiopia, Iran, Saudi Arabia, and the UAE, and Pakistan has expressed interest in joining, too.[67]

Through expansion, BRICS aims to create a new, multi-polar global governance structure. The bloc has long called for reform of multilateral institutions that currently do not represent the majority world. Brazil's president has described BRICS as a complement to Western institutions: "We do not want to be a counterpoint to the G7, G20 or the United States…we just want to organise ourselves."[68] Similarly, China has maintained that it does not want the bloc to engage in major power competition, although it sees the group as important in strengthening emerging markets and developing economies, and combatting U.S. hegemony.[69] `

While the current five-country bloc represents about 40% of the world's population and a quarter of global GDP, its states have diverse economies, governance structures, and a range of diplomatic relations with the U.S. and the E.U. Some experts argue that the wide range in trade and foreign policy approaches weaken the group's potential for alignment and impact, but others see potential for impact on specific priorities. This is mostly clearly seen through BRICS' goal to reduce reliance on the U.S. dollar and use alternative currencies in trade agreements, which could impact dollar dominance.[70]

BRICS has made initial forays into other technology governance. At the 2023 summit, Xi Jinping announced the formation of an AI study group. "We need to jointly fend off risks and develop AI governance frameworks and standards with broad-based consensus, so as to make AI technologies more secure, reliable, controllable and equitable."[71] It is reported that at the 2024 BRICS summit, Russia will introduce a proposal on quantum technologies and semiconductors. Researchers at Russia's Quantum Centre have reportedly visited India to meet with scientists and are keen for collaboration. "[We] see a lot of potential for collaboration. We need to create a BRICS quantum laboratory. And this network of labs which we will create in different countries, (will) work under maybe a joint research program."[72]

It is likely that 2024-2025 will lead to more BRICS updates on quantum technologies.

- India plays an important leadership role in Global North-South relations and may be uniquely positioned to facilitate downstream applications of quantum computing across G-77 states.

While close to the U.S., India has played an important leadership position within the G-77 through its G20 presidency, advocating for greater global participation, welcoming the African Union as a permanent G20 member, and organising the Global South Summit.[73] India's quantum computing initiative should be considered alongside its ambitious plans and investment to become a global semiconductor hub. It is still too early to tell whether India's investment will succeed. However, if India were to achieve its quantum computing and semiconductor manufacturing objectives, it would play an even more important role in engaging other G-77 states with quantum computing, as well as facilitating downstream impacts of the technology. For example: accessible medication has been a foreign policy priority for India, including throughout its G20 presidency,[74] and India plays an important role in supplying generic pharmaceuticals in G-77 states. It has long been known as the 'pharmacy for the world' and is the biggest supplier of pharmaceuticals in Africa.[75] If India were to make headway with quantum computing-enabled drug discovery, it could leverage its global supply chain and potentially circumvent a tense area of Global North-South relations related to pharmaceutical intellectual property protections (known as Trade-Related Aspects of Intellectual Property Rights (TRIPS) -plus provisions).

- Currently, G-77 states have less private sector quantum computing investment. This impacts quantum computing technology start-up activity and commercialisation opportunities.

China only accounts for 4.3% of private quantum technology investment globally,[76] while the United States, Canada, the U.K., and the E.U. account for 88%. Chinese private sector activity is closely linked to the state. Alibaba recently closed its in-house quantum research laboratory amidst restructuring efforts and has raised the possibility of spinning off its cloud business.[77] Baidu, another large cloud service provider, has followed suit, donating its entire research facility on quantum technologies to the state-owned Beijing Academy of Quantum Information Sciences.[78]

Domestic Chinese start-ups appear to access capital through state-owned venture capital companies, such as Shenzhen Capital Group, which raised funds for the start-up Origin Quantum, [79] and through angel investment, which supported quantum communications start-up Qike Quantum. [80] China's private sector plays a role as an international investor, too. In March 2023, Tencent – the Chinese multinational conglomerate that operates WeChat – joined the Series A funding round for Horizon Quantum Computing, a Singapore start-up. The funding will be used to fund product development and European expansion, including plans to open an office in Dublin, Ireland. Horizon specified that the investment was purely financial, and its founder noted that it "took Tencent's investment because the giant is an expert in the area". [81] High-tech venture investment – especially in Singapore and the Asia Pacific, where there is a more mature, globally networked, and well-resourced technology ecosystem – may offer China broader inroads to the international start-up ecosystem and opportunities for knowledge transfer.

Singapore has a strong tech funding ecosystem, which benefits from state support as well as the country's role as global financial centre and technology hub. In Singapore, a key funding vehicle for research commercialisation is SGInnovate, Singapore's state innovation fund for deep technology investments, which manages over $2 billion in investment capital to support research-driven deep tech entrepreneurship. Start-ups at national level can also gain funding from the Startup SG Tech program, which provides funding for the commercialisation of innovative technologies.[82] Singapore also hosts offices for local, international, and regional venture capital firms and start-up incubators.[83] This is discussed further in Section 4 of this report.

In India, most investment is focused on research and academic institutions.[84] However, the Indian government has stated that its strategy will complement other programs like Start-up India, an initiative to foster and support early-stage companies across the country.[85] Domestic start-ups also raise seed funds from local venture capital firms. Indian start-up BosonQ PSI, which develops quantum simulations in the aerospace and automotive sectors,[86] raised pre-seed funding in a round led by 3to1Capital, an Indian venture capital firm.[87] QpiAI, a provider of AI and quantum technology solutions, raised $4.8 million in a seed funding round led by We Founder Circle, a Mumbai-based start-up platform.[88]

3. In Focus: 'Cloud Access' States

Overview: Domestic Quantum Computing Activity

Country	Academic Activity	Cloud Computing Access	Public-Private Partnership(s)	Global or Regional Quantum Initiative(s)	National Quantum Strategy	Quantum Strategy Budget ($)
Africa						
Algeria	✓					
Cameroon	✓			✓		
Egypt	✓			✓		
Ethiopia	✓	✓		✓		
Ghana	✓	✓		✓		
Kenya	✓	✓		✓		
Morocco	✓			✓		
Nigeria	✓	✓		✓		
Libya	✓					
Rwanda	✓	✓		✓		
Senegal	✓	✓		✓		
South Africa	✓	✓		✓		
Tanzania	✓	✓		✓		
Tunisia	✓					
Uganda	✓	✓		✓		
Zimbabwe	✓					
Asia						
Azerbaijan	✓					
Indonesia		✓				
Malaysia		✓				
Pakistan	✓			✓	✓	245 million
Thailand	✓	✓		✓		
Vietnam		✓				
North America						
Cuba	✓					
Costa Rica	✓					
Honduras	✓					
South America						
Argentina	✓	✓		✓		
Brazil	✓	✓		✓	✓	11 million
Chile	✓	✓		✓		
Colombia	✓	✓				
Ecuador	✓					
Mexico	✓	✓		✓		
Peru		✓				
Uruguay	✓	✓				
Middle East						
Bahrain	✓					
Oman		✓				
Saudi Arabia	✓	✓	✓	✓		
Qatar	✓	✓				
UAE	✓	✓	✓			

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Insights

- G-77 states engage with a wide range of quantum cloud computing providers, although certain states face access restrictions. Incumbent U.S.-based cloud providers appear to be the most active, and IBM appears to have an especially large footprint across G-77 states.

States across the G-77 access quantum computing cloud services from start-ups and incumbent cloud providers. (While these are often state-of-the-art, they are still preliminary services best suited for exploratory research and experimentation, reflecting the state of quantum computing R&D).

- In **South Africa**, the academic community has strong relationships with a range of quantum cloud providers. The University of Witwatersrand (Wits) was IBM's Q Network first African partner. (In South Africa, momentum for national quantum computing activity is partially credited to research and training provided by the IBM Research Lab, which opened in 2016. [89])The University of KwaZulu-Natal has an educational agreement for quantum computing with Microsoft and uses Amazon AWS Braket. The Center for High Performance Computing has a relationship with Intel and uses their quantum computing simulation software. [90]

- **Qatar** recently announced a partnership with Xanadu Computing, a Canadian start-up. While Xanadu sells quantum computing hardware, the partnership will focus on using Xanadu's cloud-based software for education and workforce training.[91] (Qatar's $10 million initiative is based at Hamad Bin Khalifa University and financed by Barzan Holdings, the procurement arm of Qatar's defence ministry.[92])

- In the **United Arab Emirates**, the Quantum Research Centre announced an agreement with IonQ, which will provide access to IonQ's Aria computer for the testing and development of quantum algorithms.[93]

This suggests that high-income G-77 states will be able to negotiate partnerships and more bespoke access with cloud service start-ups. Meanwhile, a wider range of states will access quantum cloud services from large incumbent cloud providers.

However, any access will depend on provider terms of usage and restrictions, which are often guided by U.S. export control targets. For example, IBM's quantum cloud services are not available to individuals ordinarily resident in or who access its services from Afghanistan, Bahrain, Myanmar, China (including Hong Kong), Cuba, Iran, Pakistan, Qatar and Vietnam, among other G-77 states.[94] (Many of these states have some academic activity underway but do not have sovereign quantum computing ambitions; they would likely need quantum cloud services to engage with the technology).

