

From Promise To Power

How Europe can compete in the
global quantum computing race

Our thanks go to the interviewees who made this study possible:

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MANAGEMENT SUMMARY

The race to build the first fault-tolerant quantum computer with industrial applications is accelerating. After years of steady research and development progress, recent breakthroughs have pushed the industry into a rapid scaling phase. For the first time, the goal of manufacturing a machine with 100 logical qubits and industrial applications by 2030 seems within reach. What remains missing is consensus on the optimal technological path. For Europe, and Germany in particular, this is welcome news.

Over the past decade, the US and China have poured vast sums into quantum technologies – governments for geostrategic reasons and private investors for commercial opportunity. Yet neither has managed to pull decisively ahead. The contrast in cost efficiency between platforms is striking: superconducting systems, long favored by big tech, have absorbed at least EUR 3 billion in total R&D funding and, so far, have delivered, in practice, only single logical qubits below threshold, not linked to others. By contrast, neutral atom systems, having only recently entered the race to build fault-tolerant machines, have already demonstrated 48 interconnected logical qubits with comparatively modest funding, bringing their effective R&D cost per logical qubit down to around EUR 12 million.

For Europe and Germany, neutral atom quantum computing represents a unique opportunity. Development costs per logical qubit are significantly lower than in competing platforms, and German players are already among the global frontrunners. Crucially, this field builds on the continent's established strengths in optics and photonics, providing a solid industrial and research base from which to scale. Strengthening this position now is essential to secure sovereignty and long-term economic impact – missing the moment would be a serious strategic error.

Europe must deploy concentrated resources to the most promising national champions and their high-potential platforms, with investment bundled at sufficient scale to reach the 100-logical-qubit target for industrial applications and to attract private capital. The overarching goal must be to create new global champions such as ASML, SAP, or ARM. The current fragmented system, with its emphasis on geographical proportionality rather than excellence, lacks the focus on funding required to scale.

At the same time, investment must support end-to-end funding schemes that co-design software and algorithms for specific hardware platforms, rather than relying on hardware-agnostic approaches that dilute impact. Dedicated hubs should integrate hardware and software development to ensure that industry can rely on “Quantum Computers Made in Europe”, not just accessed as foreign cloud services. A co-investment vehicle should mobilize private funds under strict milestones, with governments as anchor customers, and embed quantum computing in defense budgets.

By harnessing its unique strengths, Europe can shape the global quantum future on its own terms. Only such focused, large-scale action will allow it to secure sovereignty in this critical technology and build world-leading quantum computers by 2030. But Europe must act fast!

Double down on Europe's strengths

Five levers for how the continent can stay competitive in the global quantum computing race

1. Competitive funding for European champions:

Concentrate funding on European players with the highest potential to become global leaders, assessed by technical feasibility and economic ability to scale, to ensure that know-how, talent, and value creation stay in Europe. This also ensures a resilient European-led supply chain. Against this backdrop, the German High-Tech Agenda sets the right course, but it must be implemented quickly and expanded into a lasting, unbureaucratic, milestone-based funding framework that is internationally competitive.

2. Make fewer, bigger bets:

Select no more than three high-potential technologies, create unified platform hubs, and supply sufficient funding for them to reach ambitious targets such as 100 logical qubits by 2030. A milestone-based evaluation framework must ensure that underperforming approaches can exit in a transparent and efficient manner, while channeling resources toward successful ones with the potential to leverage up to a billion euros in funding for a single scale-up over the next five years.

3. Establish a dual funding boost:

Set up a powerful, unbureaucratic public-private investment vehicle to mobilize large-scale private capital enabling European start-ups to compete in the global scaling race and reach the growth state where ticket sizes of EUR 100 million to EUR 1 billion are required.

4. Act as reliable anchor customers:

Strategic autonomy requires reliable anchor demand. Governments must continue to use public procurement to back start-ups and scale-ups with credible scaling roadmaps, linking support to strict milestones and fostering up-or-out progress toward fault tolerance.

5. Open up defense budgets:

Quantum computing is critical for national security. Defense budgets should allocate substantial resources to accelerate European platforms, ensuring that sovereignty in this key technology is secured on European soil.

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1

A MARATHON TURNS INTO A SPRINT:

Quantum computing is in
a rapid phase of scaling



Technological revolutions rarely advance in straight lines. More often, years, sometimes decades, of painstaking experimentation in the lab are followed by a sudden breakthrough that unleashes a cascade of innovations and rewrites the rules. So it was with the classical computer, when more than a decade after the invention of the transistor, silicon emerged as the ideal semiconductor. Now quantum computing is at a similar inflection point.

For decades, quantum computing has held the promise of tackling problems far beyond the reach of classical machines. The foundation of this promise lies in quantum bits, so-called qubits, that leverage the rules of quantum mechanics to represent and process information in ways classical bits cannot. Unlike a bit that is strictly 0 or 1, a qubit can be in superpositions of both. Furthermore, many qubits can be entangled, giving rise to exponentially growing information-processing capabilities with no classical counterpart. This makes quantum computers uniquely suited to challenges that overwhelm classical machines. Simulating molecules and materials already strains the limits of today's supercomputers. Optimizing networks in logistics and finance becomes unmanageable as complexity explodes. In cryptography, factoring the large numbers that underpin RSA encryption would require impractical amounts of time and resources on classical machines, which is why current systems remain secure.

But building such machines has never been easy. The physical realizations of qubits in any technology platform are fragile and prone to errors. To leverage the computational power in a regime relevant for potential com-

“Europe gets only a quarter of the venture capital, even though our universities produce as much IP as America’s – and we actually create more start-ups. So it’s not an IP problem, and it’s not a start-up problem. It’s a scale-up problem.”

Hermann Hauser, Founding Partner of Amadeus and ACORN COMPUTERS

mercial applications, information must be redundantly encoded across many physical qubits to form a more stable, so-called logical, qubit. Unlike raw physical qubits, logical qubits can preserve information reliably enough to run long and complex calculations and are widely seen as the true building blocks of scalable quantum machines.

In recent years, experiments have shown convincing demonstrations that logical qubits and error correction work in practice. The challenge now is to scale the hardware and refine the platforms so that at least 100 interconnected, stable logical qubits can be realized, enough to enter a regime where no classical supercomputer can compete. From there, progress will depend on steadily expanding the number of logical qubits while improving their quality and efficiency, as well as the fidelity of the operations processing information. With advances in manufacturing, control electronics, and system integration, the field is shifting from scientific proofs of concept to an engineering race to scale. To avoid any misunderstandings: the goal of 100 logical qubits is only the beginning. Industrial applications in pharma or cryp-

