German Council on Foreign Relations

No. 10
April 2025

DGAP POLICY BRIEF

Quantum Technologies

Ranking Germany's Ambition and International Reputation

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This policy brief juxtaposes Germany's national quantum strategy with ten other published national quantum strategies to examine how Germany's ambitions in quantum technologies compare to the ambitions of other countries. Germany is ranked among the top five in quantum computing and post-quantum cryptography. In terms of reputation, only the United States and the United Kingdom are mentioned in national quantum strategies more frequently than Germany as desirable bilateral partners.

– Ranked alphabetically, the most ambitious countries in quantum computing are Australia, Canada, France and Germany, as well as the UK and the US, followed by Japan and South Korea. Trailing behind are Denmark, Ireland, and Singapore.

– In post-quantum cryptography, Germany leads jointly with Australia, Denmark, France, Ireland, and the US. Japan, South Korea, and the UK closely follow. Romania and Singapore are some way behind.

– The US is the most frequently mentioned partner (8) in the analyzed national quantum strategies, followed by the UK (6), and Germany (4). Ireland, Romania, and Singapore are not mentioned in the national strategies analyzed.

To propel quantum innovation, Germany should establish a Quantum Benchmarking Initiative within its new Digital Ministry. This would help German and European companies verify and validate their progress with quantum computing.

INTRODUCTION

Quantum technologies are rapidly emerging as a cornerstone of technological competitiveness and national security. Quantum computing and post-quantum cryptography offer transformative capabilities, from resolving complex optimization problems to enabling ultra-secure communications that are resistant to cyberthreats. These advances have significant geopolitical implications that are driving governments worldwide to develop comprehensive national quantum strategies.

Developments in quantum technologies are especially important for Germany, since, in contrast to developments in artificial intelligence (AI), it is among the leading countries in the race to develop such technologies. Germany has the potential to profoundly shape developments in quantum technologies and a first mover advantage in deploying these across its important manufacturing sectors, thereby unlocking additional economic growth.

In recent years, leading economies — from the European Union and its member states, such as Germany and France, to the United States, and China — have launched substantial initiatives to gain a competitive advantage in quantum research and development. Germany, for instance, invested €2 billion in quantum technologies between 2020 and 2024.[1] The US, for its part, passed the National Quantum Initiative Reauthorization Act in 2024, which allocated $2.7 billion in federal funding over five years to advance quantum research and development in federal agencies.[2] Similarly, the European Union's Quantum Flagship program, launched in 2018 with a budget of €1 billion, fosters collaboration among research institutions, industry, and governments across the EU member states.[3]

An increasing number of countries have published national quantum strategies in recent years. These documents vary in scope. Some prioritize research and development while others emphasize industrial competitiveness or military applications. As quantum technologies are deployed increasingly to tackle real-world challenges, national strategies will play a critical role in shaping the direction of their development. An understanding of these policies will be essential if stakeholders across government, industry, and academia are to navigate the emerging quantum landscape effectively. This policy brief analyzes how Germany's quantum ambitions compare to those of other countries, and whether those countries perceive it as a leader in the field.

METHODOLOGY

This policy brief analyzes the ambitions of Germany and ten other countries as outlined in their published national quantum strategies.[4] Ambition is analyzed using two variables: the most powerful quantum computer a country is planning to build on its territory by a certain year and when that country aims to transition to post-quantum cryptography.[5]

The policy brief does not examine all major countries: To the authors' knowledge, neither Russia nor China has published a national quantum strategy document. They were therefore omitted from this study. Nor do countries that already have initiatives, such as "Quantum Austria" or India's "National Quantum Mission", fall within the remit of this study.[6] Where we identified that a country has published a quantum strategy, we also consulted other sources on that country's quantum ambitions, such as initiatives and documents, the websites of companies that operate on their territory, and media articles related to the country. This was done to address information scarcity, such as where the initial strategy only mentions the country's post-quantum cryptography ambitions and its international partnerships, but not its quantum computing goals. For example, the British National Quantum Strategy (2023) does not set out its ambitions regarding quantum computing power, but

1 Reuters, "Germany aims to be world leader in quantum technologies, says Scholz" https://www.reuters.com/technology/germany-aims-be-world-leader-quantum-technologies-says-scholz-2024-10-01/ (accessed April 14, 2025).

2 US House of Representatives, H.R. 6213, National Quantum Initiative Reauthorization Act, July 25, 2024, https://www.congress.gov/bill/118th-congress/house-bill/6213/text (accessed March 24, 2025); National Development and Reform Commission, "The Outline of the 14th Five-Year Planfor Economic and Social Development and Long-range Objectives through the Year 2035 of the People's Republic of China," https://en.ndrc.gov.cn/policies/202203/P020220315511326748336.pdf p. 8.

3 European Commission, "Quantum Technologies Flagship," https://digital-strategy.ec.europa.eu/en/policies/quantum-technologies-flagship (accessed March 24, 2025).

4 Singapore has a website that is equivalent to a strategy document. We therefore included Singapore in our analysis.

5 This does not include countries' ambitions regarding quantum communications or sensing, or their financial commitments to quantum computing or cryptography.

6 Austrian Research Promotion Agency (FFG), "Quantum Austria," https://www.ffg.at/en/quantum-austria; Indian Ministry of Science and Technology, "National Quantum Mission: India's Quantum Leap," https://pib.gov.in/PressReleasePage.aspx?PRID=2111953 (accessed April 10, 2025).

these are set out in the UK National Quantum Technologies Programme.[7]

When describing the power of quantum computers, most countries' strategies mention qubits as a **benchmark** of performance. Some countries also go into more detail by specifying whether they mean physical or logical qubits.[8] A logical qubit comprises a group of physical qubits.[9] This is a low level of precision for assessing ambition, but it is the level of precision that most country strategies provide. There is often no mention of gate fidelity, error correction capacity, or the type of hardware platform, which are all essential aspects of running a powerful quantum computer.[10] The policy brief therefore relies on qubits as a benchmark for how powerful the planned computer will be.

Regarding the transition to post-quantum cryptography, countries are vague about the infrastructure they aim to transition to post-quantum cryptography by a certain year. The UK , for instance, states that it aims to transition high-priority systems by 2031. Australia intends to ban certain weak algorithms by 2030, which makes it a crucial date in its post-quantum cryptography transition. Despite their different approaches, we take both Australia's and the UK's examples as indications of when they aim to transition.