At this point in time, all U.S.-based cloud computing incumbents have introduced quantum cloud services, and offer their customers access to early-stage quantum computing hardware, and training and networking opportunities.

Case studies

Amazon Braket is a fully managed quantum computing service designed. It provides AWS customers access to quantum computing technologies from multiple quantum hardware providers, including superconducting, trapped ion, neutral-atom, and photonic quantum computers. The list of AWS providers include IonQ, Oxford Quantum Circuits (OQC), QuEra and Rigetti.[95] AWS provides these services to customers from the G-77, including Argentina, Chile, India, Nigeria, Mexico, Oman, Peru, Taiwan and Thailand.[96]

Microsoft's Azure Quantum Network works with governments, scientific institutions, and public-private coalitions globally.[97] Its Cloud Services allows partners and clients to explore scaled quantum computing and use state-of-the-art cloud tools and learning resources to learn how to build and refine quantum algorithms. Microsoft's Azure Quantum Computing offers access to a portfolio of hardware from IonQ, PASQAL, Quantinuum and Rigetti. Its G-77 customers include those in Chile, Colombia, India, Indonesia, Kenya, Malaysia, Nigeria, Saudi Arabia, Singapore, South Africa, Thailand and Vietnam.[98]

Google's Quantum AI lab provides Quantum Computing Service,[99] which offers customers access to Google's quantum computing hardware. Programs are written in Cirq, an open-source quantum computing program language, and run on a quantum computer in Santa Barbara, California. Currently, access is only granted to those on an approved list; the list is not public. [100]

All of these providers restrict cloud access in specific countries, stemming from U.S. export control targets.

Desk research suggests that IBM has the largest quantum cloud computing footprint within the G-77. The company's quantum computing activity is driven through its Quantum Network (Q Network), a global network of 250+ stakeholders who can make use of IBM's quantum cloud services, educational materials, and training with IBM staff. Q-Network is active across at least 12 countries within the G-77. In Latin America, members include Uruguayan fintech and Brazilian bank Itaú, and companies from Mexico, Chile, and Colombia are negotiating membership.[101] IBM also integrates its cloud offerings with other services. For example, in 2022 IBM and Aramco announced a strategic collaboration to establish an Innovation Hub in Riyadh, Saudi Arabia. The partnership focuses on applying emerging technology, including quantum computing, to the energy sector, and extends to IBM's consulting services.

IBM's Q-Network and G-77 state outreach can be understood in relation to the company's broader strategy to compete in cloud services. Currently, IBM has less than 5% of the cloud computing market, which is dominated by Amazon, Microsoft, and Google. [102] In 2018, IBM's CEO said that the company would bet heavily on emerging technologies like blockchain and quantum computing and make them available through the cloud.[103] At the 2023 G7 summit, IBM announced a $100 million, 10-year partnership with the University of Tokyo and University of Chicago to develop a 100,000 qubit quantum-centric supercomputer.[104]

Commercial cloud computing services are a critical access and training point for G-77 states. However, overreliance on commercial cloud providers, especially current cloud providers, can deepen existing structural dependencies and asymmetries with new technologies, including through current access restrictions.

Cloud Computing and Competition

Currently, the computing stack is controlled by a small number of dominant firms. A handful of companies control chip design, chip fabrication and data centres on which the entire AI and machine learning ecosystem is built, whether that is proprietary algorithms that require scarce state-of-the-art computing chips or start-ups that use APIs run on cloud services. Commercial access to cloud computing infrastructure is controlled by big technology companies: Google through Google Cloud; Microsoft, through Microsoft Azure; and Amazon, through Amazon Web Services. This has long raised concerns about anti-competitive effects from dominant actors who work to protect their market position.

The private U.S.-based companies investing heavily in quantum computing R&D and making initial forays into quantum cloud computing are the same actors with existing cloud computing dominance. The AI Now Institute predicts: "Paradigm shifts in compute development, such as neuromorphic computing or quantum computing, could create an entirely new market structure and much higher compute capacity. However, we have yet to see these paradigms truly emerge as capable, let alone as scalable or commercially viable—*and if they did emerge, the likelihood is that they would be the product of investments by the same firms already dominant in compute*" (emphasis added).[105]

However, regulators have begun to pay attention. In the U.S., regulators have begun a review of cloud computing.[106] In the U.K., regulators have begun a formal investigation of Amazon and Microsoft.[107] In the E.U., the Data Act applies new rules to cloud providers.[108] These efforts may change the cloud marketplace for quantum computing.

Simultaneously, there are sovereign infrastructure initiatives to reduce reliance on U.S.-based cloud providers. In 2023, the European Commission approved €1.2 billion for a European cloud computing project.[109] There is also the European High Performance Computing Joint Undertaking which signed agreements with six EU Member states to host and operate quantum computers.[110] (Currently, European cloud service providers have limited global reach. A recent study of cloud service providers globally only featured one European company, OVHcloud, which ranked 8th in the world. OVHcloud operates in 17 locations with data centres situated across nine countries – France, Canada, United States, Germany, Poland, United Kingdom, Australia, India, and Singapore.[111] The list was otherwise populated by U.S. and Chinese entities.)

- Chinese cloud computing providers have a global presence. At present, they do not seem to be pursuing the same global quantum cloud computing strategy as their U.S. counterparts.

In recent years, Chinese cloud service providers have experienced rapid growth. Huawei has reinvented itself into a leading cloud services provider, while other Chinese companies – such as Alibaba, Tencent and Baidu – are following suit to capture the global market. Chinese cloud providers operate in the United Kingdom, Japan, Australia, the Philippines and South Korea, and are making major inroads in developing nations across Southeast Asia, Latin America and Africa.[112] For example, Huawei has a core data centre in Saudi Arabia for cloud services in North Africa, the Middle East, and Central Asia.[113] In Southeast Asia, Alibaba, Huawei and Tencent run more availability zones than AWS, Google or Microsoft, with plans to invest hundreds of millions more in the region in the coming years.[114] In Latin America, Chinese cloud providers are growing at more than 60% per year, with Huawei Cloud customers in the region doubling in 2021 alone through two data centres in Mexico and others in Peru, Chile, Argentina, and Brazil.[115] Reports indicate that the Chinese government is investing heavily in targeted strategic industries, including cloud computing. In addition, Chinese cloud providers are reportedly subsidised by the government, allowing them to undercut competitors on price and expand internationally.[116]

If the technology is developed to sufficient maturity (and can be commercialised), it can be assumed that Chinese companies will introduce quantum computing services through existing cloud service infrastructure. However, they have yet to package and market early-stage quantum computing hardware like their U.S. counterparts. As mentioned previously, Chinese industry efforts appear closely linked to the state. Additional quantum cloud computing activity seems to focus on domestic users. For example, Alibaba launched an 11-qubit quantum cloud computing service with the Chinese Academy of Sciences. This was made publicly available on the Alibaba Cloud Quantum Development Platform, a simulator-driven development tool for quantum algorithms and quantum computers. [117]

China's commercial quantum cloud activity suggests that G-77 states will rely on large U.S. quantum cloud providers initially, unless they face access restrictions.

4. Additional Insights and Considerations

- G-77 states often engage with quantum technologies through academic research and teaching.

As can be seen, many G-77 states have some form of academic research activity and partnerships around quantum technologies. These are often housed within specific institutions and departments that have a history of scholarship in quantum science, especially theoretical quantum physics, quantum chemistry and quantum optics.

Many countries are also exploring dedicated academic programs on quantum technologies. South Africa has launched specialised master's degrees to accelerate research training,[118] and experts in Mexico have recommended offering a diploma in quantum technologies focused on undergraduate students in engineering, physics, and related fields.[119] Countries offering quantum degrees at a Bachelor or Master's level include Argentina,[120] Azerbaijan,[121] Bahrain,[122] Cameroon,[123] Chile,[124] Colombia,[125] Costa Rica,[126] Cuba,[127] Ecuador,[128] Egypt,[129] Ethiopia,[130] , Ghana,[131] Honduras,[132] Qatar,[133] Pakistan,[134] and Thailand.[135]

As certain states prioritise quantum computing software development, it is likely that new curriculum and degree programs will shift to align with necessary skills and training. For example, South Africa has most of its quantum expertise within its physics departments, some in chemistry, and little activity in engineering.[136] Moving forward, we can expect that academic programs and training will look to bolster engineering departments.

Academic activity is often formalised through national quantum strategies. Brazil and Pakistan have announced national quantum strategies, and South Africa's national quantum strategy is forthcoming. In each of these countries, academic institutes often guide or direct programming. For example, South Africa's Quantum Technology Initiative will be driven by a university-led research consortium. [137] Other examples of universities driving quantum activity and research at national level are found in Algeria,[138] Mexico,[139] Brazil,[140] and Pakistan.[141]

Case Studies

Brazil

In December 2022, the Brazilian government announced an R$60 million investment in EMBRAPII, a government agency to create a Competence Centre in Quantum Technologies.[142,143] The Center will be hosted at Senai Cimatec in Salvador, [144] and advance research and the training of skills in quantum technology in Brazil.