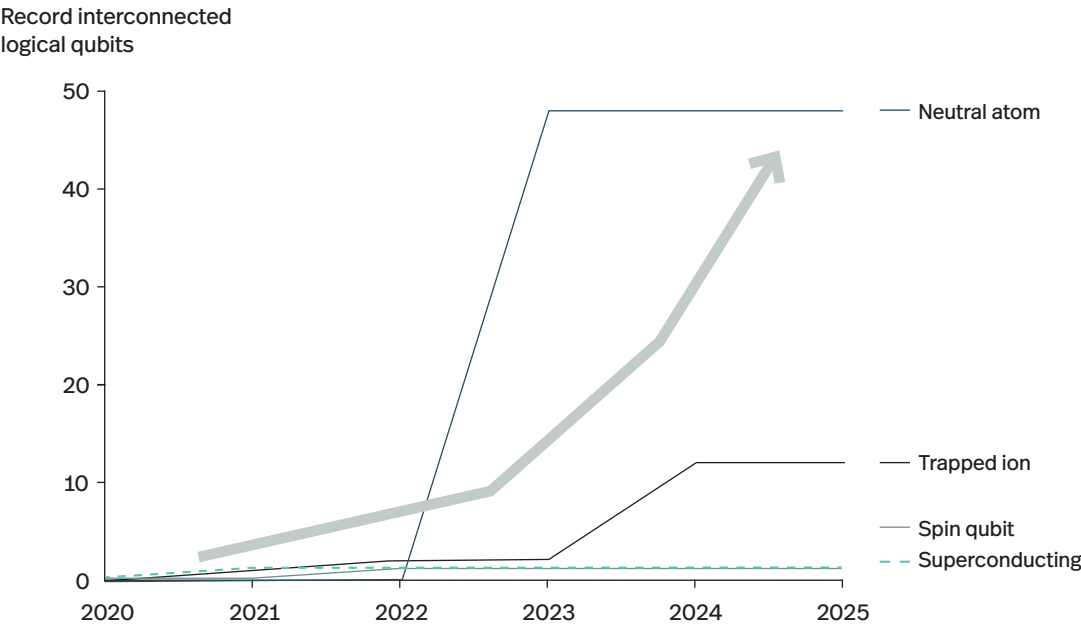
tology require thousands of logical qubits. This is also why the medium-term goals extend beyond the 100-logical-qubit mark and are considerably more ambitious.

What lies ahead is an immense industrialization effort: scaling up to ever larger qubit arrays, ensuring reliable

control and integration, improving error correction, and reducing overall system costs. Yet the reward is enormous. A utility-scale quantum computer, once a distant idea, is beginning to come into view. For industries, from pharmaceuticals to energy, materials science to agriculture, the impact could be transformative. →A

A The sky is the limit

Logical qubit count on leading quantum computing platforms¹⁾



¹ The specific characteristics of the different hardware platforms (neutral atoms, trapped ions, spin qubits, and superconducting qubits) will be discussed in detail in Chapter 3; here only the record numbers of interconnected logical qubits are shown to illustrate the rapid scaling in recent years

Source: Press releases, Nature

This study analyzes the intensifying scientific and commercial race in scaling quantum computers. As **Chapter 2** highlights, Germany and Europe must remain at the forefront: quantum computing will not only shape tomorrow's industries but also become a cornerstone of national and technological sovereignty.

Europe is not starting from behind. In quantum sensing, Germany is regarded as a leader, and in quantum communication, Europe can likewise point to groundbreaking scientific achievements and strong regional hubs in Munich, Vienna, and Delft. Most importantly, the contest to build fault-tolerant quantum computers remains wide open. Several technological approaches are still competing, and it is too early to tell which one will prevail.

Against this backdrop, **Chapter 3** compares the most promising platforms from a distinctly European vantage point: which technology offers Germany and Europe the strongest international prospects? Which approach fares best, under current geopolitical strains, from the perspective of technological sovereignty? And where could financial resources be deployed most effectively?

In **Chapter 4**, we address policymakers directly with a set of recommendations. We call for a focus on a select group of national champions, rather than dispersing support thinly, in order to remain as competitive as possible on the global stage. We also favor an end-to-end integration of software and hardware, with the aim of avoiding dependency and strengthening Europe's quantum ecosystem in depth.

“The beauty of quantum computing is that there is no inherent advantage one can derive from the US’s near dominance in classical IT over the past 50 years that automatically carries over to the quantum computing sector. It is truly a greenfield technology – a completely zero-based, start-from-scratch kind of field.”

Bob Sorensen, Chief Analyst for Quantum Computing, Hyperion Research

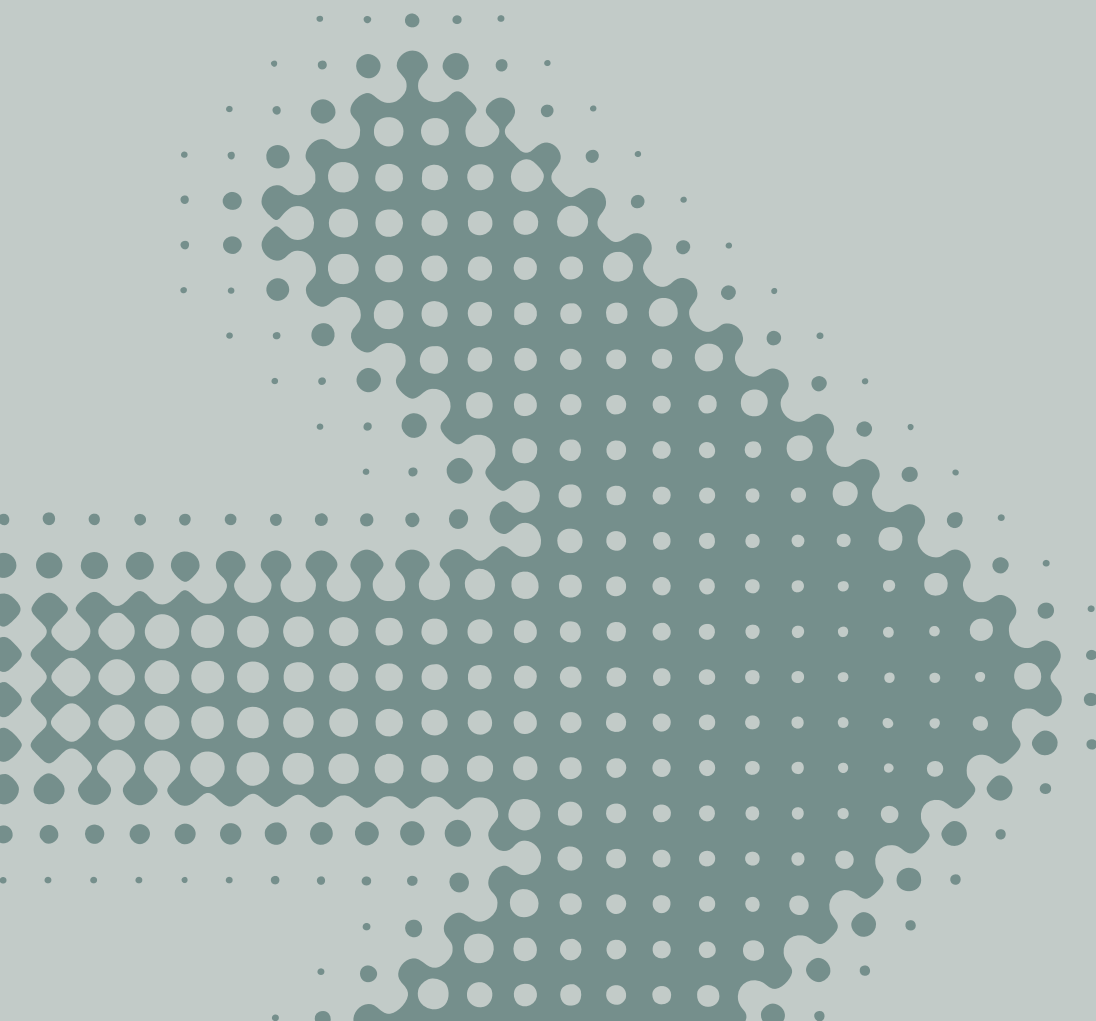
“In America, investors bet big on the companies most likely to win. In Europe, everyone gets a slice of the pie. But to build champions, Europe must give its frontrunners a bigger slice.”