Finally, we assessed whether a country's ambition is commensurate with its international reputation. Germany might be very ambitious, for example, but other countries may not believe in its quantum capabilities. To assess international quantum reputation, we analyzed how many countries mention in their strategies a desire to partner with Germany. We also examined how this compares to the number of countries aiming to collaborate with the US or the UK, among others.[11]

As far as possible, we have aimed to explain technical terms in layperson's terms in the main text. If more detail is required for further contextualization, however, it is provided in footnotes.

ANALYZING AMBITION

First Criterion for Ambition: Quantum Computing

The first variable for assessing ambition is how powerful the quantum computer is that each country is aiming to build by a specific date. When comparing quantum computing power ambition, the countries analyzed and the entities operating within their borders mention diverging metrics: physical qubits, useful qubits, logical qubits, individually controllable qubits, and the amount/quality of operations that a quantum computer can accomplish in a certain amount of time. The information provided in the strategies is often vague, and scattered across documents, which makes a comparison of the countries difficult. Nonetheless, we believe that comparative assessments of aspirations can be made using deep dives into the strategies.

Findings

All lists start with Germany; the countries that follow are in alphabetical order.

Germany

Germany aims to develop a fully operational quantum computer with at least **100 individually controllable [physical] qubits by 2026 (scalable to 500 in the medium term).**[12] Pasqal's 100-Qubit Quantum Computer was delivered to the Jülich Supercomputing Centre (JSC) in late 2024. It will be coupled with the JURECA DC supercomputer, which will allow researchers to use hybrid quantum-classical computing to resolve

7 UK Research and Innovation, "UK National Quantum Technologies Programme," https://uknqt.ukri.org/ (accessed April 23, 2025).

8 "Logical qubits are central to quantum error correction schemes, where multiple physical qubits are entangled to encode a single logical qubit. For example, a common encoding might use seven physical qubits to represent one logical qubit, allowing for the correction of certain types of errors." QuEra, "Logical Qubits," https://www.quera.com/glossary/logical-qubit.

9 QuEra "Logical Qubit" https://www.quera.com/glossary/logical-qubit (accessed April 10, 2025).

10 Higher gate fidelity means fewer errors introduced, and lower computational overheads needed for error correction. For more on gate fidelity see Matt Swayne, "MIT Researchers Report Record-Setting Quantum Gate Fidelity," *The Quantum Insider*, https://thequantuminsider.com/2025/01/21/mit-researchers-report-record-setting-quantum-gate-fidelity/; "Quantum error correction works by encoding the quantum information in a way that allows errors to be detected and corrected. This is typically done by encoding the information into a larger set of qubits, called a "quantum error-correcting code," which is designed to be resilient to errors. For more on error correction see Microsoft, "Explore Quantum," https://quantum.microsoft.com/en-us/insights/education/concepts/quantum-error-correction (accessed April 10, 2025).

11 Country A's strategy mentioning that country B or C is advanced when it comes to quantum technologies is not sufficient to increase country B's or C's international reputation. There must be an indication that country A's strategy shows a willingness to collaborate with country B or C. This is why the report only counts examples where a country explicitly states in its strategy that it wants to collaborate with Germany, rather than those that mention Germany as a leader in quantum technologies.

12 We assume that, given the timeframe, Germany means physical qubits. Maintaining controllability as systems scale-up is a daunting challenge. Federal Ministry of Research and Education, "Quantum Technologies Conceptual Framework Programme of the Federal Government," April 2023, https://www.quantentechnologien.de/fileadmin/public/Redaktion/Dokumente/PDF/Publikationen/Quantum-Technologies-Conceptual-Framework-2023_english_bf_C1.pdf, p. 7.

scientific and industrial challenges.[13] In addition, Forschungszentrum Jülich purchased the D-WaveTM annealing quantum computer in early 2025. It will be connected to the JUPITER supercomputer, in "the world's first coupling of an annealing quantum computer with an exascale supercomputer," to provide new ways to resolve complex computational problems.[14] Planqc, a company based near Munich, has received German federal funding to develop a **1000 qubit** computer by 2027.[15]

Australia

The Australian Commonwealth and Queensland governments will invest AU$940 million (US$593 million / €544 million) in PsiQuantum,[16] a Palo-Alto, California-based company that aims to build and deploy commercially useful quantum computers. The company aims to have a site in Brisbane operational by the end of 2027. It states that its "system will be in the regime of **1 million physical qubits** and hyperscale [large-scale] in footprint with a modular architecture that's able to leverage existing cryogenic cooling technologies."[17]

Canada

Canada's long-term objectives for 2032 and beyond are to develop a quantum computer with more than **1 million physical qubits** and achieve quantum error correction at a scale of 100 to 1,000 qubits to one logical qubit.[18] Canada is also aiming to develop a quantum computer with **100 logical qubits** and develop 100-way inter qubit connectivity from 2032. [19]

Denmark

Denmark's national strategy highlights a joint Novo Nordisk Foundation-Niels Bohr Institute collaboration to build a fully functional quantum computer in the time frame of 2032–2042.[20]

France

France has already achieved **350 useful [physical] qubits** and aims to reach 2,000 by 2026.[21] By the end of the decade, the goal is to achieve between **100 and 200 logical qubits**. In 2024, the government launched the PROQCIMA program, which aims to develop at least two prototype universal quantum computers by 2032, each with **128 logical qubits**, expanding to **2,048 logical qubits** by 2035.[22]

Ireland

Ireland launched the Quantum Computing in Ireland (QCoIr) initiative in 2020, allocating €11.1 million in funding.[23] In addition, Equal1, a quantum computing company originated at University College Dublin, is at the forefront of scalable quantum computing technology. The company launched Bell-1 in March 2025,

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13 Jülich Forschungszentrum, "Pasqal's 100-Qubit Quantum Computer Arrives at JUNIQ," February 12, 2025, https://www.fz-juelich.de/en/ias/jsc/systems/quantum-computing/juniq-facility/news/pasqals-100-qubit-quantum-computer-arrives-at-juniq (accessed March 24, 2025).