Senai Cimatec will support R&D in quantum technologies, training and degrees, and support quantum technology activities in Latin America. In addition, it will support an open innovation environment for start-ups, involving national and international partnerships and associated companies. The wider goal is to develop research activities according to market needs, in order to best position Brazil globally.[145]

Pakistan

In August 2023, Pakistan's Ministry of Planning Development and Special Initiatives announced the establishment a National Centre for Quantum Computing (NCQC). This Centre, which forms part of a wider digital policy agenda, is intended to support innovation in quantum computing and connect academic research with industry application. The

NCQC complements other centres of excellence focused on fields like artificial intelligence and nanotechnology, and is similar to approaches taken in China and India, where activity in quantum technologies is coordinated through government initiatives.

The NCQC and other centres will be hosted across several universities and research institutes. One priority is to leverage existing academic activity in Pakistan and fund the creation of a knowledge economy, including through excellence in quantum technologies.

- 'Cloud access' states are looking to engage with quantum technologies by leveraging existing expertise and networks, especially in metrology.

While not quantum computing-specific, many countries across the G-77 have expertise in quantum sensing through metrology, the scientific study of measurement. G-77 states have strong metrology-based international networks, and experience informing and applying metrology standards. This is also active area for South-South cooperation and knowledge transfer, some of which is led by Brazil with other Portuguese-speaking countries. Countries across the G-77 recognise this as an advantage and have incorporated quantum sensing within their national roadmaps.

Case Studies

Brazil
Brazil's National Institute of Metrology, Quality and Technology (INMETRO) is a leading metrology institute at the international level, which has developed a quantum vector digital voltmeter.[146] INMETRO enjoys partnerships with stakeholders across the globe, including the United Nations Conference on Trade and Development (UNCTAD) and the World Trade Organisation (WTO), with which it collaborates on standards setting procedures related to different categories of products.[147] In the context of Brazil's broader quantum technology investment of R$ 60 million, Brazil is developing quantum projects in the area of sensory systems.[148]

Mexico
Mexico has substantial expertise in quantum sensing and precision measurement. This has specific applications for underground resource exploration (such as oil), as well as in the monitoring of volcanological and seismological risks. A national multi-institutional collaboration has developed 'Grávico', aiming to build a portable atomic gravimeter.[149] The device is achieved with a minimum of optical components, which reduces cost, size and weight, making it competitive internationally. With minor variations, the same design can be transformed into other sensors: atomic clocks, magnetometers, accelerometers and gyroscopes. It is expected to have the first functional prototype within two years.[150]

South Africa
South Africa has six national research centres participating in academic projects on quantum metrology standards. [151] The centres collaborate closely with international partners, such as the U.S.' National Institute for Standards and Technology.[152] Over the past decade, such partnerships have led to academic publications in journals including *Nature*.[153]

Thailand

The National Institute of Metrology (NIMT) in Thailand has initiated three research projects focused on measurement standards, including an optical atomic clock of Ytterbium ions, a quantum impedance bridge and a Kibble balance.[154] NIMT collaborates with world-leading metrology institutes and quantum technology research institutes in Japan, Korea, Singapore, and Germany.[155]

- Individual researchers often drive domestic quantum computing activity, leveraging their access to international science and expert networks.

In states without a national quantum computing strategy, key individuals play an especially critical role to support domestic quantum computing ecosystems. These individuals are typically academics who leverage their own scientific networks based on personal research interests and areas of expertise. They initiate international academic partnerships and collaboration, coordinate domestic initiatives, and are critical to developing scientific momentum and interest that can lead to national quantum strategies.

Such researchers often have limited opportunities to participate in state-negotiated bilateral or multilateral arrangements with the U.S. or G7 on quantum technologies due to geopolitical and economic disparities, the size and relative progress of their countries' quantum technology programs or national security concerns. (It is important to note that Global North states that are not leaders in quantum computing can still participate and access cutting-edge technologies and scientific projects. For example the European High Performance Computing Joint Undertaking, which aims to develop an EU supercomputing data infrastructure and includes quantum computing and quantum simulation infrastructure, is available to European countries such as Montenegro, North Macedonia and Serbia,[156] which do not have a national strategy or national-level quantum computing R&D initiatives).

The specific nature of key individual's professional networks often depends on their specific discipline, training, research interests, career stage, and home institution. Opportunities with organisations such as the Institute of Electrical and Electronics Engineers (IEEE) and The Abdus Salam International Centre for Theoretical Physics (ICTP) are often identified as specific international fora that are open to scientists and engineers from G-77 states and offer high-impact opportunities for professional and academic development.

The Abdus Salam International Centre for Theoretical Physics (ICTP)
Traditional international science research institutions play an important role in engaging researchers from G-77 states in quantum technology. The Abdus Salam International Centre for Theoretical Physics (ICTP) is, along with CERN, one of the world's oldest international research institutions. While CERN's activities are concentrated mainly in developed countries, ICTP has a mandate to focus on the developing world and reduce the educational and scientific divide.

ICTP has partner institutes in Brazil, China, Rwanda, and Mexico, and affiliate centres in Argentina, Cameroon, Rwanda, Morocco, Tunisia, Pakistan, and China. It also has a range of quantum-focused initiatives, including activities like the weeklong ICTP–Quantinuum hackathon,[157] which has participation from researchers across G-77 states.

The Institute of Electrical and Electronics Engineers (IEEE)

IEEE is a professional association with 400,000 members globally.[158] IEEE Quantum is its initiative for all quantum projects,[159] which includes the Quantum High-Performance Computing Working Group. The working group convenes stakeholders from various disciplines – researchers, scientists, engineers, as well as those from academia and government– to achieve reliable and scalable quantum systems for practical applications.[160]

Through conferences and publications, the IEEE could contribute to both informal and formal standards relating to quantum technologies, such as consistent hardware measurements and common software interfaces.[161]

- There is growing international science collaboration focused on quantum computing, including through South-South partnerships.

One of the landmark international quantum computing initiatives is the Open Quantum Institute (OQI), located in Geneva, Switzerland. OQI is a partnership with the Swiss Federal Department of Foreign Affairs, the non-profit GESDA and CERN. Its vision is 'Quantum for All',[162] and it aims to be the first multilateral effort to accelerate applications of quantum computing for the SDGs. CERN will host the OQI through its three-year pilot implementation phase from 2024-2026.[163]

Unlike CERN, which provides infrastructure for science research, OQI will not provide quantum computing hardware. Instead, through industry collaboration – including with IBM Quantum, Amazon Web Services, Microsoft and Pasqal – OQI will provide access to a pool of quantum computers and simulators via the cloud.[164] While it is at an early stage, OQI will likely be a significant initiative for scientists from G-77 states who are looking for community and training around specific application areas related to SDGs, and would benefit from negotiated access to quantum cloud computing. In its design phase, OQI has participated in informal conversations with Brazil, Egypt, India, Mexico, Morocco, Pakistan and Singapore.[165]

In Singapore, the Centre for Quantum Technologies (CQT) has developed a wide network of collaborators at both the individual and institutional level. It actively collaborates with stakeholders from G-77 states, including United Arab Emirates, Taiwan, South Africa, Turkey, Argentina, Chile, Saudi Arabia, Malaysia, Colombia, Indonesia, India, Thailand, Belarus, Botswana, Egypt, Kuwait, Nigeria and Uruguay.[166]

Other South-South quantum science initiatives appear to cluster within the African continent through pan-African initiatives such as Quantum Africa – a conference series that began in 2010 – and Quantum Leap Africa, an African-led, African-driven research centre created by the African Institute for Mathematical Sciences in 2017.[167] Quantum Leap Africa is focused on foundational and applied research, and offers post-doctoral fellowships funded by the Carnegie Corporation of New York. Its director has relationships with ICTP and with the World Economic Forum through the Global Future Council on the Future of Quantum Economy.[168] Quantum technologies research is also supported through existing research initiatives. For example, the Algerian University of Constantine has been awarded a grant by the African Research Initiative for Scientific Excellence (ARISE) to conduct research on quantum applications.[169]

- G-77 states are engaging in post-quantum cryptography and quantum key distribution initiatives.

A major potential impact area for quantum computing is, of course, quantum decryption. This is often framed in terms of state-led decryption; however, cloud-computing reliant states are more likely to be impacted, rather than to be instigators, of such attacks.

In the Global North, post-quantum cryptography efforts are being driven by the U.S. Department of Commerce's National Institute of Standards and Technology (NIST). NIST's post-quantum cryptography initiative will specify one or more unclassified cryptographic algorithms capable of protecting information after the advent of quantum computers. In China, a parallel initiative is underway. The Chinese Association for Cryptologic Research (CACR) held a post-quantum cryptography competition and announced its results in early 2020.[170] It is generally believed that most G-77 states will adopt the standards established by international standards bodies like the European Telecommunications Standards Institute (ETSI). In practice, it is likely that adoption of post-quantum cryptography will be driven by commercial technology providers. In September 2023, a new coalition of companies – with IBM Quantum and Microsoft among the founding members – was launched, with the goal of supporting public adoption of NIST standards and rolling them out within their products.