Helmut G. Katzgraber, Chief Science Officer and General Partner 55, North

2

QUANTUM SPEED-UP:

Mapping the future market
and its geostrategic stakes



It is hardly surprising that governments and the world's largest tech companies continue to place hefty bets on quantum technology. Strip away the hype, and even in its narrowest framing, the technology still holds the potential to reshape the world. Among the multitude of possible applications, a few stand out.

Drug discovery and materials science are expected to benefit first, since molecules and materials behave according to the laws of quantum mechanics and quickly overwhelm even the largest classical supercomputers. Quantum computers, by directly exploiting quantum effects, are expected to tackle classically intractable problems in these domains, enabling simulations beyond the reach of classical methods.¹⁾ The implications could redefine entire sectors, spurring faster development of new medicines, breakthroughs in next-generation batteries, catalysts that break down microplastics, improve soil fertility, or even enable self-healing concrete.

Beyond chemistry and materials science, cryptography is another domain where the impact is clear. Shor's algorithm is one of the very few proven cases of exponential speed-up: once sufficiently powerful quantum computers become available, today's widely used public-key systems such as RSA cryptography could be broken.²⁾ This threat has already triggered global efforts to develop quantum-safe alternatives, underlining how seriously

the threat is taken. Quantum computing may also bring advances in machine learning, while in optimization expectations remain cautious, with only modest speed-ups considering the necessary hardware effort, and advantages being restricted to very narrow use cases

Against this backdrop, forecasting the trajectory of the quantum computing market remains fraught with uncertainty. The more powerful the machines become, the faster demand is likely to accelerate. Yet, by extrapolating from recent growth rates and the potential scope of future applications, it is possible to sketch at least the contours of the market ahead. To this end, we outline two scenarios: one conservative, the other optimistic.

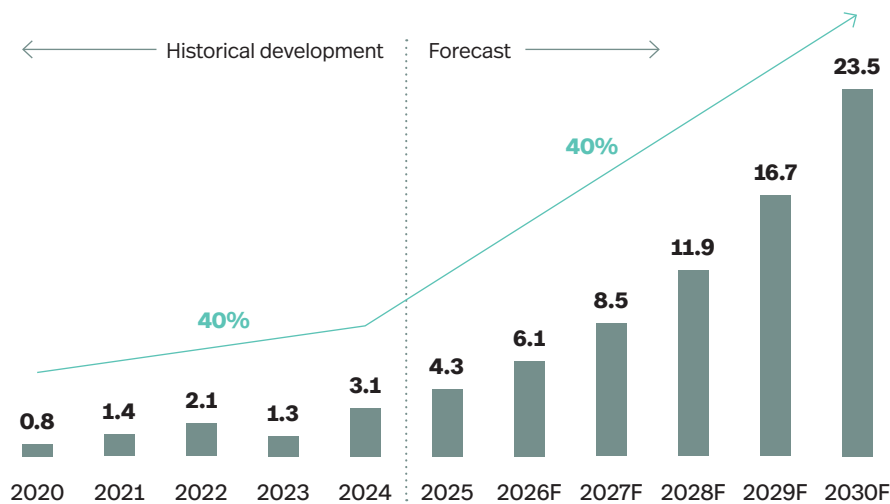
Even if investment in quantum computing were to grow only at its historical rate of 40 percent, the trajectory would already be steep. Funding would rise from EUR 3.1 billion in 2024 to EUR 23.4 billion by 2030. This conservative scenario does not account for the acceleration that further technological breakthroughs could trigger – similar to the rapid scaling currently seen in generative AI. Furthermore, these figures capture only investment in the quantum computing platforms themselves; they exclude the ripple effects in end markets, from pharmaceuticals and materials discovery to agriculture and energy, where the economic impact could be many times greater. →B

1 McArdle, S., Endo, S., Aspuru-Guzik, A., Benjamin, S. C., & Yuan, X. (2020). Quantum computational chemistry. *Reviews of Modern Physics*, 92(1), 015003

2 Shor's algorithm is a quantum algorithm that factors large numbers exponentially faster than classical computers, threatening classical encryption schemes such as RSA-2048 that rely on the hardness of factoring

B Quantum computing's relentless climb

Annual funding in quantum computing hardware¹⁾ [EUR bn]



1 Assumptions for corporate R&D spending: EUR 100 m per major player (IBM, Google, Amazon) on superconducting qubits in 2025; EUR 50 m by Intel on spin qubits; Alibaba EUR 20 m in 2023 before exiting quantum R&D; linear funding growth from market entry assumed; Microsoft EUR 50 m over last 5 years evenly on topological qubits

Source: Crunchbase, Pitchbook, S&P Capital IQ

Amid all the economic promise, quantum computers also carry disruptive potential in security. In the mid-1990s, the American mathematician Peter Shor showed that a sufficiently powerful quantum computer could break RSA encryption – the backbone of today's digital security. Doing so would require thousands of stable logical qubits (and millions of physical qubits),³⁾ far beyond today's prototypes. Yet if such machines are realized, they could factor the large prime numbers that

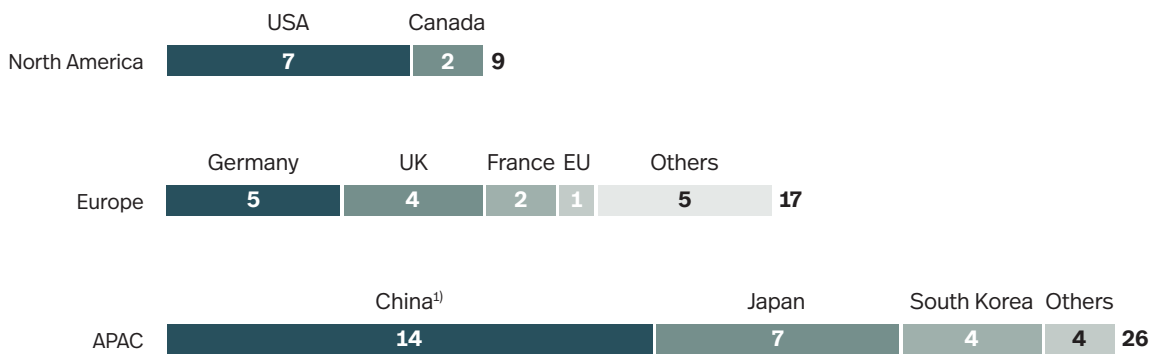
safeguard today's online communications, financial transactions, medical records, and corporate secrets. This so-called "Q-Day" may still be distant, but the faster quantum systems scale, the closer it looms.

This uncertainty explains much of the ferocity with which China and the United States are vying to build the first "full stack" quantum computer. Possession of such a machine would confer a decisive geostrategic and

³ The difference between logical and physical qubits is explained in detail in Chapter 3

C Quantum capitalism – State cash in China, venture bets in America, a hybrid path in Europe

Public funding of quantum initiatives by region and country [EUR bn]



¹ The recently announced RMB 1 trillion (EUR 138 bn) Chinese fund for “cutting-edge technologies” is not included, as the allocation to quantum technologies is unclear

Source: Press search, Qureca

economic advantage. In response, both have imposed export controls on critical quantum components, such as high-performance cooling systems needed to operate quantum hardware. The UK, France, Spain, the Netherlands, and others in Europe, as well as allies like Australia and Canada, have followed with similar restrictions. China, meanwhile, is working assiduously to develop the necessary equipment, e.g. specialized lasers, domestically, with the stated aim of eliminating reliance on Western suppliers. The result is an extra dose of momentum in the already charged quantum technology race.