14 Jülich Forschungszentrum, "Forschungszentrum Jülich strengthens quantum research with purchase of D-WaveTM annealing quantum computer," February 13, 2025: https://www.fz-juelich.de/en/news/archive/press-release/2025/forschungszentrum-julich-strengthens-quantum-research-with-purchase-of-d-wavetm (accessed March 24, 2025).

15 Planqc only mentions qubits, not physical qubits. That the company means physical qubits is an assumption on our part. Planq, "planqc to build 1,000-Qubit Neutral-Atom Quantum Computer in €20 Million Government-Funded Project for Leibniz Supercomputing Centre," November 13, 2024, https://www.planqc.eu/news/20241113-1000_qubit_quantum_computer_for_lrz/ (accessed March 24, 2025); Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities, "Planqc to build neutral-atom quantum computer for LRZ, " November 13, 2024, https://www.quantum.lrz.de/bits-of-qubits/detail/planqc-to-build-neutral-atom-quantum-computer-for-lr (accessed March 24, 2025).

16 Australian Government, Department of Industry, Science and Resources, "State of Australian Quantum Report 2024," (November 13, 2024): https://www.industry.gov.au/publications/state-australian-quantum-report-2024/progress (accessed March 21, 2025).

17 PsiQuantum, "PsiQuantum to Build World's First Utility-Scale, Fault-Tolerant Quantum Computer in Australia," (April 29, 2024): https://www.psiquantum.com/news-import/psiquantum-to-build-worlds-first-utility-scale-fault-tolerant-quantum-computer-in-australia (accessed March 24, 2025). Australian Government, Department of Industry, Science and Resources, "State of Australian quantum report 2024," (November 13, 2024): https://www.industry.gov.au/publications/state-australian-quantum-report-2024/progress (accessed March 24, 2024

18 "[T]he simplest distinction of logical qubit vs physical qubit is that a logical qubit is a cluster of physical qubits," *QuEra*, https://www.quera.com/glossary/logical-qubit (accessed March 24, 2025).

19 Government of Canada, "National Quantum Strategy roadmap: Quantum computing," February 17, 2025, https://ised-isde.canada.ca/site/national-quantum-strategy/en/national-quantum-strategy-roadmap-quantum-computing (accessed March 24, 2025); 100 inter-qubit connectivity means that each qubit can interact with 100 other qubits in a quantum system, either directly or through other logical qubits. "If qubits are well-connected, fewer operations are needed to perform a computation, increasing the speed and efficiency of the quantum computer." *The Quantum Insider*, July 10, 2023, https://thequantuminsider.com/2023/07/10/why-qubit-connectivity-matters/ (accessed March 24, 2025).

20 Danish Ministry of Higher Education and Science, "Strategy for Quantum Technology: Part 1 – World-Class Research and Innovation," June 21, 2023, https://ufm.dk/en/publications/2023/strategy-for-quantum-technology-part-1-2013-world-class-research-and-innovation (accessed March 24, 2025).

21 The term "useful qubit" is not well defined. The press release does not specify what is meant by "useful".,

22 Ministère chargé de l'Enseignement supérieur et de la Recherche, "France 2030: Point d'étapes trois ans après le lancement de la stratégie nationale des technologies quantiques et lancement du programme Proqcima," [France 2030: An update three years after the launch of the national quantum technology strategy and the Proqcima program], March 6, 2024, https://www.enseignementsup-recherche.gouv.fr/fr/france-2030-point-d-etapes-trois-ans-apres-le-lancement-de-la-strategie-nationale-des-technologies-95121 (accessed March 24, 2025).

23 Government of Ireland, "Quantum 2030: A National Quantum Technologies Strategy for Ireland," November 16, 2023, https://assets.gov.ie/276661/61f7f8f1-636b-48e1-91c9-a9bf63e00ce8.pdf, p. 20.

which is described as **"the first quantum system purpose-built for the HPC [high-performance computing] era."**[24] It features a **6-qubit quantum processing system**.[25]

Japan

Japan plans to achieve a 100-qubit noisy intermediate-scale quantum (NISQ) computer by 2030. [26] It also aims to implement around 1000 physical qubits, including about 50 logical qubits, by that date.[27]

Singapore

This National Quantum Computing Hub aims to establish a quantum computer in Singapore. The National Quantum Processor Initiative (NQPI)[28] was established to design and build a quantum processor, which is often referred to as the "brain" of a quantum computer. Thus far, two versions of a quantum processor have been installed at the Hub. In March 2025, Singapore launched the Hybrid Quantum Classical Computing Initiative, which combines the capabilities of supercomputers and quantum computers.[29]

South Korea

South Korea has stated that it began developing a 50-qubit quantum computer in June 2022, with the goal of completing development by 2027. The country aims to develop a **1,000 [physical] qubit quantum computer** with world-class reliability, and an error rate of 0.5% or less, by 2031. [30]

United Kingdom

The UK's goal is to have an accessible quantum computing sector capable of delivering quantum advantage in 2025,[31] and going beyond **1 million operations by 2028**.[32] The UK also aims to go beyond NISQ-era quantum computers by 2028.[33] By 2032, the sector should be able to demonstrate large-scale error correction capability in **1 billion operations**.[34] It is planned that UK-based quantum computers will be able to run **1 trillion** coherent quantum operations by 2035.[35]

United States

A US government document from late 2024 highlights two projects that appear to be closest to building utility-scale, fault-tolerant quantum computers in the United States.[36] These have been identified in the US Defense Advanced Research Projects Agency (DARPA) Quantum Benchmarking Program, which seeks to "verify and validate whether any quantum computing approach can achieve utility-scale operation – meaning its computational value exceeds its cost – by the

24 The distinguishing feature of this quantum processor is that it can run inside an HPC environment alongside other Central Processing Units (CPUs) and Graphics Processing Units (GPUs).

25 Equal1, " Equal1 Launches Bell-1: The First Quantum System Purpose-Built for the HPC Era," March 16, 2025: https://www.equal1.com/post/equal1-launches-bell-1-the-first-quantum-system-purpose-built-for-the-hpc-era (accessed March 24, 2025).