Nonetheless, across the G-77, cloud-computing reliant states are interested in actively securing information through quantum communications and quantum key distribution approaches.

Case Studies

Brazil: Post-Quantum Cryptography in Payment Systems

In 2020, the Central Bank of Brazil launched an electronic payment scheme called Pix. Following international efforts and technological innovations in the field of quantum cryptography, the Central Bank conducted a feasibility study to evaluate post-quantum cryptography (PQC) algorithms for the Pix system. The team ran a series of tests evaluating the Picnic PQC algorithm against Pix's requirements, focusing on security, performance and cryptographic agility.[171] This work was delivered in 2022 by Brazil Quantum with the support of Microsoft Brazil and the Central Bank's technology team.

Mexico: Quantum Key Distribution

The University of Guanajuato has proposed that it can provide training and support for a quantum cryptography system. The proposal focuses on government and industry and covers: the ideal and real behaviour of the components for a quantum key distribution system; the global operation of such a system; and security analysis. The university would use technology that is operable at the prototype level for training and demonstrations. The proposal identifies that quantum key distribution methods will become more prominent in the next decade, and such training would reduce dependencies on foreign companies. [172]

Historically, standards have played a critical role in computing governance[173] and we expect this will remain true for quantum computing. The International Organization for Standardization and the International Electrotechnical Commission will oversee a suite of standards for quantum technologies focused on supporting the quantum marketplace.[174] ETSI's quantum computing working group focuses on practical implementation of post-quantum cryptography algorithms, such as those identified by NIST, including migration and deployment guidance.[175]

International standards bodies have been critiqued their exclusivity, including industry dominance; barriers-to-entry involving membership requirements and membership fees; and business models that rely on proprietary, pay-walled standards.[176] There have been concerns about China's attempts to try influence processes within international standards bodies through vote manipulation, although such practices have been described as the exception rather than the norm.[177] (Separately, there have been concerns about the U.S.' National Security Agency's interference in the NIST standards process.)[178] While standards organisations' membership skews heavily towards the Global North, they often have members across the G-77, offering an avenue for participation in the standards setting processes.

- Across the G-77, states are identifying application areas for quantum computing technologies based on existing sectoral expertise. These are often – but not exclusively – framed by the Sustainable Development Goals.

Beyond cryptography, states are trying to identify application areas that leverage specific competitive advantages.

- In **Brazil** and **Saudi Arabia**, quantum computing has been discussed in relation to the oil and gas industry, including network optimisation and management, reaction network generation and refinery linear programming.
- In **Mexico**, research is underway that applies mathematical models, quantum algorithms, and digital simulation algorithms to the study of genomic medicine. It is led by the Tecnológico de Monterrey and the University of South Florida.[179]
- In **South Africa**, this could be linked through industries where the country is globally competitive, such as mining, industrial manufacturing, agriculture, and food processing.
- In the **UAE**, scientists are engaging on research on applications such as quantum algorithms for drug discovery and navigation devices.[180]

When it comes to G-77 states, technology applications are often framed in terms of Sustainable Development Goals (SDGs). The 17 goals are intended to address global challenges, including Good Health and Well-being, Zero Hunger and Affordable and Clean Energy.

The SDGs offers a framework for positive applications of quantum computing. For example, quantum computing could support:

- **SDG 2: Zero Hunger:** Supporting crops through developing specialised pesticides and herbicides targeting specific species, reducing the need for toxic alternatives.[181]
- **SDG 3: Good Health and Well-being**: Improving pharmaceutical research by supporting DNA sequencing for personalised medicine.[182]
- **SDG7: Affordable and Clean Energy:** Accelerating development of new materials for air capture of CO_2 that helps achieve sustainable energy targets.[183]

(These applications are tentative, based on quantum computers with an advantage over high-performing computers and specific, relevant technical contributions to the SDGs.)

However, applications of quantum computing exist beyond SDGs. In addition, application areas are not necessarily focused on domestic markets. For example, the Uruguayan start-up Quantum-South, founded in 2019 at the University of Montevideo, is a quantum computing software company that offers optimisation solutions for air cargo, maritime cargo, and financial services. It was the first Latin American-based start-up to join IBM's Q- Network.

The company recently developed a successful proof-of-concept project using quantum algorithms with Amerijet International, one of the largest U.S. cargo carriers.[184] Quantum-South has raised less than $5 million to date,[185] which indicates the potential for companies to participate in the global quantum economy even if they are founded in countries without national quantum initiatives or strong funding ecosystems.

- Across the G-77, there is far less private investment in quantum computing technologies and limited commercial funding for start-ups.

Based on the current landscape, we expect quantum computing start-ups in the G-77 to rely on funding from existing high-technology venture capital and private investment funds, especially those with a regional focus. For instance, Savannah Fund, which offers $50,000 - $1 million investments to start-ups in sub-Saharan Africa,[186] or Peak XV Partners (formerly Sequoia Capital India and South East Asia), which has $2.5 billion available for investment.[187] A notable development is ROCX in Thailand, a newly announced $50 million fund launched in partnership with the Israeli VC fund OurCrowd. The early-stage fund will focus exclusively on deep tech, including quantum computing.[188]

Elsewhere within the G-77, we see some private investment from large companies that invest in quantum computing when aligned with sectoral interests. In January 2023, Saudi Arabia's Wa'ed Ventures invested in the Series B funding round for the Paris-based quantum computing start-up PASQAL. (Wa'ed Ventures is the $500 million venture capital fund of ARAMCO, Saudi Arabia's state-owned petroleum company). As a part of the deal, ARAMCO will access PASQAL's quantum computing platform. It may also incorporate PASQAL's technology in future training programs.[189] This suggests that higher income G-77 states may, in the future, be able to position themselves as investors who also have high-impact quantum computing application areas.

However, the Saudi Arabian deal is an outlier; a more widely shared concern is the lack of dedicated quantum technology funding for start-ups and industry. For example, in South Africa, academics highlighted that there are no strategic funding sources dedicated to the support of quantum technologies along the innovation chain, from research through development to commercialisation.[190]

- As quantum computing technology develops further, the following issues could develop into policy priorities for G-77 states:

    - Brain Drain

As can be seen, countries across the G-77 have some level of quantum computing activity – even if the ecosystem is not formalised by a national strategy and funding – and do not typically have robust seed funding environments. This may leave such countries especially vulnerable to emigration, as academic talent and quantum-related skillsets are nurtured within the G-77 but domestic programs are unable to offer sufficient support and opportunities across research, application, and commercialisation.

The G-77 recently identified confronting brain drain as a priority through its Havana Declaration.[191] However, as of writing, brain drain is not often discussed as a risk exclusive to, or exacerbated by, quantum computing education or strategic partnerships.

It is important to note that 'brain drain' is an umbrella term used widely in globalisation, migration, and nationalist discourses, but its net-zero framing can oversimplify the economics of country, region, and community-level migration, including the role of the diaspora and remittances for certain economies. In the high technology sector, brain drain is not limited to the G-77. The EU and Canada have experienced 'brain drain' due to emigration the U.S.,[192] and a specific form of brain drain – with academics moving to industry – has arisen in AI.[193]

However, brain drain poses a specific set of challenge for the G-77 as it concentrates human capital in the most advanced economies,[194] and widens the technological gap for developing nations. At this phase of development, most states are focused on growing domestic quantum computing activity; however, as R&D progresses, brain drain will likely become a more pressing policy issue.

- Supply chain

Countries like Botswana have expressed interest in exploring the potential of nanodiamonds for quantum computing.[195] Given the stage of quantum computing development and heterogeneity of quantum computing research approaches, it is still unclear which specific critical raw materials will be implicated in future supply chains, and how this will differ substantially from materials currently required for advanced semiconductors or hardware manufacturing. (Though some research reveals that certain bottlenecks can be already spotted in the current quantum supply chain.[196]) For example, Helium-3, a rare isotope, is a refrigerant for quantum computing methods – yet innovations in cooling research may bypass or reduce this requirement. While some leading qubit technology approaches require dilution refrigerators, others require high-quality lasers. As the RAND Institute states: "This technological uncertainty means that, in ten years, dilution refrigerators might be a critical link in the quantum supply chain, or they might be completely irrelevant."[197]

Existing technologies are reliant on critical and rare-earth materials, most of which are found within the African continent, including in the Democratic Republic of Congo (DRC), Zimbabwe, Ghana and Namibia. China, through its Belt and Road initiative and ownership of mining infrastructure, has strong positions in mining and processing critical minerals and materials. It currently has 90% of the world's refining capacity for rare earth elements required for high-powered magnets and has imposed a licensing regime on gallium and germanium products, which are used for chip production.[198]

Against a backdrop of the Russian-Ukraine war and China's dominance in specific raw materials, the U.S. and EU have been moving to secure their critical raw materials supply chains. The EU, through its Critical Raw Materials Act and Global Gateway strategy, is forming strategic partnerships across G-77 states, including with Chile, which has lithium deposits; the DRC, which produces 70% of the world's cobalt;[199] and Namibia, which has lithium deposits and rare earth materials required for magnets (Lithium is used in electric batteries and is a crucial material for clean energy and sustainability objectives).