At first glance, Europe and Germany appear to have recognized the strategic importance of keeping pace with global leaders in quantum computing. Germany’s planned public investment (ca. EUR 5 billion) is not lagging far behind US government commitments (ca. EUR 7 billion). China, with publicly announced pledges amounting to ca. EUR 14 billion, trails the combined national programs of EU member states. Yet the picture is misleading – for several reasons. →C

Headline figures on public funding obscure the structural differences between ecosystems. In the US, it is not only the state but deep-pocketed venture capital and technology giants such as Google, IBM, Amazon, and Microsoft that drive quantum innovation. This has left America's leading firms in the field far better financed than their European rivals.

A closer look at the numbers confirms the imbalance: Microsoft spends about EUR 250 million annually⁴⁾ on quantum computing, nearly three times the total venture funding raised by all EU start-ups in the field of quantum technologies in 2024. Looking at the overall financing of quantum computing start-ups, the same picture emerges. The top five US start-ups have raised about more than twice as much capital as their European rivals. But there is an encouraging sign of progress: the recent EUR 275 million Series B funding round for IQM, led by American investors alongside strong European participation and representing the largest Series B in quantum computing outside the United States, turned the Finnish company into Europe's first quantum computing unicorn. Progress has begun, but to build real momentum, Europe will need many more success stories of this scale in the years ahead. Overall, this tally does not even account for the internal R&D budgets of other tech giants such as IBM, Google, and Amazon, which are not disclosed but are thought to be on a par with Microsoft's spending. → **D**

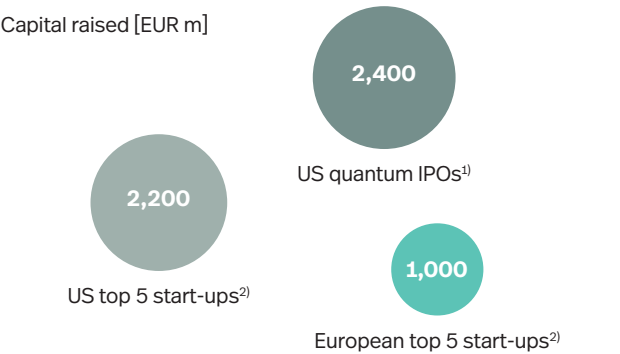
The gap with China in quantum computing may be far wider than official figures suggest. Private investment plays only a marginal role there, with most research

housed in state-run university laboratories. The country's most promising start-ups are typically state controlled or heavily backed by state capital. The true scale of funding is opaque, not least because of scarce and incomplete data. China is also planning a RMB 1 trillion (ca. EUR 120 billion) investment fund for "emerging technologies", part of which is explicitly earmarked for quantum.

By contrast, Europe's approach is best described as a hybrid system. Individual nations invest independently, complemented by EU-level programs. Funding typically flows into clusters that link research institutions with

D In a league of its own

Funding of US start-ups compared with their European rivals



1 Incl. IonQ and Rigetti
2 Largest five start-ups building quantum computers by funding raised

Source: S&P Capital IQ, Crunchbase

4 Wall Street Journal, The Man Behind Microsoft's Decadeslong Quest to Build a Quantum Computer, March 16, 2025

start-ups, working in tandem to advance the technology. This model has so far allowed Europe to keep pace with both China and the United States in quantum technologies. Whether it can continue to do so, however, is increasingly in doubt.

A central weakness lies in the way funding is allocated. Resources are often diluted by geographical proportionality – ensuring that not just every country but even individual regions receive their own share, with quantum hubs scattered all over the place. Combined with support being spread across a wide range of hardware platforms, a luxury not many countries can afford, this leaves no single company with the critical mass of capital required to scale, putting Europe's start-ups at a disadvantage compared with their global peers.

As the sector shifts into a crucial scaling phase, this broad-based funding approach – combined with Europe's underdeveloped venture capital ecosystem – could become a significant competitive disadvantage. Companies aiming to launch the first universal quantum computer urgently need capital to bring their platforms to industrial-grade performance. Otherwise, Europe risks seeing valuable know-how drift to the US, as has happened in other technology sectors. A foretaste came with the recent record takeover of UK-based Oxford Ionics by US-listed rival IonQ for EUR 922 million, or the USD 1 billion round of the UK-founded PsiQuantum that relocated to the US. Both are regarded as leaders in quantum computing on their respective technology platforms.

These deals also carry a clear geostrategic dimension. For the US, the benefits are threefold: access to cutting-edge expertise, entry into Europe's talent pool and university networks, and a foothold in European grant funding. From a European perspective, this is cause for concern. The silver lining: not every technology niche demands such deep capital reserves to keep critical know-how anchored in Europe.

Quantum computing is not a single technology but a race between competing hardware platforms. Today, four approaches have demonstrated error-corrected logical qubits: superconducting qubits, spin qubits,⁵ trapped ions, and neutral atoms. Each relies on different physical principles, and each has distinct advantages and limitations. The competition between these platforms is still wide open – there is no consensus yet on which will ultimately prove most scalable. A deeper dive into their technical workings will follow in the next chapter; for now, the focus is on funding patterns and the progress they have enabled. →E

“The neutral atom approach is exciting. It has leaped from behind to join the frontrunners, alongside superconducting and ion trap systems.”

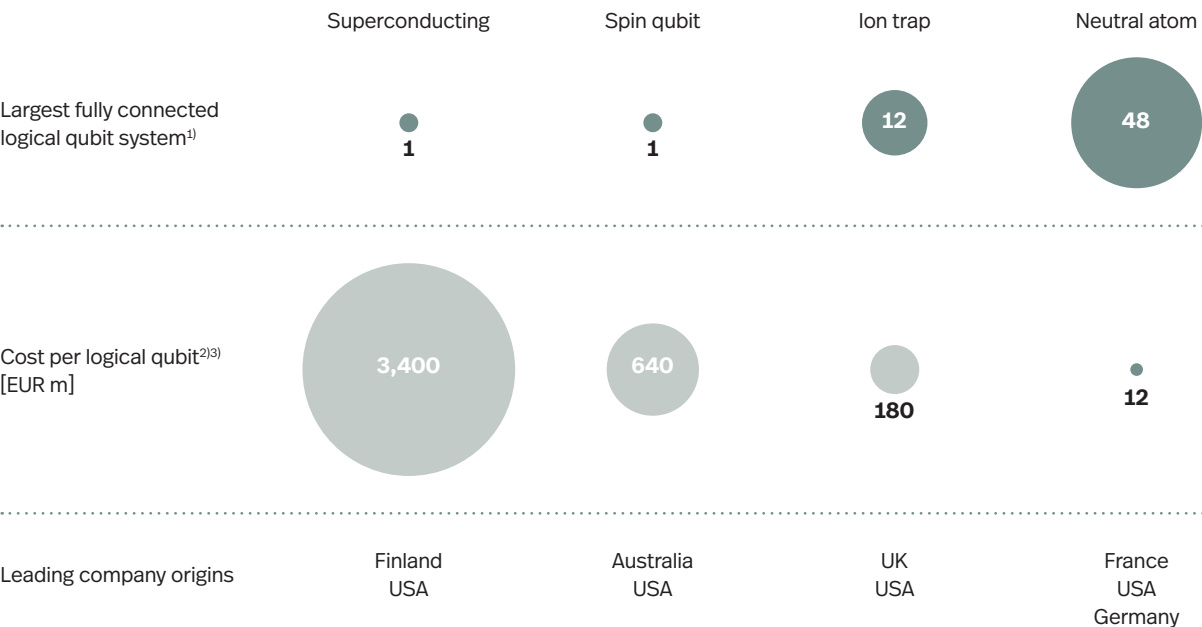
Michele Mosca, CEO, evolutionQ Inc. and
Geschäftsführer, evolutionQ GmbH.
Co-founder and Professor, Institute for Quantum
Computing, University of Waterloo