26 The NISQ era of quantum computers refers to an era where quantum computers reach up to around 1000 qubits but still have significant error rates. Wikipedia "Noisy intermediate-scale quantum era." https://en.wikipedia.org/wiki/Noisy_intermediate-scale_quantum_era; Quantum Insider "What Is NISQ Quantum Computing?" https://thequantuminsider.com/2023/03/13/what-is-nisq-quantum-computing/ (accessed April 10, 2025). Moonshot Research and Development Program, "Working Group 6", https://www8.cao.go.jp/cstp/stmain/mspaper8.pdf (accessed March 24, 2025). Noisy Intermediate Scale Quantum (NISQ) computing refers to "…current quantum computers … [that] are prone to considerable error rates and limited in size by the number of logical qubits (or even physical qubits) in the system. https://thequantuminsider.com/2023/03/13/what-is-nisq-quantum-computing/ (accessed March 24, 2025).

27 Government of Japan, "Japan's Quantum Technology Innovation Strategy Roadmap", "https://dig.watch/resource/japans-basic-act-on-cybersecurity (accessed March 24, 2025).

28 National Quantum Office Singapore, "National Quantum Processor Initiative (NQPI)" https://nqo.sg/programmes/#nqpi (accessed March 24, 2025); National Quantum Office Singapore, "Engineering Capabilities" https://nqo.sg/nqs/engineering-capabilities/ (accessed March 24, 2025).

29 Centre for Quantum Technologies Singapore, "Singapore launches new Hybrid Quantum Classical Computing initiative" March 12, 2025: https://www.cqt.sg/blog/highlight/2025-03-hybrid-quantum-classical-computing/ (accessed March 24, 2025).

30 That South Korea means "physical" qubits is an assumption on our part. Ministry of Science and ICT, "Korea's National Quantum Strategy," June 27, 2023, https://quantuminkorea.org/wp-content/uploads/2024/06/Koreas-National-Quantum-Strategy-2023_c.pdf p. 28.

31 Quantum advantage is reached when a quantum algorithm running on a quantum computer solves a real-world problem faster than any classical algorithm deployed on a classical computer. This can be an experimental demonstration. See QuEra, "Quantum Advantage," https://www.quera.com/glossary/advantage (accessed March 24, 2025).

32 UK National Quantum Technologies Programme, "National Quantum Strategy Missions," https://uknqt.ukri.org/our-programme/#_ftn1 (accessed March 24, 2025).

33 UK Research and Innovation, "UK Quantum Technologies Programme," https://uknqt.ukri.org/our-programme/#_ftn1 (accessed April 8, 2025).

34 Ibid.

35 The UK claims that 1 trillion operations are the scale of computing power needed for it to have economic value. The time range for this number of operations for a classical computer is set between a few minutes to a few days. Quantum computers could reduce the time needed for such a computation. However, qubit operations imply both qubit quality and amount, which makes it difficult to compare with other countries' claims. See UK National Quantum Technologies Programme, "National Quantum Strategy Missions," https://uknqt.ukri.org/our-programme/#_ftn1 (accessed March 24, 2025).

36 Subcommittee on Quantum Information Science, Committee on Science of the National Science & Technology Council, "National Quantum Initiative Supplement to the President's FY 2025 Budget," December 2024, https://www.quantum.gov/wp-content/uploads/2024/12/NQI-Annual-Report-FY2025.pdf.

year 2033."[37] Microsoft and PsiQuantum are part of this program and both companies aim to scale up to **1 million [physical] qubits**.[38] PsiQuantum aims to do so by 2027 (see Australia above) but Microsoft does not give a specific date. The fact that Microsoft is part of DARPA's program, however, indicates that its goal is to achieve this scale of qubits by 2033 at the latest.[39]

Australia, Canada, France, Germany, the UK, and the US lead the pack in terms of ambition. They all aim to go beyond 1000 physical qubits by 2028 at the latest. The first tier of countries is followed by a second tier of countries, Japan and South Korea, that aim to go beyond 1000 physical qubits by 2030 and 2031, respectively. Ireland, Denmark, and Singapore do not mention their ambitions in terms of quantum performance metrics, which leads us to place them in a third tier of countries in terms of ambition.

Second Criterion for Ambition: The Year by Which Countries Plan to Transition to Post-quantum Cryptography

The second criterion examines the year by which countries have publicly stated that they intend to transition to post-quantum cryptography. This is important for ambition, since an earlier date means a much tighter implementation framework and less international experience to draw on that could help with the transition.

Findings

Germany

The Federal Office for Information Security (BSI) operates under the assumption that cryptographically relevant quantum computers will be available in the early 2030s. High-security systems should have completed the transition by then. For this reason, the BSI initiated the transition to post-quantum cryptography in 2020.[40]

Australia

Australia will not approve cryptographic algorithms such as AES-128 and AES-192, SHA-224, SHA-256, RSA, ECDSA, DH, and ECDH, HMAC-SHA256, ML-DSA-65, ML-KEM-768 for use beyond 2030. The Australian document notes that "for interoperability reasons, the design and provision of new cryptographic equipment and software, which is intended to be used beyond 2030, should support MLDSA-87, ML-KEM-1024, SHA-384, SHA-512 and AES-256."[41]

Canada

The aim is to complete Canada's transition to post-quantum cryptography in the 2030s. However, the strategy outlines that the transition of Canada's government systems to post-quantum cryptography should already be completed between 2028 and 2032. [42]

Denmark

Denmark's strategy mentions that a sufficiently powerful quantum computer could be developed by 2030 but does not set out a timeline for post-quantum cryptography transition.[43] In a common publication with other European national cybersecurity agencies, Denmark aims for the most critical systems to have transitioned by 2030.[44]

France

The French Cybersecurity Agency (ANSSI) has accelerated its initial schedule. The first security approvals for products implementing hybrid post-quantum cryptography were expected in 2024–2025. The agency continues to encourage security product designers

37 Darpa, "DARPA selects two discrete utility-scale quantum computing approaches for evaluation" February 6, 2025 https://www.darpa.mil/news/2025/quantum-computing-approaches (accessed March 24, 2025).

38 That they aim to achieve "physical" qubits is an assumption on our part. Rachel Hall, "Microsoft unveils chip it says could bring quantum computing within years" *The Guardian*, February 19, 2025 https://www.theguardian.com/technology/2025/feb/19/topoconductor-chip-quantum-computing-topological-qubits-microsoft

39 Microsoft is the unique user of a specific hardware platform that promises great future results, but Microsoft has not yet conclusively demonstrated qubits on this platform.