Simultaneously, G-77 states are looking to secure positions further along the supply chain. In December 2022, Zimbabwe banned lithium ore exports, only allowing concentrates to be shipped out. In June 2023, Namibia banned the export of unprocessed critical materials, including lithium (in October 2023, the country enforced the ban against Xinfeng Investments, a Chinese mining company suspected of transporting lithium ore for export).[200] It is possible that partnerships will help implement this strategy, although civil society groups have cautioned about the risks involved. AfreWatch, a DRC-based natural resources watchdog warned: "It is very important that Africa is not seen as a reservoir of raw materials that continues to be exploited by Westerners to create added value elsewhere."[201]

In July 2023, Afrewatch and a broad coalition of civil society organisations, based primarily in resource-rich countries within the G-77, submitted an open letter to the European Union identifying risks of EU legislation and partnerships: "[EU legislation] will have a direct impact on our health and well-being, cultural practices, traditions and values, livelihoods, and environment. People are regularly killed attempting to safeguard the environment we rely on.".[202] The authors advocated for effective human rights safeguards, meaningful community participation, and for partnerships that support development, including through climate finance, and knowledge and technology transfer.

While it is too early to declare the specific impacts of quantum computing on the global supply chain, the existing AI and high-technology supply chain has demonstrated the potential intersection with G-77 states, especially exploitative labour practices. This ranges from the mining of critical raw materials, as described above, to poor labour conditions for Kenyan contractors who label data required for large language models.[203] When anticipating the impacts of quantum computing, attention should be paid to existing dynamics and vulnerabilities, including dependencies linked to colonisation.

- Environmental impact of quantum computing

Quantum computing is often discussed in terms of scope for positive impact on the environment and computing efficiency. (The energy consumption of noisy intermediate-scale quantum computers is orders of magnitude smaller than a supercomputer solving the same problem.)[204] Given the heterogeneity of quantum computing research approaches and stage of technology development, it is still too soon to calculate the exact impact of quantum computing on the environment. However, there is already an environmental cost linked to the technology's research and development. In addition, concerns have already been raised in relation to cooling requirements of quantum computers. Cryogenic cooling systems, which provide the extremely low temperatures required to operate quantum computers, are energy intensive and consume large amounts of water.[205]

Such analysis can be linked to developments in AI governance and regulation, which offer one model for future quantum computing governance. The AI Act recognises the tremendous energy requirements for training and running AI models and requires developers to make their models more energy efficient and to include logging capabilities to record energy consumption.[206]

Early work on quantum computing governance by The World Economic Forum has identified the environmental cost of quantum technologies as an area of focus: sustainability is one of the Quantum Computing governance principles, which also recommends establishing an energy consumption metric for quantum technologies.[207] In Singapore, the Centre for Quantum Technologies recently hosted an international workshop on quantum energy, which included discussion of standards for energetic efficiencies.[208]

Finally, it is important to note that the climate crisis disproportionately impacts G-77 states. While countries in the Global North are leading contributors of carbon emissions, the Global South tends to experience the disproportionate impacts of this with extreme weather, droughts, floods, and pollution.[209]

5. Recommendations

1. Support in-depth documentation of domestic quantum computing ecosystems within G-77 states.

This report provides a high-level assessment of diverse G-77 states to demonstrate the variety and depth of existing quantum computing activity and the technology's implications beyond global superpowers. Further research could support detailed country-level analysis by in-country experts. The findings could support local stakeholders – from scientists to policymakers – as they develop domestic quantum ecosystems and pursue advocacy in international fora. In the medium term, the findings could support planning for future investment vehicles or serve as roadmaps for G-77 states as they prepare to engage with quantum computing.

Sample activities

- Country-specific focus groups and surveys of quantum computing stakeholders, especially researchers, to understand areas of expertise, areas of interest, current funding, and gaps.
- Develop standardised methodologies, such as:
    - A strength-weakness-opportunity threat framework for domestic quantum computing initiatives, drawing on similar assessments conducted in Mexico and South Africa.
    - A framework to map specific technical and academic requirements across the quantum computing value chain. This could be used to support analysis of current domestic capabilities.
    - A stakeholder mapping to catalogue activity linked to government entities, regional and federal bodies; domestic and multinational industry players; and commercial cloud providers.

2. Support meaningful G-77 state participation in quantum computing governance initiatives

The report suggests a two-fold approach: a more expansive view of G-77 state participation within existing quantum governance initiatives; and the introduction of quantum computing within other governance initiatives, such as those focused on SDGs. It also indicates that 'cloud access' states may develop a set of policy priorities that are distinct from states with sovereign quantum computer aspirations.

It is inevitable that opportunities to engage with quantum computing governance will shift based on milestones in quantum computing R&D. For example, assuming technology maturity, governance mechanisms will likely shift from principles to best practices and later, regulation, as we have seen with AI governance.

Sample activities

- Map existing quantum computing governance initiatives and criteria for participation, including expertise requirements. Support analysis to determine skills gaps, if any, and identify relevant training.

- Map existing skills and networks related to quantum sensing (especially metrology) and quantum communications. Assess feasible opportunities to extend this expertise to newer quantum governance initiatives.
- Map needs and opportunities for G-77 states that will not access quantum computing at all but, nonetheless, will be impacted by the technology. This is a slightly more speculative activity as it assumes long-term development and impact of the technology; however, the exercise could expand groups of G-77 stakeholders and support development of future policy priorities.
- Identify appropriate venues to introduce quantum computing in present-day initiatives focused on:
    - Climate change and environmental impact of high technology
    - Skills-based migration and brain drain
- Conduct a detailed study on a specific high-impact industry for quantum computing, such as pharmaceuticals, to identify specific marketplace and supply-chain dynamics that could impact access within the G-77.
- Anticipate different stages in quantum computing governance based on R&D milestones, identify the relevant bodies/organisations that will engage at each stage, and map opportunities for G-77 states. This could be modelled on lessons from AI governance.
- Analyse developments in the quantum computing stack to identify dependencies and risks that could, in the future, increase barriers-to-entry or adversely impact 'cloud-access' states that are focused on software applications.

3. Study the impact of commercial quantum cloud providers on G-77 states

Rudimentary commercial quantum cloud computing has been crucial for supporting research and education within the G-77. It has allowed students and researchers in states without sovereign quantum computer aspirations to participate in and prepare for the technology. However, this is an area that should be studied critically, including through assessments of existing restrictions and limitations on quantum cloud services within the G-77; documenting or forecasting specific research and skills gaps due to an overreliance on commercial cloud computing; and more broadly, anticipating the impact on the G-77 if current dominant cloud computing players further entrench their positions.

Sample activities

- Conduct a detailed review of commercial quantum cloud offerings – such as hardware portfolio, current pricing models, educational materials and training, analysis of restrictions and terms and conditions – within specific G-77 states.
- Map research and commercial interests in domestic quantum computing initiatives against capabilities available through cloud computing services.
- Extend analysis of current cloud computing anti-trust and competition efforts to include quantum computing.

4. Study supply chain developments and anticipate impacts on G-77 states

Within the report typology, the 'Procure' category is the most nascent; however, it could eventually grow into a large category of countries. While it is too soon for a detailed evaluation of the quantum computing supply chain, this is an area that should be monitored.

Sample activities

- Map commercial availability of components across the quantum computing supply chain (hardware and software), pricing, and restrictions on sale and usage.
- Assess findings against specific G-77 states' priorities and quantum computing strategies to identify or anticipate possible impacts.
- Map R&D approaches against critical raw material supply chains that may impact G-77 states.

5. **Engage with a wider set of disciplines and methodologies, including decolonial and postcolonial approaches, to inform technology governance and development.**

The previous recommendations focus on present-day dynamics, including realities bound by geopolitics and existing technical infrastructure. However, quantum computing is not a present-day technology, which creates opportunities to engage with a wide circle of scholars and critical technologists who apply a range of methodologies, including speculative and creative interventions, to inform technology governance and development.

Such activity could engage a wider variety of G-77 academics and civil society, including those who apply decolonial and postcolonial approaches to computing, moving away from narratives of North-South relations based solely on technical deficit. Such approaches offer pathways to subvert or resist coloniality by producing alternate analyses of contemporary power relations, situating G-77 states as the centre.[210]

Sample areas of interest

- Reimagining technology governance bodies, including different configurations of decision-making power.

Decolonial scholarship on AI governance warns of limitations of current global structures and the 'paradox of participation', whereby Global South stakeholders can participate in governance structures while structural harms persist. To support meaningful Global South participation, they recommend structural reform, including financial allocation and redistribution of decision-making.[211] This body of work could be engaged with and extended in relation to quantum computing.