5 For spin qubits, demonstrations of error-corrected logical qubits have been achieved in nitrogen-vacancy centers in diamond, while T-centers in silicon and semiconductor spin qubit platforms have not yet reached this stage

E Value for money – Newcomer outpaces incumbents

Development cost per logical qubit in different quantum computer platforms

The target for a digital error-corrected quantum computer able to solve real-world applications is 100 connected logical qubits



1 Photonics are not included here, given that no logical qubit has yet been demonstrated

2 Total funding on a platform divided by the maximum number of interconnected logical qubits demonstrated on that platform

3 Assumptions for corporate R&D spending: EUR 100 m per major player (IBM, Google, Amazon) on superconducting qubits in 2025; EUR 50 m by Intel on spin qubits; Alibaba EUR 20 m in 2023 before exiting quantum R&D; linear funding growth from market entry assumed; Microsoft EUR 50 m over 5 years evenly on topological qubits

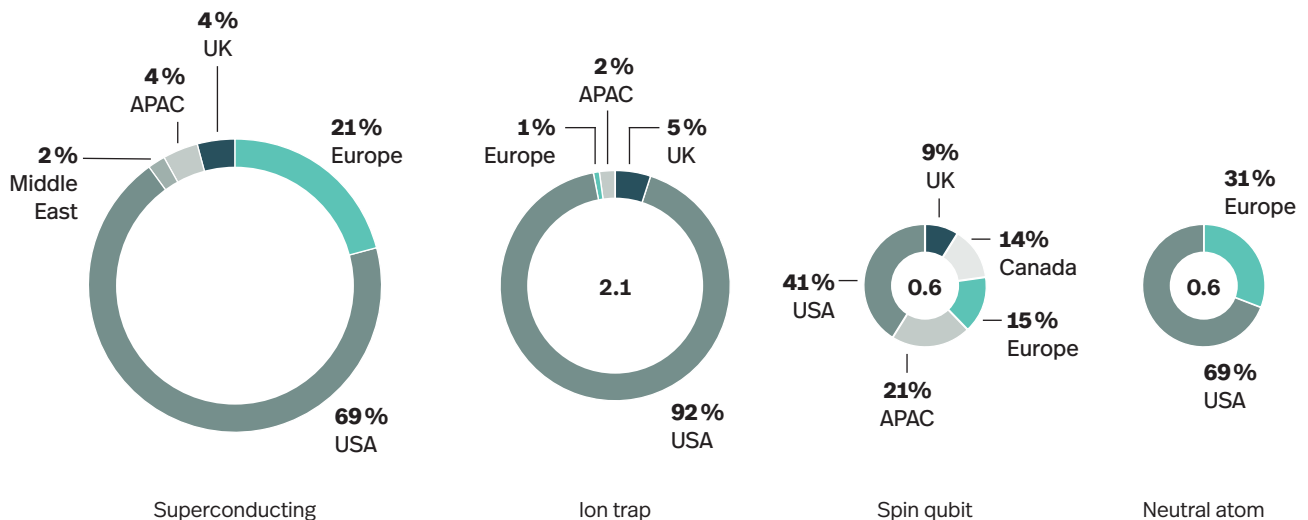
Source: Crunchbase, S&P Capital IQ, Nature, press releases, interviews with market participants, internal analysis

A comparison of investment levels and realized qubits highlights striking differences. The most established approaches are superconducting qubits, backed by tech giants and large-scale start-ups, and ion traps, supported by a handful of well-financed specialists. Yet when measured against the number of interconnected logical qubits demonstrated so far, neutral atoms stand out.

With comparatively modest funding, they have already produced by far the highest count of stable, interconnected qubits – 48 in a single system. On a “funding per qubit” basis, the platform is by far the most efficient, at roughly EUR 12 million per logical qubit, underscoring its potential to leapfrog more established approaches. →F

F Quantum capital – American dominance, European footholds

Total start-up and corporate R&D funding by platform and country/region [EUR bn; %]



1 Assumptions for corporate R&D spending: EUR 100 m per major player (IBM, Google, Amazon) on superconducting qubits in 2025; EUR 50 m by Intel on spin qubits; Alibaba EUR 20 m in 2023 before exiting quantum R&D; linear funding growth from market entry assumed; Microsoft EUR 50 m over 5 years evenly on topological qubits
2 Photonics are not included here, given that no logical qubit has yet been demonstrated

Source: Crunchbase, S&P Capital IQ, Nature, press releases, interviews with market participants, internal analysis

Looking at absolute funding volumes confirms the imbalance. Superconducting qubits and ion traps have attracted the lion's share of capital, with spin qubits trailing. Neutral atoms, in contrast, have absorbed the least funding of all four platforms. Yet here, too, the story carries a European angle: Europe accounts for around 31% of global investment in neutral atom quantum computing, compared to 69% in the United States. China's share is difficult to assess due to opaque reporting, though visible scientific progress indicates commitment.

This combination of efficiency, momentum, and scientific depth gives neutral atoms the profile of a potential "dark horse" in the quantum race. As the sector enters a decisive scaling phase, the fact that the youngest platform has already demonstrated the highest number of interconnected logical qubits with the lowest relative funding should not be overlooked. Europe's strong research base and active start-up landscape in this field mean that the continent is not merely playing catch-up but is positioned to shape the frontier of a critical platform.

Against this backdrop, the neutral atom approach offers significant opportunities for Germany and Europe, with French and German companies counted among the global leaders in the field. The relative strengths and challenges of the main technology platforms will be examined in the next chapter.

"Currently, there is no winning horse in sight in the race for a utility-scale quantum computer. This offers many opportunities for Europe, especially in neutral atom systems, where we are roughly on a par with our competitors."

Ignacio Cirac, Director at the Max Planck Institute of Quantum Optics, Germany

3

STATUS QUO:

One of Europe's best chances in quantum computing lies with neutral atoms



In classical computing, it eventually became clear that silicon chips provided the right combination of scalability, reliability, and manufacturability to dominate the field. But that outcome was not obvious in the early days where many competing technologies were once considered viable. Quantum computing is at a similar stage today. Multiple hardware platforms are being explored in parallel, each offering distinct strengths and facing specific bottlenecks when measured against coherence time, connectivity, and scalability.

Superconducting qubits and trapped ions were the first potentially scalable platforms to demonstrate working prototypes in the early 2000s, and remain the most advanced today, with companies like IBM, Google, IQM, AQT, IonQ, and Quantinuum bringing systems to market. Since around 2018, new contenders such as neutral atoms (e.g. QuEra, PASQAL, Atom Computing, planqc), photonics (PsiQuantum, Xanadu), and semiconductor spin qubits (Intel, Quantum Motion) have attracted growing investment and scientific momentum. The field now counts over 100 active companies worldwide, with superconducting qubits and trapped ions dominating early commercialization but neutral atoms rapidly gaining ground. This timeline illustrates how leadership in quantum hardware has shifted over the past two decades and how the race remains open.

Despite their different architectures, all quantum computers face the same fundamental challenge: qubits are fragile and prone to errors. To perform reliable calculations, many imperfect physical qubits must be combined into a single logical qubit that can detect and correct errors continuously. This error correction comes at

a steep cost in scale, as hundreds or even thousands of physical qubits may be required to sustain one useful logical qubit.