40 Federal Office for Information Security, "Quantum-safe cryptography – fundamentals, current developments and recommendations" https://www.bsi.bund.de/SharedDocs/Downloads/EN/BSI/Publications/Brochure/quantum-safe-cryptography.pdf?__blob=publicationFile&v=4 p. 4

41 Ibid., p. 9.

42 Government of Canada, National Quantum Strategy roadmap: Quantum communication and post-quantum cryptography, February 17, 2025 https://ised-isde.canada.ca/site/national-quantum-strategy/en/national-quantum-strategy-roadmap-quantum-communication-and-post-quantum-cryptography

43 The Danish Government, National Strategy for Quantum Technology Part 2 - Commercialisation, Security and International Cooperation, September 2023 https://www.em.dk/Media/638315714019915522/National%20Strategy%20for%20Quantum%20Technology.pdf

44 Bundesamt für Sicherheit in der Informationstechnik (BSI), "Securing Tomorrow, Today: Transitioning to Post-Quantum Cryptography," November 11, 2024, https://www.bsi.bund.de/SharedDocs/Downloads/EN/BSI/Crypto/PQC-joint-statement.pdf?__blob=publicationFile&v=3, p. 1.

to experiment with prototype hybrid post-quantum and pre-quantum solutions, especially for products designed for confidential protection or that are likely to be used beyond 2030. [45]

Ireland

Beyond the common statement it made with other EU member states, Ireland has not made any specific pronouncements regarding its transition to post-quantum cryptography.[46]

Japan

Japan plans to initiate its transition to post-quantum cryptography between 2025 and 2030. The transition is expected to extend beyond 2040. [47]

Romania

Romania has not publicly announced a specific deadline or timeline for migrating to post-quantum cryptography.

Singapore

Singapore's National Cyber Security Agency (CSA) has started work on adopting quantum-safe cyber defenses with organizations that handle highly sensitive data. It will start publishing guidelines in 2025.[48] However, no timeline has been announced for when this work will be completed.

South Korea

The South Korean government has established a comprehensive plan to transition the national cryptographic system to post-quantum cryptography by 2035. In 2025–2028, the government will carry out a four-year pilot transition project across key industries, such as healthcare, defense, and finance.[49]

United Kingdom

The UK National Cyber Security Centre expects migration to post-quantum cryptography (PQC) to be completed for the highest priority systems by 2031 and for other systems by 2035. This goal is tailored to large organizations, such as critical infrastructure providers.[50] There will be two transitions: one for systems taking a hybrid approach to cryptography and a later one where only post-quantum cryptography is used.[51]

United States

The United States currently plans to transition to post-quantum cryptography standards between 2024 and 2030, which could be before a cryptographically relevant quantum computer is available.[52]

To sum up, Germany is among the most ambitious countries, jointly with Australia, Denmark, France, Ireland, and the US. All these countries aim to transition their most sensitive systems by 2030. Canada (transition by 2032), Japan (initiates its transition between 2025 and 2030), South Korea (aims to transition by 2035) and the UK (transition by 2031) are following close behind. Romania and Singapore have set no official transition timelines.

INTERNATIONAL QUANTUM REPUTATION

This section assesses the international reputation of a country and whether it is a sought-after partner in quantum technologies. The higher the number of countries that mention in their strategies that they

45 Agence nationale de la sécurité des systèmes d'information "Avis de l'ANSSI sur la migration vers la cryptographie post-quantique (suivi 2023)" [ANSSI's Opinion on the Migration to Post-Quantum Cryptography (2023 Follow-Up)] December 21, 2023 https://cyber.gouv.fr/sites/default/files/document/Avis%20de%20l%27ANSSI%20sur%20la%20migration%20vers%20la%20cryptographie.pdf, p. 2.

46 Bundesamt für Sicherheit in der Informationstechnik (BSI), "Securing Tomorrow, Today: Transitioning to Post-Quantum Cryptography," November 11, 2024, https://www.bsi.bund.de/SharedDocs/Downloads/EN/BSI/Crypto/PQC-joint-statement.pdf?__blob=publicationFile&v=3, p. 1.

47 Cabinet Office, Council for Science, Technology and Innovation, "量子技術イノベーション戦略 ロードマップ改訂," [Quantum Technology Innovation Strategy Revised Roadmap], April 2022, https://www8.cao.go.jp/cstp/ryoshigijutsu/roadmap_220422.pdf, p. 25.

48 Krist Boo, "Guidelines to help S'pore businesses shield themselves from quantum threats from 2025: CSA," *The Straits Times*, December 7, 2024, https://www.straitstimes.com/business/guidelines-to-help-spore-businesses-shield-from-quantum-threats-from-2025-csa.

49 양자 시대 위협 대비 국가 암호체계의 대전환을 위한 첫걸음을 내딛다 [Taking the First Steps toward Transforming National Cryptosystems against Quantum-era Threats], February 27, 2025 https://www.msit.go.kr/bbs/view.do?sCode=user&mId=307&mPid=208&pageIndex=&bbsSeqNo=94&nttSeqNo=3185512&searchOpt=ALL&searchTxt=, p. 2.

50 National Cyber Security Centre, "Timelines for migration to post-quantum cryptography ," March 20, 2025, https://www.ncsc.gov.uk/guidance/pqc-migration-timelines (accessed March 24, 2025).

51 National Cyber Security Centre, "Next steps in preparing for post-quantum cryptography," August 14, 2024 https://www.ncsc.gov.uk/whitepaper/next-steps-preparing-for-post-quantum-cryptography#section_1 (accessed March 24, 2025).

52 Executive Office of the President of the United States, "NSM-10 and the Transition to Post-Quantum Cryptography," April 2024, https://csrc.nist.gov/csrc/media/Presentations/2024/u-s-government-s-transition-to-pqc/images-media/presman-govt-transition-pqc2024.pdf, p. 5.

would want to engage in partnerships with a particular country, the greater the probability is that that country will achieve its ambitions. The intentions of potential collaborators can lead to actual collaboration, and international scientific collaboration propels scientific progress.