- Identifying forms of quantum computing access beyond sovereign computers and the commercial cloud.

Quantum computing development is a capital-intensive endeavour that is being driven by states and industry. This paper presents two forms of access for quantum computing: sovereign quantum computers and commercial cloud access. While these correspond to real-world dynamics around compute and infrastructure, they also present a future technology that automatically reinforces existing dynamics. Alternate models of development and access could explore more speculative options, including those driven by G-77 states.

- Restrictions, including moratoria and bans, on quantum computing R&D.

There is growing critique around the assumptions of progress and advancement that often underpin technology development.[212] Researchers ask whether specific technologies should be developed at all, which can include evaluating costs and risks, such as environmental costs and the opportunity costs of capital-intensive R&D. This could be assessed using G-77 states as an anchor, introducing new frames for discussions of quantum computing equity and global development.

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Annexes

Annex 1: G-77 states with quantum technology activity.

- **National Quantum Strategy.** A national government has announced a coordinated strategy on quantum technologies, which includes specific activities, objectives, and a funding commitment.
- **Building a Quantum Computer.** A national government supports the development of a sovereign quantum computer.
- **Global or Regional Quantum Initiative(s).** Country representation in a global or regional quantum technology initiative. This includes individuals who participate in a personal capacity.
- **Public-Private Partnership(s).** A national government has announced a private sector partnership involving access to and/or the development of quantum technology in its country.
- **Academic Activity.** A country has academic initiatives or networks on quantum technology, or academic research within a university on quantum technology that is supported or funded by its national government.

	Description of Activity
Africa	
Algeria	Academic Activity and Regional Quantum Initiative The University of Constantine is hosting the Constantine Quantum Technologies Collaborative, which is a collaborative research group intending to understand quantum systems and mimic their properties on classical and quantum simulators.[213] This Algerian Collaborative is supported by the African Research Initiative for Scientific Excellence (ARISE).[214] Their research projects focus on different areas, including Topological Quantum Computing, Quantum programming languages, Tailored variational quantum algorithms (VQAs), like VQE, as well as quantum simulation systems.
Cameroon	Academic Activity and Regional Quantum Initiative Cameroon hosts one of the five centres of excellence of the African Institute for Mathematical Sciences (AIMS).[215] This institute is a network of centres of excellence for post-graduate training in mathematical sciences. As part of its work, AIMS has created Quantum Leap Africa (QLA) which is a quantum research centre focused on researching and training in the field of quantum technology.[216] The Cameroonian government is one of the institutional partners for AIMS Cameroon.[217] AIMS offers students the possibility to obtain a degree of *Master of Science in Mathematical Sciences*. One of the courses in this M.Sc.'s curriculum is Open Quantum Systems. It is concerned with the theory of quantum systems under the influence of external noises. The theory describes generic noise induced features, such as decoherence, entanglement, and thermalization. They are of core interest in various branches of science: in quantum information and computation, chemistry, material sciences and even in biology. Basic familiarity with this theory is considered to be a good and necessary foundation for a more advanced understanding of most modern quantum sciences.[218]

Egypt	<u>Global Quantum Initiative</u> Egypt took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[219] <u>Academic Activity</u> QEgypt is a community for researchers and universities in Egypt to collaborate and raise awareness on quantum technologies.[220] The community was founded in 2021 by the Alexandria Quantum Computing Group at the Faculty of Science at Alexandria University.
Ethiopia	<u>Academic Activity and Regional Quantum Initiative</u> Through Wit University's (South Africa) membership of the IBM Q Network, the Addis Ababa University is able to access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[221] Moreover, the Department of Physics in the College of Natural Sciences Arba Minch University provides a M.Sc. diploma in Physics with special courses on quantum mechanics, as well as quantum optics.[222]
Ghana	<u>Academic Activity and Regional Quantum Initiative</u> Ghana hosts one of the five centres of excellence of the African Institute for Mathematical Sciences (AIMS).[223] This institute is a network of centres of excellence for post-graduate training in mathematical sciences. As part of its work, AIMS has created Quantum Leap Africa (QLA) which is a quantum research centre focused on researching and training in the field of quantum technology.[224] The Ghanian government is one of the funders for AIMS Ghana.[225] In addition, through Wit University's (South Africa) membership of the IBM Q Network, the University of Ghana can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[226] QGhana is a group of Ghanian researchers, lecturers and educators aiming to educate, promote and raise awareness of quantum science and technologies.[227] The group was founded in 2023 and hosts workshops, seminars, webinars, conferences and other research activities. Lastly, the University of Cape Coast offers a Master of Philosophy in Physics program, which offers elaborated courses on advanced quantum mechanics, as well as quantum statistics.[228]
Kenya	<u>Academic Activity and Regional Quantum Initiative</u> Through Wit University's (South Africa) membership of the IBM Q Network, the University of Nairobi can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[229]
Morocco	<u>Global Quantum Initiative</u> Morocco took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[230] <u>Academic Activity</u>

	The Moroccan Network of Quantum Information (MN-QI) is a network coordinating the work of researchers in the quantum field from different universities in Morocco.[231] Its activities include organising and participating in global programmes and events, as well as coordinating workshops, talks and seminars. Members of this network include Mohammed V University, Hassan II University, Sultane Moulay Slimane University, Moulay Ismail University, Ibn Tofail University, Ibn Zohr University and Adelmalek Essaadi University.
Nigeria	Academic Activity and Regional Quantum Initiative Through Wit University's (South Africa) membership of the IBM Q Network, the University of Lagos, the University of Ibadan and Obafemi Awolowo University lle-Ife can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[232] QNigeria is a community of students, physicists, engineers, software developers, researchers and other professionals collaborating on quantum technologies in Nigeria.[233] Founded in 2021, its activities include webinars, talks, workshops and hackathons.
Libya	Academic Activity QLibya is a non-profit organization bringing together quantum computing researchers in Libya to advocate and build quantum education programmes.[234]
Rwanda	Academic Activity and Regional Quantum Initiative Rwanda hosts one of the five centres of excellence of the African Institute for Mathematical Sciences (AIMS).[235] This institute is a network of centres of excellence for post-graduate training in mathematical sciences. As part of its work, AIMS has created Quantum Leap Africa (QLA) which is a quantum research centre focused on researching and training in the field of quantum technology.[236] The Rwandan government is one of the institutional partners for AIMS Rwanda.[237] Through Wit University's (South Africa) membership, the University of Rwanda can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[238]
Senegal	Academic Activity and Regional Quantum Initiative Senegal hosts one of the five centres of excellence of the African Institute for Mathematical Sciences (AIMS).[239] This institute is a network of centres of excellence for post-graduate training in mathematical sciences. As part of its work, AIMS has created Quantum Leap Africa (QLA) which is a quantum research centre focused on researching and training in the field of quantum technology.[240] The government in Senegal is one of the institutional partners of AIMS Senegal.[241] In addition, through Wit University's (South Africa) membership of the IBM Q Network, Cheikh Anta Diop University can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[242]
South Africa	Academic Activity and Regional Quantum Initiative In June 2019, University of the Witwatersrand (Wits University) joined the IBM Q Network as its first African academic partner.[243] The

	university shares a campus with IBM research in Johannesburg where students are able to access the company's quantum computers via the cloud to run experiments related to "the efficient use of resources based on optimization problems".[244] Wits University's membership also provides an avenue for academic collaboration with other South African universities that are part of the African Research Universities Alliance (ARUA). South Africa hosts one of the five centres of excellence of the African Institute for Mathematical Sciences (AIMS). This institute is a network of centres of excellence for post-graduate training in mathematical sciences. As part of its work, AIMS has created Quantum Leap Africa (QLA) which is a quantum research centre focused on researching and training in the field of quantum technology. QSouthAfrica, is a community of quantum enthusiasts focused on advancing quantum computing in South Africa.[245] It was founded in 2023 by members of Stellenbosch University, the University of KwaZulu-Natal and Wits University. South African is also home to the South African Quantum Technology Initiative which is aims to bring together universities in the country to conduct research in quantum technology and grow the industry in South Africa. This initiative is funded by the Department for Science and Innovation within the South African government. [246]
Tanzania	<u>Academic Activity and Regional Quantum Initiative</u> Tanzania hosts one of the five centres of excellence of the African Institute for Mathematical Sciences (AIMS).[247] This institute is a network of centres of excellence for post-graduate training in mathematical sciences. As part of its work, AIMS has created Quantum Leap Africa (QLA) which is a quantum research centre focused on researching and training in the field of quantum technology.[248] In addition, through Wit University's (South Africa) membership of the IBM Q Network, the University of Dar es Salaam can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[249]
Tunisia	<u>Academic Activity</u> QTunisia is a community of quantum enthusiasts promoting and raising awareness about the potential of quantum technologies in Tunisia.[250] Its activities include organising workshops and hosting talks and webinars. The community was founded in 2020 by students and academics in the quantum field from Tunisian universities.
Uganda	<u>Academic Activity and Regional Quantum Initiative</u> Through Wit University's (South Africa) membership of the IBM Q Network, Makerere University is able access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[251]
Zimbabwe	<u>Academic Activity</u>