In this context, it is important to recognize that progress on logical qubits has been underpinned by steady advances in physical qubit scaling and quality. Across all leading platforms, record physical qubit counts have increased along exponential trajectories when plotted on a logarithmic scale. Neutral atoms have expanded the fastest, with a doubling time of about 1.4 years, driven by the relative ease of assembling large atomic arrays with optical tweezers and lattices, followed by superconducting qubits at roughly 1.9 years. Ion traps and spin qubits have grown significantly more slowly, with doubling times of 6.1 and 6.3 years, respectively. While sheer numbers of physical qubits do not guarantee useful performance – fidelity, connectivity, and gate speed remain equally critical – these scaling trends provide the essential baseline from which recent demonstrations of logical encoding have become possible. Yet scaling tells only part of the story. The real measure of progress lies in whether these larger devices can perform reliably. →G

“In Europe, we devote far too little attention to scaling. Where are the business models that enable scaling and ensure a return on investment?”

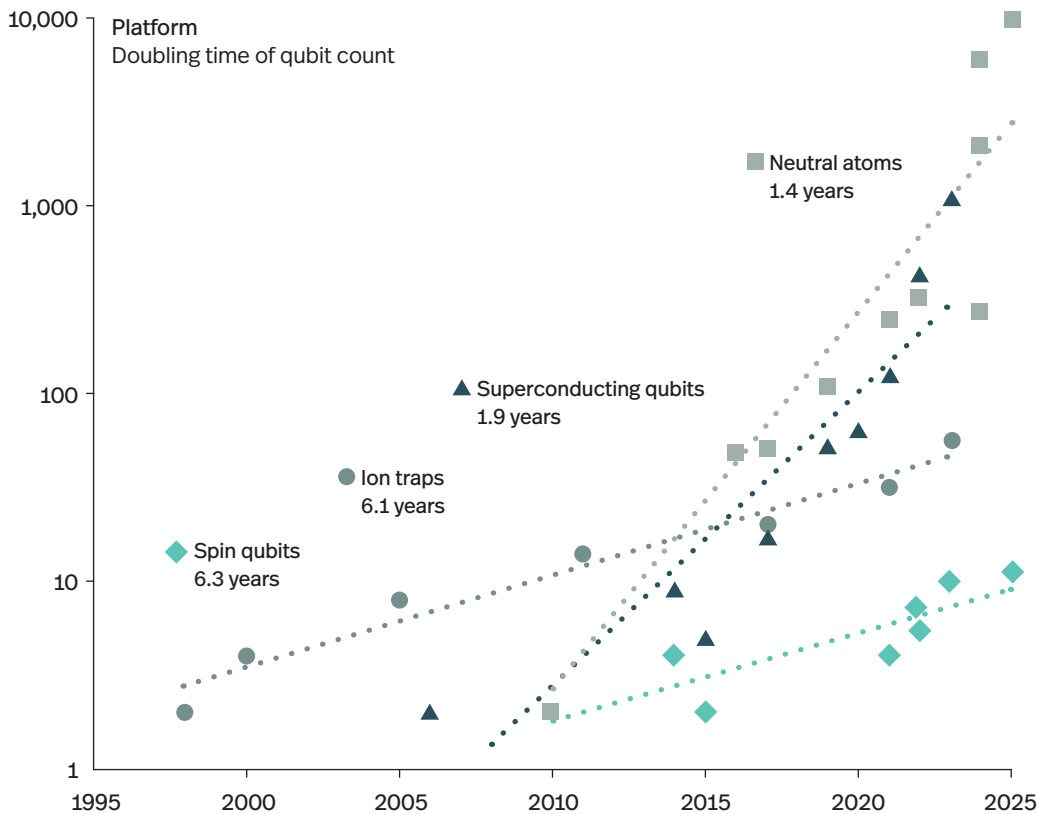
Carsten Polenz, Vice President and Head of Quantum Computing, SAP SE

3
Status quo:
One of Europe's best
chances in quantum computing
lies with neutral atoms

G Rising fast

Increases in physical qubit counts across the respective platforms

Record physical qubit count (log scale)



1 Exponential (log-space) regression R^2 values: superconducting (2006–2023) = 0.83;
ion trap (1998–2023) = 0.96; spin qubits (2010–2025) = 0.79; neutral atom (2010–2024) = 0.88

Source: IE.F

Performance must also be judged by fidelity, the depth of circuits that can be executed, the cycle speed of calculations (similar to clock speed in classical computers), and the efficiency of qubit connectivity. However, the ability to demonstrate and operate logical qubits is a critical milestone, marking the transition from proof-of-principle physics experiments to scalable quantum computing. From there, the decisive challenge is not just increasing logical qubit numbers but scaling systems while maintaining or improving high performance, since only then can useful applications be unlocked. Against this backdrop, we can distinguish platforms that have already realized logical qubits from those that are still working toward this goal.

PLATFORMS WITH DEMONSTRATED LOGICAL QUBITS:

• Superconducting qubits

Superconducting circuits, operated a fraction of a degree above absolute zero, are pursued by big tech companies such as IBM and Google and scale-ups such as IQM, which have shown devices with hundreds of qubits, and more recently, a first logical qubit, albeit stand-alone and not interlinked with other logical qubits. The advantages are fast qubit interactions and reliance on mature microfabrication techniques from the semiconductor industry. The main challenges are scaling processors to thousands of qubits, overcoming limited qubit connectivity, and building the extensive cryogenic infrastructure required to keep both processor and qubit control cabling and electronics at such low temperatures.

• Trapped ions

Ions, or electrically charged atoms, held in electric radio-frequency fields and manipulated by lasers, offer qubits of exceptional quality. They enable operations with low error rates and allow all-to-all connectivity in small registers. Yet their drawbacks are scalability and speed. The mutual repulsion of ions complicates the construction of larger processors, the viability of proposed 2D architectures for scaling must still be demonstrated on a larger scale, and operations remain slower than in solid-state systems.

• Neutral atoms

Electrically neutral atoms arranged in optical lattices or captured by optical tweezers represent a promising platform with strong recent momentum. They combine long coherence times with scalability, since large arrays can be assembled with relative ease. A recent first demonstration of a 48-qubit logical register, the largest interconnected logical system realized so far, highlighted the potential of this approach to advance quickly.

At the same time, significant challenges remain. Operations on neutral atoms (gates, readout) are generally slower than those in superconducting qubits, though much faster than in ion traps. This means algorithms generally take longer to run compared with superconducting platforms. Scaling high-precision optical control to thousands of atoms without loss of fidelity is demanding, and building the necessary laser and optical infrastructure at industrial scale poses substantial engineering hurdles. Still, with its balance of coherence, connectivity, and scalability, combined with platform-specific, more efficient error correction

schemes, neutral atoms are increasingly viewed as a serious alternative to the more established superconducting and ion trap platforms.

• Spin qubits in semiconductors

Electron or hole spins confined in semiconductor quantum dots can serve as qubits, with control via electrical or microwave signals. This approach benefits from direct compatibility with semiconductor fabrication processes, enabling prospects for integration and scaling similar to today's CMOS technology. Recent progress in silicon spin qubits has shown small error-correcting codes, marking first steps toward logical encoding, but a fully error-corrected logical qubit has not yet been demonstrated in this platform (in contrast to diamond-based spin systems). The main challenges for semiconductor spin qubits are reducing device variability, achieving high-yield fabrication, and improving two-qubit gate fidelities at scale. They are nonetheless regarded as the most promising spin-based route to large-scale quantum computers because of their natural link to semiconductor industry scaling.