Findings

Germany

Germany highlights the key role of partnerships with the EU and EU member states in its strategy, especially in terms of technological sovereignty, arguing that "it is important that close coordination with European partners continues, especially in quantum computing and quantum communication."[53] The goal is to position Europe as a "technology provider."[54] Germany is mentioned as a partner in the strategies of Denmark, France, South Korea, and the US.

Australia

Australia has built a robust network of quantum partnerships that span the Association of Southeast Asian Nations (ASEAN) member states, various Indo-Pacific nations, the United Kingdom, the European Union and North America. The **Quad**, which comprises Australia, India, Japan, and the United States, further enhances its horizon-scanning collaboration. Australia also aims to convene the Quad Technology and Business Investment Forum to network with industry. In parallel, Australia, the United Kingdom, and the United States are accelerating investments to develop next-generation quantum military capabilities through the **AUKUS Quantum Arrangement** (AQuA).[55] Australia and the US have also signed a joint statement on enhancing market access to and knowledge exchange on quantum technologies.[56] Australia is mentioned as a partner in the US strategy.

Canada

The Government of Canada is seeking to strengthen collaboration and expand opportunities with like-minded nations. Its strategy discusses the partnerships launched by the Natural Sciences and Engineering Research Council of Canada (NSERC) to foster research collaboration with the US,[57] the UK,[58] and the European Commission.[59] Canada is mentioned as a partner in the strategies of Australia, Romania, and the UK.

Denmark

Denmark intends to build on existing cooperation with the Nordic countries and EU member states on research into quantum technology. It is seeking to strengthen cooperation with locations where quantum technology is a focus, such as Silicon Valley, Boston, Munich, Tel Aviv, and Seoul.[60] Denmark refers to EU and NATO member states with strong quantum research environments as partners.[61] To strengthen its position in the international quantum landscape, Denmark has established an International Quantum Hub to foster bilateral, multilateral, and regional cooperation.[62] Denmark is mentioned as a partner in the US strategy.

53 Federal Ministry of Education and Research, "Quantum Technologies Conceptual Framework Programme of the Federal Government," April 2023, https://www.quantentechnologien.de/fileadmin/public/Redaktion/Dokumente/PDF/Publikationen/Quantum-Technologies-Conceptual-Framework-2023_english_bf_C1.pdf p. 33.

54 Ibid., p. 33

55 Australian Government, Department of Industry, Science and Resources, "National Quantum Strategy," 2023, https://www.industry.gov.au/sites/default/files/2023-05/national-quantum-strategy.pdf, p. 19-20. While quantum computing appears not to be the initial focus of the Arrangement it might be in the future. See UK House of Commons Library, "AUKUS pillar 2: Advanced capabilities," September 2, 2024, https://commonslibrary.parliament.uk/research-briefings/cbp-9842/.

56 Australian Government, Department of Industry, Science and Resources, "Joint Statement of the United States of America and Australia on Cooperation in Quantum Science and Technology," November 19, 2021, https://www.industry.gov.au/publications/joint-statement-united-states-america-and-australia-cooperation-quantum-science-and-technology.

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59 Natural Sciences and Engineering Research Council of Canada, "NSERC-European Commission – Joint call on quantum technologies," https://www.nserc-crsng.gc.ca/Innovate-Innover/NSERC_EC-CRSNG_CE_eng.asp (accessed March 24, 2025).

60 Ministry of Higher Education and Science Denmark, "Strategy for Quantum Technology June 2023 Part 1 – World-Class Research and Innovation," June 2023, https://ufm.dk/en/publications/2023/strategy-for-quantum-technology-part-1-2013-world-class-research-and-innovation, p. 19.

61 Ministry of Industry, Business and Financial Affairs, "National Strategy for Quantum Technology Part 2 - Commercialisation, Security and International Cooperation," September 2023, https://www.eng.em.dk/publications/2023/national-strategy-for-quantum-technology, p. 21.

62 Ibid., p. 21.

France

In its National Quantum Strategy, France commits to lead European efforts, in particular with Germany and the Netherlands,[63] to make Europe a global hub for quantum technologies. In addition, the strategy states that "France will be a driving force behind proposals to intensify the historic joint research dynamics with Europe's leading quantum technology nations," with reference to the Netherlands and "England".[64] France is also supporting the High Performance Computer – Quantum Simulator hybrid (HPCQS) project, together with Austria, Germany, Ireland, Italy, Spain, and the High Performance Computing Joint Undertaking (EuroHPC JU), which aims to integrate two quantum computers into two existing supercomputers.[65] France is mentioned as a partner in the South Korean and US strategies.

Ireland

Ireland aims to develop stronger links on quantum technologies research with the EU, the US, and the UK, using new and existing sources of funding.[66] However, Ireland is not mentioned as a partner in any of the strategies examined.

Japan

Japan does not mention any international partnerships in its strategy. In November 2024, however, the EuroHPC JU launched a call to advance EU-Japan collaboration on quantum computing.[67] Japan has also launched a partnership with South Korea and the US to build a skilled quantum workforce and enhance their collective competitiveness.[68] Japan is mentioned as a partner in the strategies of Australia, South Korea, and the US.

Romania

Romania's strategy prioritizes cooperation with the US, Israel, Canada, the UK, and South Korea. At the multilateral level, Romania is seeking active participation in initiatives such as the EU Quantum Flagship. The strategy also highlights engagement with key forums, such as the Organization for Economic Co-operation and Development, the World Economic Forum, the G7, and NATO.[69] However, Romania is not mentioned as a partner in any of the strategies examined.

Singapore

A Memorandum of Understanding with Finland to promote research collaboration is the only international partnership mentioned in the partnerships section of the website of National Quantum Office, which is developing Singapore's National Quantum Strategy. [70] Nonetheless, Singapore's Centre for Quantum Technologies has been party to agreements with research institutions and universities in countries such as Australia, France, India, Israel, Italy, New Zealand, Thailand, Switzerland, and the UK.[71] Singapore is not mentioned as a partner in any of the strategies examined.

South Korea

South Korea aims to strengthen cooperation with major quantum entities worldwide, specifically in the US and the EU. South Korea mentions in its strategy that it has joined the Entanglement Exchange initiative, which the US, the UK, Japan, France, and Germany have set up to facilitate investment in and research on quantum technologies.[72] South Korea is mentioned as a partner in the strategies of Denmark, Romania, and the US.