	Founded in 2021, QZimbabwe is a community of quantum enthusiasts promoting and raising awareness about the potential of quantum technologies in Zimbabwe.[252]
Asia	
Azerbaijan	Academic Activity Khazar University provides bachelor's degrees covering quantum physics.[253]
Bahrain	Academic Activity The Arabian Gulf University provides for a M.SC. degree in the field of quantum technologies. The program's main objective is to allow students to gain a deep understanding of the specificities of quantum algorithms, to master the design and the architectures of quantum computers, to design, implement and maintain quantum information systems, as well as to conduct innovative applied research in the field of quantum computing applied in particular to artificial intelligence and cybersecurity that have concrete impact on industries.[254]
China	National Quantum Strategy The CCP's 14th Five Year Plan, which was passed in March 2021, sets out the economic goals for China for 2021 to 2025.[255] The development of quantum technology is included as part of these plans, including quantum communications, computers, simulators and precision measurement technology. In particular, China aims to establish national laboratories and industrial policies focused on quantum information.[256] It is also seeking to deepen collaborations between military and civilian in science and technology regarding, among other things, quantum technology.[257] China has committed $15.3 billion in public funds to quantum technology development.[258] Building a Quantum Computer China's policy does include ambitions to deploy quantum computing and quantum communication technologies.[259] This includes the country's latest quantum computer called 'Wukong',[260] and its first quantum-enabled satellite 'Micius' capable of quantum-key distribution.[261] Additionally, China has reportedly begun producing dilution refrigerators needed for superconducting quantum computing.[262] Public-Private Partnership China's latest quantum computer was developed by Origin Quantum Computing Technology, a Chinese quantum start-up.[263] The company is also aiming to build a 1,000 qubit computer by 2025.[264] The Chinese Academy of Sciences (CAS), a national research institute, hosts the Center for Excellence in Quantum Information and Quantum Physics.[265] CAS also has a lab with Alibaba providing quantum computing services via the cloud.[266] Academic Activity The University of Science and Technology of China (USTC) worked on the 66-quibit Zuchongzhi 2 which, until Wukong, was China's most advanced quantum computer.[267]

India	National Quantum Strategy In 2020, the Department of Science & Technology in India announced a National Mission on Quantum Technologies & Applications with a budget of Rs 8000 Crore (over $960 million) over a five-year period.[268] Then in April 2023, the Indian government approved a $730 million funding package for the mission.[269] The purpose of the NMQTA is to encourage industrial R&D via research hubs each focused on different aspects of quantum technology. This includes quantum computing and simulations, quantum communications, quantum sensing and metrology, and quantum material and devices.[270] Building Quantum Computer Among the aims of the NMQTA is to build quantum computers with 50-1,000 physical qubits by 2031. Global Quantum Initiative India took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[271] Stakeholders from India take part in WEF's Quantum Computing Governance[272] and the Institute of Electrical and Electronics Engineers.[273] India is also a member of the Quantum Economic Development Consortium (QED-C).[274] Academic Activity The Indian Institute of Science, Indian Institute of Technology Jodhpur, and the Indian Institute of Technology Madras all have partnerships with IBM for quantum computing cloud access and training.[275] Within the Tata Institute of Fundamental Research is the Quantum Measurement and Control Laboratory.[276] The main focus of this lab is investigating quantum phenomena in superconducting circuits. Its researchers have had its work published in several scientific journals, including Nature, and receives funding from the Department of Science and Technology in India. QIndia is a non-profit organisation spreading awareness of quantum technology and engaging people of diverse backgrounds in India.[277] The group organises lecture series, workshops and research projects to create a platform to engage in and learn about quantum computing.
Pakistan	National Quantum Strategy In August 2023, the Ministry of Planning Development and Special Initiatives formally launched three new centres of excellence, including a National Centre for Quantum Computing (NCQC).[278] The purpose of the Centre is to foster an innovation culture, nurture new talent and catalyse "the transformation of Pakistan's digital landscape." It is also hoped that the NCQC serves as a "nexus for academic research, technological innovation, and industry application in the field of quantum computing." During the launch of the NCQC, it was also announced that the Higher Education Commission would have its budget increased to Rs 70 billion (around $245 million).

	<u>Global Quantum Initiative</u> Pakistan took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[279] <u>Academic Activity</u> The NCQC will be established in several universities in Pakistan (though it is unclear which institution will be hosting the NCQC). QPakistan is an initiative bringing together faculty from leading Pakistani universities to create a local community of quantum computation and information practitioners.[280] Universities participating in this initiative include the Institute of Business Administration Karachi, Lahore University of Management Sciences, National University of Science and Technology and Habib University.
Singapore	<u>National Quantum Strategy</u> In 2018, the Singaporean government launched its Quantum Engineering Programme to support research in quantum technology across the country. The programme is coordinated across different research organisations supported by the National Research Foundation, and is based at the National University of Singapore.[281] Under the QEP, Singapore has three national platforms carrying out work in quantum technology: the National Computing Hub, the National Quantum Fabless Foundry and the National Quantum Safe Network.[282] Singapore's budget spent on quantum appears to be 138 million US dollars.[283] <u>Building Quantum Computer</u> The National Computing Hub leads Singapore's efforts to develop quantum hardware and middleware.[284] <u>Global Quantum Initiative</u> Singapore took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[285] Singapore is also a member of the Quantum Economic Development Consortium (QED-C).[286] <u>Public-Private Partnerships</u> The National Quantum-Safe Network works with public and private sector organisations to enhance the network security of critical infrastructure in Singapore using quantum-safe communication technologies.[287] Some of the private sector organisations involved in this work include Amazon Web Services, Hitachi and T-Systems. <u>Academic Activity</u>

	Singapore's Centre for Quantum Technologies (CQT) brings together physicists, computer scientists and engineers to lead the country's research endeavours on the field of quantum.[288] Over the past years, CQT has developed a wide network of collaborators at both the individual and institutional level. The CQT is hosted by the National University of Singapore and also collaborates with Nanyang Technological University and the Singapore University of Technology and Design.
Thailand	<u>Global Quantum Initiative</u> The IEEE Thailand Section Quantum Information Technology consists of Thai IEEE members promoting quantum development within the organisation.[289] This group helped form the Thai Quantum Information (Q-Thai) Forum that works with private and public sector organisations to promote the potential of quantum technology.[290] <u>Academic Activity</u> The Faculty of Science of Chiang Mai University hosts the Research Center for Quantum Technology.[291] This laboratory consists of scientists and engineers focused on quantum atom optics and quantum medicine research. The university also offers graduate programs in quantum science and technology (an international program).[292] The Quantum Technology Foundation (Thailand), a startup based on Bangkok, partners with universities in the country (such as Suranaree University of Technology) to deliver quantum technology education programs for university or high school students.[293] These programs provide participants with credits with partner universities that count towards the fulfilment of degrees at those institutions.
North America	
Cuba	<u>Academic Activity</u> In 2018, the Universidad de las Ciencias Informáticas La Habana provided a special class in the field of Quantum Computing in the context of a Winter School with students ranging from a wide range of backgrounds, such as bioinformatics, cryptography, and physics, among others. [294]
Costa Rica	<u>Academic Activity</u> The Universidad de Costa Rica offers a special M.Sc. in Physics, which includes courses on Quantum theory and applications.[295]
Honduras	<u>Academic Activity</u> The Universidad Nacional Autónoma de Honduras offers a M.Sc. diploma in Physics, including special classes on quantum mechanics.[296]
Latin America	
Argentina	<u>Global Quantum Initiative</u> Stakeholders from Argentina participate in the WEF's Quantum Computing Governance.[297] <u>Academic Activity</u> The La Plata National University,[298] as well as the University of Buenos Aires[299] provide for M.Sc. courses in the field of quantum physics. Moreover, the latter university is also home of the Quantum Foundations

	and Information Buenos Aires (QUFIBA) research group, which studies quantum information and computation, quantum simulations, quantum process tomography, quantum algorithms as dynamical systems, the potential physical realizations of quantum computers, as well as quantum error correction.
Brazil	National Quantum Strategy In December 2022, the Brazilian government announced a $12 million dollars (BRL 60 million) investment in the Brazilian Company of Industrial Research and Innovation (EMBRAPII) to create a Competence Center in Quantum Technologies.[300] The EMBRAPII is a government agency established in 2013 that supports technological research institutions.[301] One year later, in October 2023, it was announced that the Senai Cimatec in Salvador, was selected to be Embrapii's Competence Center in Quantum Technologies.[302]The purpose of the Center is to advance research and the training of skills in quantum technology in Brazil. Chico Saboya, president of Embrapii highlighted that "Senai Cimatec will focus on Quantum Communication, focused on improving data security processes. But, it will also work in Quantum Computing whose benefits are based on carrying out a high load of data processing".[303] The contract with Senai Cimatec will be valid for 42 months and provides for research and development activities in quantum technologies, HR training and qualification for Research, Development and Innovation-related activities in Latin America.. Moreover, it strives to create an open innovation environment for the creation and attraction of startups, involving national and international partnerships and associated companies. The wider goal is to develop research activities according to market needs, in order to better position Brazil in the international scene of R&D activities related to quantum technologies.[304] Global Quantum Initiative Brazil also took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[305] Academic Activity Senai Cimatec, a research institution based in Salvador, was selected as a Centre in Quantum Technologies in accordance with the Brazilian government's strategy announced in December 2022.[306]
Chile	Global Quantum Initiative Chile took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[307] Academic Activity Universidad de Santiago de Chile provides for M.Sc. diplomas in the field of quantum mechanics.[308]
Colombia	Academic Activity