Beyond quantum dots, defect-based spin systems are also relevant: nitrogen-vacancy centers in diamond have enabled early demonstrations of logical encoding but are not regarded as scalable, while silicon T-centers, though still at a very early stage, may offer a more integrable path within semiconductor platforms.

While superconducting, ion trap, neutral atom, and spin qubit systems have all achieved first demonstrations of logical encoding, other approaches remain at an earlier stage. These platforms show promise but have not yet realized a fully error-corrected logical qubit:

• Photonic qubits

Photons can encode qubits at room temperature and are naturally suited for transmission across optical networks, promising modular architectures. However, reliable single-photon sources, manipulation, and detection remain difficult, and detectors still require cryogenic operation. While first demonstrations of logical encoding in single photonic modes have been achieved, a functional error-corrected logical qubit, comparable to those demonstrated in ion trap or neutral atom systems, with multiple qubits interconnected and manipulated under active error correction, has not yet been realized in photonics.

• Topological qubits

A more exotic idea, pursued notably by Microsoft, is the topological qubit, where the information is not stored in a single particle, like an atom or ion, but in the braiding of special quasiparticles across the system. The information of the qubit is the braid itself, like a rope woven into a pattern that remains intact even if you shake it, so in theory it is naturally protected from many local errors. This intrinsic robustness could make building large-scale quantum systems much easier. In practice, however, the required topological materials are extremely difficult to realize, and no working topological qubit has been demonstrated so far.

In addition, there are special-purpose architectures that do not aim for universal quantum computing but exploit quantum effects for narrower classes of problems:

- **Quantum annealers**

Another approach is the quantum annealer, a specialized type of quantum computer developed most prominently by D-Wave. The word “annealer” comes from metallurgy, where heating up a piece of metal and slowly cooling it down (“annealing”) lets it settle into a stable, low-energy form. In the same way, a quantum annealer lets a network of qubits settle into its lowest-energy state, which corresponds to the solution of an optimization problem. These machines are not universal quantum computers and have limited applicability, but they demonstrate quantum principles at larger scales and have already found some early commercial use cases. Beyond superconducting implementations, analog neutral atom platforms have also been explored for annealing-type tasks, with experiments approaching the quantum supremacy regime.

“Does every federal state really need its own Quantum Valley? Maybe a focused, resource concentrated approach – like in China – is smarter. Why can’t we replicate the Airbus success in other fields?”

Peter Zoller, Professor Emeritus at the University of Innsbruck and Scientific Director Emeritus of IQOQI, Austrian Academy of Sciences.

It remains unclear which platform will ultimately prevail. In theory, some may prove better suited to specific use cases than others, raising the possibility of multiple winners – even if the trajectory of conventional computing points in a different direction. What is clear, however, is that momentum in the field has shifted with the emergence of newer approaches. The still-nascent neutral atom method offers compelling reasons for further investment. For Europe and Germany, this is encouraging news: they hold competitive advantages in this area. Five reasons stand out in particular:

1. FIRST-MOVER ADVANTAGE IN AN OPEN RACE

Superconducting and trapped-ion qubits are currently dominated by American big tech companies and well-funded start-ups. Both fields have been advanced for two decades, supported by investments in infrastructure, know-how, talent, and supply chains. These efforts have yielded important milestones, with superconducting qubits reaching the demonstration of a single logical qubit and trapped ions extending to around a dozen interconnected logical qubits.

Error-corrected quantum computing with neutral atoms, by contrast, is a younger technology that has broader commercial traction since 2018–2020. Yet within this shorter timeframe, the platform has already demonstrated 48 interconnected logical qubits. This achievement highlights its structural advantages in scalability. Neutral atoms therefore represent a potential “leapfrog” moment in the technological race. Unlike in superconducting and ion-based approaches, the competitive field remains open, with promising start-ups emerging on both sides of the Atlantic.

3
Status quo:
One of Europe's best
chances in quantum computing
lies with neutral atoms

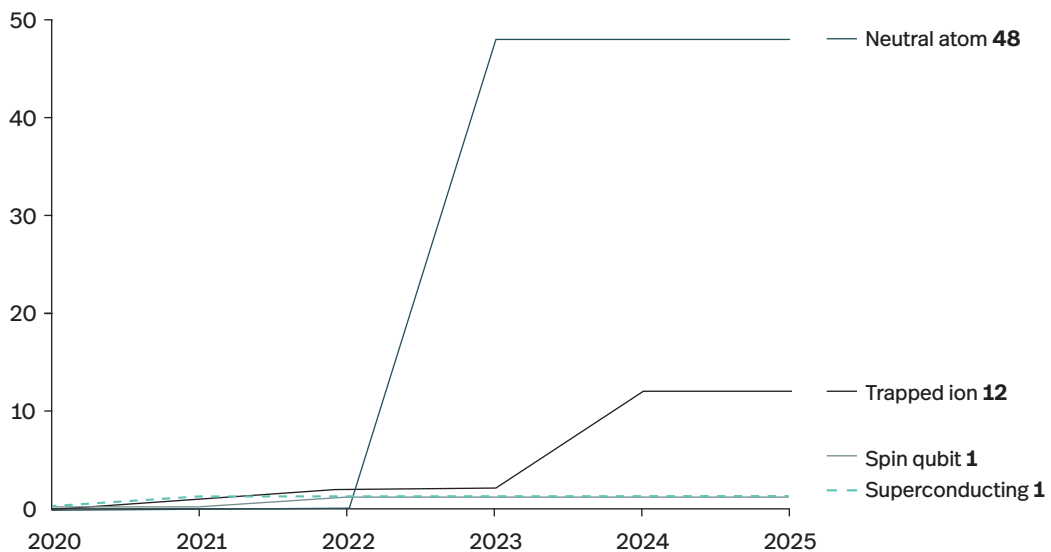
This creates a genuine first-mover advantage: early, focused commitment could allow Europe not only to

participate but to shape the global trajectory of quantum computing. →H

H The quantum computing scaling race

Record interconnected logical qubits per platform

Record interconnected
logical qubits



Source: Corporate information, Nature

2. ANCHORING THE VALUE CHAIN IN EUROPEAN STRENGTHS

Europe, and particularly Germany, holds a distinct advantage in the photonics and precision engineering sectors – critical components for scaling neutral atom quantum computing. Germany alone accounts for over 40 percent of Europe’s photonics production, generating EUR 56 billion in revenue in 2022. The sector employs nearly 192,000 people and is one of Germany’s most research-intensive industries, with around 10 percent of revenues invested in R&D.⁶ This strength is not concentrated in a few conglomerates but rests on a dense network of highly specialized small and medium-sized enterprises, many of them global “hidden champions” in optics, lasers, and photonics, complemented by strong research and technology organizations with expertise in specialized areas relevant for photonics. Together, they provide the technological backbone for neutral atom quantum computers. Supporting this platform therefore builds directly on Europe’s established strengths, anchoring high-value jobs and know-how within Europe, while strengthening sovereignty and avoiding reliance on foreign supply chains.

3. CAPITAL EFFICIENCY AND BUSINESS CASE FEASIBILITY

Not all quantum technologies are created equal when it comes to capital requirements. Competing platforms such as superconducting qubits, ion traps, or photonic quantum computers have so far required massive capital investments to reach their current state of the art –

ranging from semiconductor fabs to large-scale cryogenic infrastructure. Neutral atom quantum computing, by contrast, achieves cost efficiency at the level of individual logical qubits, making it more realistic for Germany and Europe to compete on equal footing without the need for outsized subsidies. The “cost per qubit” metric highlights a structural advantage: with public resources used efficiently, Europe and Germany can back a platform where a credible business case exists and scaling is financially viable, making an error-corrected quantum computer with 100 logical qubits for tackling real-world applications achievable by 2030.