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63 French Government, "Stratégie nationale sur les technologies quantiques" [National Strategy for Quantum Technologies], January 21, 2021, https://www.enseignementsup-recherche.gouv.fr/sites/default/files/content_migration/document/Dossier_de_Presse_Presentation_de_la_strategie_nationale_sur_les_technologies_quantiques_1372307.pdf , p. 3.

64 Ibid., p. 21.

65 Jülich Forschungszentrum, "Boosting Europe's Quantum Computing Infrastructure," December 2, 2024, https://www.fz-juelich.de/en/news/archive/press-release/2024/boosting-europe2019s-quantum-computing-infrastructure

66 Government of Ireland, "Quantum 2030: A National Quantum Technologies Strategy for Ireland," November 16, 2023, https://assets.gov.ie/276661/61f7f8f1-636b-48e1-91c9-a9bf63e00ce8.pdf p. 19.

67 EuroHPC Joint Undertaking, "New Call to Strengthen EU-Japan Partnership in Quantum Computing," November 19, 2024, https://eurohpc-ju.europa.eu/new-call-strengthen-eu-japan-partnership-quantum-computing-2024-11-19_en (accessed March 24, 2025).

68 US Embassy & Consulate in the Republic of Korea, "US, Japan, and the Republic of Korea Launch Cutting-edge Quantum Collaboration," January 18, 2024, https://kr.usembassy.gov/011924-u-s-japan-and-republic-of-korea-launch-cutting-edge-quantum-collaboration/ (accessed March 24, 2025).

69 Ministry of Research, Innovation and Digitalization, "Strategia națională în domeniul tehnologiilor cuantice pentru perioada 2024-2029," [National Quantum Technologies Strategy for 2024-2029], https://sgg.gov.ro/1/wp-content/uploads/2024/08/ANEXA-41.pdf p. 30.

70 National Quantum Office Singapore, "Finland and Singapore's National Quantum Office ink MOU - National Quantum Office," March 5, 2024, https://nqo.sg/finland-and-singapores-national-quantum-office-ink-mou/ (accessed March 24, 2025).

71 Centre for Quantum Technologies, "Annual Report 2022," https://www.cqt.sg/wp-content/uploads/2024/09/annualreport2022.pdf p. 37

72 Ministry of Science and ICT, "Korea's National Quantum Strategy," June 27, 2023, https://quantuminkorea.org/wp-content/uploads/2024/06/Koreas-National-Quantum-Strategy-2023_c.pdf p. 44.

United Kingdom

The UK strategy highlights its partnership with the US, referencing a joint statement to strengthen quantum collaboration, and cooperation on quantum science between the US National Institute of Standards and Technology (NIST) and the UK National Physical Laboratory (NPL).[73] Canada also participates in quantum research collaboration with the UK.[74] The strategy emphasizes the importance of playing an active role in key multilateral forums, such as the World Trade Organization, the World Economic Forum, the G7, the G20, the OECD, NATO, the Council of Europe, the Commonwealth, the United Nations, and the International Telecommunication Union (ITU).[75] The UK is mentioned as a partner in the strategies of Australia, France, Ireland, South Korea, Romania, and the US.

United States

The US has signed bilateral quantum cooperation statements with 11 countries: Australia, Denmark, Finland, France, Germany, Japan, the Netherlands, South Korea, Sweden, Switzerland, and the United Kingdom. It mentions the G7, the G20 and the OECD as forums for discussions. This emphasis on partnerships is further reinforced by an August 2024 report by the US National Science & Technology Council, which recommends "dedicated and long-term mechanisms to fund international [Quantum Information Science and Technology] QIST collaboration and cooperation."[76]

Germany has a good reputation internationally on quantum computing. Germany is mentioned in four of the national quantum strategies examined, making it the third most frequently mentioned country. The US has eight mentions, followed by the UK with six. Ireland, Romania, and Singapore are not mentioned as partners in the other nations' strategies.

Exceptions: Russia and China

An in-depth examination of Chinese or Russian efforts in quantum computing, post-quantum cryptography or partnerships is beyond the scope of this paper. Beijing and Moscow have not published official strategies laying out their quantum ambitions.[77] Nonetheless, some contextual information is available. Russia's 2020 Quantum Computing Roadmap declared that it wanted to build a quantum computer with at least 50 qubits before 2025. It announced that it had achieved this goal at the end of 2024. However, the lack of public information about the prototype quantum computer means that the announcement should be taken with a grain of salt.[78] The current Russian ambition is to scale to 100 qubits.[79] In March 2025, China launched Zuchongzhi 3.0, a superconducting quantum processor with 105 qubits, rivaling Google's quantum computing efforts.[80] Neither country has officially set out its international partnerships on quantum technologies in written national strategies. However, there are stated ambitions to collaborate on quantum computing within the BRICS forum.[81]

73 GOV.UK, "New joint statement between UK and US to strengthen quantum collaboration," November 4, 2021, https://www.gov.uk/government/news/new-joint-statement-between-uk-and-us-to-strengthen-quantum-collaboration (accessed March 24, 2025); UK Quantum Technologies Programme, "NPL and NIST strengthen collaboration in quantum science," November 21, 2021, https://uknqt.ukri.org/news/npl-and-nist-strengthen-collaboration-in-quantum-science/. (accessed March 24, 2025).

74 UK Research and Innovation, "UK quantum summer schools launched: will build international links," January 16, 2023, https://www.ukri.org/news/uk-quantum-summer-schools-launched-will-build-international-links/ (accessed March 24, 2025).

75 Department for Science, Innovation and Technology, "Nationwal Quantum Strategy," March 2023, https://assets.publishing.service.gov.uk/media/6411a602e90e0776996a4ade/national_quantum_strategy.pdf, p. 48.

76 Subcommittee on Quantum Information Science, Committee on Science of the National Science & Technology Council, "Advancing International Cooperation in Quantum Information Science and Technology," August 2024, https://www.quantum.gov/wp-content/uploads/2024/08/Advancing-International-Cooperation-in-QIST.pdf, p. 8.

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78 Matt Swayne, "Russia Unveils Its 50-Qubit Rubidium Neutral Atom Prototype Quantum Computer," *The Quantum Insider*, December 29, 2024, https://thequantuminsider.com/2024/12/29/russia-unveils-its-first-50-qubit-quantum-computer-prototype/#:~:text=The%20prototype%20aligns%20with%20Russia's,TASS%2C%20Russia's%20state%20news%20agency.