	QColombia is a non-profit organisation advocating for the development of quantum technologies in Colombia.[309] It provides learning and teaching resources for students and others build a community of researchers in the quantum field. Moreover, EAFIT University provides for M.Sc. diplomas in the field of applied physics, with a specific trajectory on Computational Quantum Mechanics. It aims to provide knowledge in Science and Technology with a practical and multidisciplinary approach in areas of quantum mechanics, molecular dynamics, programming and molecular simulation methods.[310]
Ecuador	Academic Activity The Yachay Tech University provides for a M.Sc. degree in Foundational Physics, offering special courses on quantum mechanics.[311]
Mexico	Global Quantum Initiative Mexico took part in the informal discussions on the multilateral governance of quantum computing within GESDA's Open Quantum Institute.[312] Academic Activity The Ensenada Scientific Research and Higher Education Center is a public research centre that is sponsored by the National Council for Science and Technology of Mexico (a government agency).[313] Among its research focuses includes the development of photonic circuits for quantum communication and computing.[314] The Tecnológico de Monterrey, the University of Guanajuato and the University Veracruzana are participating in a research project on the use of quantum algorithms for modelling mutations in the context of genomic medicine.[315] QMexico is a community of students and researchers from Mexico and Colombia developing and promoting educational resources on quantum computing.[316]
Uruguay	Academic Activity In December 2021, the Universidad de Montevideo and Quantum-South, a Uruguayan company leveraging quantum computing software for optimisation problems for air and maritime cargo, entered into an agreement concerning quantum R&D.[317] The agreement is focused on science and technology cooperation focusing on the development of quantum computing applications. Quantum-South was founded by a group of professors and students from the university.
Middle East	
Iran	Building a Quantum Computer In 2019, the Atomic Energy Organization of Iran (AEOI), an Iranian government agency, opened a lab dedicated to quantum physics research.[318] This is part of the government's roadmap for the development of quantum technologies and its application in communication and imaging as well as the construction of new computers and sensors. Use cases for the military are also being explored through a new centre of research established for this purpose.[319] However, in June 2023, the Iranian withdraw an announcement that it

	had successfully developed a quantum processor after the product that was revealed was actually identified as an ARM-based development board that is widely available online.[320] Academic Activity QIran is a community in Iran focused on popularising quantum computing and science in Iran.[321] Founded in 2022, its activities include tutorial lab sessions, workshops, short-term research projects and hosting events with academics and experts in the field.
Saudi Arabia	Global Quantum Initiative Stakeholders from Saudi Arabia participate in the WEF's Quantum Computing Governance.[322] Public-Private Partnership In March 2022, Saudi Aramco announcing that it is working with Pasqal, a French start-up, on the applying quantum computing to use cases in the energy sector.[323] In particular, the two companies agreed to develop machine learning models for quantum systems and identify businesses in Saudi Aramco that could benefit from such work. Academic Activity In June 2021, King Abdullah University of Science and Technology (KAUST) announced a partnership with Zapata Computing providing access the company's quantum computing platform to explore uses cases for aircraft and automobile aerodynamic design.[324]
Qatar	Academic Activity In April 2022, Hamad Bin Khalifa University received a $10 million research grant from Barzan Holdings, a leading industrial defence provider in Qatar, to implement a national initiative on quantum computing.[325] This involves the establishment of the Qatar Center for Quantum Computing which will host the experts and resources needed to carry out research on quantum computing, quantum cryptography and quantum artificial intelligence. Xanadu and Hamad Bin Khalifa University also announced a partnership focused on cloud-based software for education and workforce training.[326]
UAE	Building Quantum Computer Abu Dhabi's Technology Innovation Institute (TII),[327] which is a government-funded research institution, is working with Qilimanjaro to build the UAE's first quantum computer.[328] The TII's work includes explorations into quantum computing, quantum algorithms, quantum sensing and quantum communications. Additionally, the QRC is looking into building a quantum computer[329] and also quantum chips.[330] Public-Private Partnership & Academic Activity TII has created the Quantum Research Centre. The QRC is tasked with R&D of quantum technologies in the region led by experts in the field across the globe. The TII has entered several partnerships with private companies and academic institutions that support its work.[331] This

	includes a partnership with IonQ to test and develop quantum algorithms.[332] QUAE is a non-profit organisation looking to foster educational initiatives, research programmes, and collaborative environments for quantum enthusiasts and researchers.[333] Its activities include tutorial lab sessions, workshops, short-term research projects, and hosting events with academics and experts in the field.

The table below sets out the sources for the budgets identified for the national quantum strategies listed above. The figures are gathered from the public information available about the national quantum strategies announced by the respective governments. However, whilst public information for some of these national strategies could be found through desk research, it may not always be the case that governments will follow through on these financial commitments.

Country	Funding Figure ($)	Sources	Description of Source
Brazil	11,000,000	EMBRAPII	In December 2022, the Brazilian government announced a $11 million investment in the Brazilian Company of Industrial Research and Innovation (EMBRAPII) to create a Competence Center in Quantum Technologies.[334]
China	15,300,000,000	McKinsey & Company	The amount of public expenditure committed to quantum development in China is estimated to be $15.3 billion.[335]
India	730,000,000	Indian Government	In April 2023, the Indian government approved a funding package for its National Mission on Quantum Technologies & Applications worth $730 million from 2023 to 2030.[336]
Pakistan	245,000,000	Pakistani Government	During the launch of the National Centre for Quantum Computing, it was announced that the Higher Education Commission would have its budget increased to Rs 70 billion (over $800 million).[337]
Singapore	17,009,000	Quantum Engineering Programme	The QEP coordinates three key national programmes focused on quantum R&D which is supported by $17.09 million over 3.5 years under Singapore's Research, Innovation, and Enterprise 2020 plan.[338]

Annex 2: IBM and the G-77

- **IBM Q Network.** The country has a university or company participating in IBM's Q Network, which is a collection of companies, academic institutions and laboratories working on the development of quantum technology using the platforms and hardware provided by IBM via its cloud services.[339]

Country	IBM Presence
Ethiopia	Through Wit University's (South Africa) membership of the IBM Q Network, the Addis Ababa University is able to access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[340]
Ghana	Through Wit University's (South Africa) membership of the IBM Q Network, the University of Ghana is able to access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[341]
India	In September 2022, the Indian Institute of Technology Madras announced its membership of the network and is the first Indian institution to join. The partnerships will provide the institute with access to IBM's quantum hardware to test "core algorithms in research areas like Quantum Machine Learning, Quantum Optimization, and applications research in finance." The researchers will also "contribute to the advancement of research in the application of quantum computing with support from IBM Research India in such domains that are relevant to India."[342]
Kenya	Through Wit University's (South Africa) membership of the IBM Q Network, the University of Nairobi can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[343]
Nigeria	Through Wit University's (South Africa) membership of the IBM Q Network, the University of Lagos, the University of Ibadan and Obafemi Awolowo University lle-Ife can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[344]
Rwanda	Through Wit University's (South Africa) membership, the University of Rwanda is able access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[345]
Senegal	Through Wit University's (South Africa) membership of the IBM Q Network, Cheikh Anta Diop University can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[346]
Singapore	In April 2020, the National University of Singapore joined the network providing researchers from its quantum engineering programme with access to IBM's quantum computers via the cloud.[347] It is hoped that the partnership will give researchers the opportunity to apply "quantum computing to different fields, including chemistry, materials science, biology, finance and cyber security, particularly those dealing with uncertainty and constrained optimisation."
South Africa	In June 2019, University of the Witwatersrand (Wits University) joined the IBM Q Network as its first African academic partner.[348] The university shares a campus with IBM research in Johannesburg where students are able to access the company's quantum computers via the cloud to run experiments related to "the efficient use of resources based on optimization

	problems".[349] Wits University's membership also provides an avenue for academic collaboration with other South African universities that are part of the African Research Universities Alliance (ARUA).
Tanzania	Through Wit University's (South Africa) membership of the IBM Q Network, the University of Dar es Salaam is able to access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[350]
Uganda	Through Wit University's (South Africa) membership of the IBM Q Network, Makerere University can access IBM's quantum computer as a member of the African Research Universities Alliance (ARUA).[351]
Uruguay	Quantum-South, a Uruguayan quantum start-up, joined IBM's Q Network in 2022 and was the first Latin American company to do so. The company plans to leverage IBM's technology to explore quantum computing applications for use cases in the air and maritime cargo industry.[352]

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