4. SCIENTIFIC LEADERSHIP AND TALENT DENSITY

Europe has been at the scientific frontier of neutral atom quantum computing. Institutions such as the Max Planck Institute of Quantum Optics (MPQ) in Munich and the Institut d’Optique and CNRS in Paris host groups that are widely recognized as global leaders. Their research has achieved major breakthroughs in controlling, scaling, and programming neutral atom arrays, bringing the field to where it is today. These centers not only attract top international talent but also educate the next generation of experts and provide the knowledge base on which industry can build. At the same time, they foster a dynamic environment and ecosystem for researchers and entrepreneurs eager to push the technology toward real-world applications.

⁶ Source: Germany Trade & Invest (GTAI), the economic development agency of the Federal Republic of Germany

5. ESTABLISHED QUANTUM TECHNOLOGY HUBS AND SPIN-OFF ECOSYSTEMS

Germany today hosts several leading quantum technology hubs – notably Munich, Berlin, Stuttgart, Hamburg, and Jülich – each with distinct strengths. Building on this foundation, Munich has emerged as a central hub, with outstanding scientific and entrepreneurial capabilities in neutral atom quantum computing and strong industrial ties supported by Germany's deep base in optics, photonics, and laser technology. Paris has likewise become a leading center, where pioneering academic work at the Institut d'Optique and CNRS has seeded a vibrant start-up scene in neutral atom quantum computing. Both regions are embedded in established quantum technology ecosystems, such as Munich Quantum Valley and Paris-Saclay, uniting scientific institutes, industry, start-ups, talent, and governance structures. Europe therefore does not need to start from scratch: the ecosystem to build on is already in place, making it possible to sprint ahead in scaling a fault-tolerant neutral atom quantum computer rather than just take cautious steps.

In sum, Europe and Germany hold a rare constellation of advantages in neutral atom quantum computing – from scientific leadership and industrial depth to capital efficiency and a vibrant hub structure. While the global race remains open across different platforms, neutral atoms stand out as a particularly promising investment case: they combine realistic scalability with Europe's existing strengths and an ecosystem already in place. For policymakers and investors alike, this makes neutral atoms a domain where Europe can move from playing catch-up to shaping the future, with tangible opportunities to anchor high-value jobs, know-how, and industrial leadership in Europe.

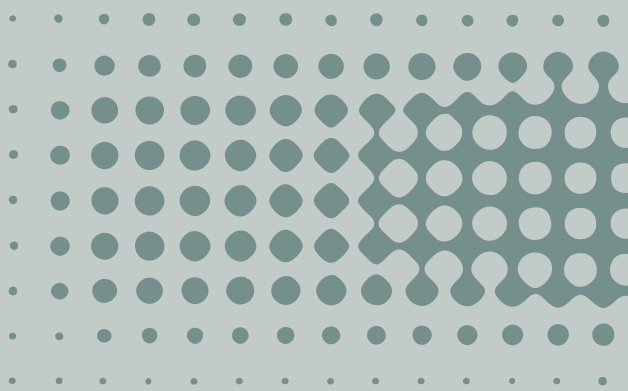
“Dispersing subsidies too broadly prevents the emergence of critical mass. Europe must place bolder, more targeted bets – focusing on select platforms and strategic locations.”

Matthias Troyer, Technical Fellow and Corporate Vice President, Microsoft

4

RECOMMENDATIONS:

Five ways Europe can
play to its strengths in the
quantum race



Europe need not shy away in the race to build the first fault-tolerant quantum computer. That is the core message of our study. But it comes with an important caveat: Europe must play to its strengths, committing focused resources to those approaches and niches where it holds a genuine edge. The reality is that the US and China are pouring vastly greater resources into the field, given its geostrategic importance. Yet sheer scale does not guarantee victory. Recent breakthroughs have shown how new quantum platforms can leapfrog older approaches, reshaping the global contest between nations and companies alike. On this principle rest our five recommendations to policymakers:

1. BACK NATIONAL CHAMPIONS AND FOCUS ON HIGH-POTENTIAL PLATFORMS.

Quantum computing is of immense strategic importance. Europe cannot afford to depend on foreign systems that expose the continent to geopolitical vulnerabilities, generate little domestic value, and transfer no know-how. Instead, Europe must deploy concentrated resources to a selected number of platforms and players with genuine potential to become global leaders.

Building such champions requires careful choices to ensure that public funding is deployed efficiently, with a clear focus on both technical feasibility, national strengths, and value for money, thereby attracting significant follow-on private capital. Funding must reach the scale required to build a fault-tolerant quantum computer to tackle real-world applications, where costs per realized logical qubit become increasingly decisive in the scaling race and differ significantly by platform.

This is not only a matter of technological sovereignty but also of ensuring long-term economic impact: public investment must translate into actual European quantum computers, designed, built, and scaled on the continent, rather than into imported black boxes.

2. BUILD DEDICATED PLATFORM HUBS.

Europe should concentrate resources on no more than two to three high-potential quantum platforms, bundling investment at scale to build globally competitive hardware. Each selected platform must be supported by a dedicated end-to-end platform hub, integrating hardware with co-developed software. This approach ensures that software is optimized directly along the hardware stack, not developed in isolation, while also guaranteeing that real machines are deployed locally in Europe, rather than relying on cloud access. Only with such anchored ecosystems can Europe scale its systems into world-leading quantum computers.

3. MOBILIZE A DUAL BOOST OF PUBLIC AND PRIVATE INVESTMENT.

Europe needs a dedicated state investment vehicle for quantum computing, modeled on the German KfW's successful venture matching fund Coparion: the government co-invests only when a private lead investor provides at least the same amount of capital. The aim is clear – channel money into Europe's most promising scale-ups, which remain underfunded compared with their American peers. A fund structured in this way must serve one overriding target: to deliver by 2030 a quantum computer useful for industry applications, with at least 100 logical qubits. Funding should follow strict milestones, with new tranches released only if companies hit predefined benchmarks.

4. ESTABLISH THE STATE AS A RELIABLE ANCHOR CUSTOMER.

Pre-orders of quantum machines have already provided vital support to Europe's ecosystem. Prominent examples include the German Aerospace Center (DLR) buying a European neutral atom quantum computer from planqc, the EuroHPC Joint Undertaking ordering a European superconducting qubit quantum computer from IQM, and Denmark's Export and Investment Fund (EIFO) together with the Novo Nordisk Foundation (NNF) announcing the purchase of a new American quantum system from Microsoft and Atom Computing. This pillar must be strengthened. But procurement must prioritize sovereignty. Buying non-European hardware undermines strategic autonomy: foreign systems are black boxes, protected by intellectual property, and offer no benefit to local know-how. Purchases should instead focus on local machines capable of running industrially relevant algorithms. The minimum threshold, again, is 100 logical qubits.

5. INTEGRATE QUANTUM COMPUTING INTO DEFENSE BUDGETS.

The security dimension is inescapable. A sufficiently powerful machine can be weaponized – whether in cybersecurity or military operations, wherever speed of data processing confers an edge. Funding for this transformative technology must therefore be embedded more firmly in defense budgets, both at EU level and among member states. The US offers a template: DARPA, through its Quantum Benchmarking Initiative, channels resources into start-ups and firms via a competitive process. Europe should follow suit, pairing research funding with early procurement of hardware to familiarize security agencies and armed forces with the technology.

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