79 Matt Swayne, "Russia Unveils Its 50-Qubit Rubidium Neutral Atom Prototype Quantum Computer," *The Quantum Insider*, December 29, 2024, https://thequantuminsider.com/2024/12/29/russia-unveils-its-first-50-qubit-quantum-computer-prototype/#:~:text=The%20prototype%20aligns%20with%20Russia's,TASS%2C%20Russia's%20state%20news%20agency.

80 Alan Bradley, "China achieves quantum supremacy claim with new chip 1 quadrillion times faster than the most powerful supercomputers," *Live Science*, March 13, 2025, https://www.livescience.com/technology/computing/china-achieves-quantum-supremacy-claim-with-new-chip-1-quadrillion-times-faster-than-the-most-powerful-supercomputers (accessed March 24, 2025). https://blog.google/technology/research/google-willow-quantum-chip/

81 BRICS STI Framework Programme, "3rd Coordinated Call for BRICS Multilateral Projects 2019," February 21, 2019, http://brics-sti.org/files/BRICS_STI_Framework_Programme_Call_2019_v11.pdf.

CONCLUSIONS

Germany is among the top five countries of the 11 examined in terms of ambition regarding quantum computing and the transition to post-quantum cryptography. Given that these are the only countries to have published a national quantum strategy, it is safe to conclude that Germany is among the world's most ambitious countries. In terms of international reputation on quantum computing, Germany is ranked third, which makes its level of ambition commensurate with other countries' perceptions of its quantum capabilities. In short, Germany is a much sought-after partner.

Compared to other leading countries, however, Germany is still too ambiguous in its goals. Its strategy and the federal financing projects for quantum computing infrastructure projects do not distinguish between physical and logical qubits as a metric, and provide vague "low error rates" as a target, without little or no detail on the performance benchmarks this aims to achieve. Canada, by contrast, boasts goals in the coming seven years related to error correction (100–1000 qubits to one logical qubit), 100-way inter qubit connectivity and number of physical (1 million+) and logical qubits (100).[82] Similarly, with regard to its post-quantum cryptography goals by 2030, it is ambiguous whether Germany aims to accomplish the transition of large organizations, critical infrastructure or IT companies by that date – or just critical government systems. Nor is there any target for what happens post-2030. The UK strategy, for example, provides more detail in all these areas (see above).

Details of technological ambition in government discourse are a key indicator of confidence and technological prowess. When it comes to quantum computing, and to a lesser extent post-quantum cryptography, Germany should set more detailed performance targets, to which it aims to hold itself accountable. Such well-defined ambitions would propel it to further heights.

Finally, the new German government should initiate a quantum benchmarking initiative for German and European companies as part of its newly established Digital Ministry. The German coalition treaty mentions that Germany should build two high-performance quantum computers but does not define high-performance. By establishing a program that assesses companies' quantum computing performance, and verifies and validates their progress, Germany would encourage competition in the sector and make it easier for government entities to assess which products to acquire for their own systems. This would make announcements by companies of quantum computing breakthroughs more credible, as genuine progress is currently difficult to assess. The US has successfully launched such a quantum benchmarking initiative. Germany should launch its own program to support the competitiveness of German and European companies.[83]

82 Government of Canada, "National Quantum Strategy roadmap: Quantum computing," February 17, 2025, https://ised-isde.canada.ca/site/national-quantum-strategy/en/national-quantum-strategy-roadmap-quantum-computing (accessed April 14, 2025).

83 DARPA, "QBI: Quantum Benchmarking Initiative," https://www.darpa.mil/research/programs/quantum-benchmarking-initiative (accessed April 14, 2025)

ANNEX 1: GOVERNMENT DOCUMENTS ANALYZED

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- State of Australian Quantum (November 2024). Australian Government/Department of Industry, Science and Resources (link).

Canada

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- National Quantum Strategy Roadmap: Quantum communication and post-quantum cryptography (February 2025). Innovation, Science and Economic Development Canada. (link).
- National Quantum Strategy roadmap: Quantum computing (February 2025) Innovation, Science and Economic Development Canada. (link)

Denmark

- Strategy for Quantum Technology: Part 1, World-Class Research and Innovation (June 2023). Danish Ministry of Higher Education and Science (link).
- National Strategy for Quantum Technology Part 2, Commercialisation, Security and International Cooperation (September 2023). Ministry of Industry, Business and Financial Affairs (link).

France

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- France 2030 : Point d'étapes trois ans après le lancement de la stratégie nationale des technologies quantiques et lancement du programme PROQCIMA [France 2030: Three years on from the launch of the national quantum technology strategy and the PROQCIMA program] (March 2024). Ministry of Higher Education and Research. (link)
- Avis de l'ANSSI sur la migration vers la cryptographie post-quantique [ANSSI opinion on migration to post-quantum cryptography] (December 2023). French Cybersecurity Agency (link).

Germany

- Quantum Technologies Conceptual Framework Programme of the Federal Government (April 2023). Federal Ministry of Education and Research (link).
- Quantum-Safe Cryptography: Fundamentals, Current Developments and Recommendations (October 2021). Federal Office for Information Security (link).

Ireland

- Quantum 2030: A National Quantum Technologies Strategy for Ireland (November 2023). Department of Further and Higher Education, Research, Innovation and Science (link).

Japan

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Singapore

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- https://www.imda.gov.sg/about-imda/emerging-technologies-and-research/national-quantum-safe-network-plus (accessed March 24, 2025).
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United States

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- National Quantum Initiative Supplement to the President's FY 2025 Budget (December 2024). Subcommittee on Quantum Information Science, Committee on Science of the National Science and Technology Council. (link)
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DGAP receives funding from the German Federal Foreign Office based on a resolution of the German Bundestag.

Publisher
Deutsche Gesellschaft für Auswärtige Politik e.V.

ISSN 2198-5936

Editing Andrew Mash

Layout Marie Bauer

Design Concept WeDo

Author picture(s) © DGAP

The authors would like to thank Luka Bavdaž for his immensely valuable comments on an earlier draft of the policy brief. His feedback was especially helpful in the quantum computing section.