

Quantum technologies: Can they boost the EU's decarbonisation?

SUMMARY

Quantum technologies have transformative potential and are already exerting a significant impact on global economies and society. The European Union (EU) supports the development of these technologies through initiatives such as the Quantum Flagship and Horizon Europe, as well as through national initiatives and programmes. However, the specific role of quantum technologies in supporting the EU's energy and climate goals has so far received limited and fragmented policy attention. This briefing explores how the emerging quantum ecosystem could help accelerate decarbonisation and address the existing innovation gap that must be bridged to achieve climate neutrality (i.e. net-zero emissions) by 2050. Achieving this goal requires technological breakthroughs in sectors that are currently difficult to decarbonise.

Quantum computing has the potential to transform these areas by, for example, simulating complex molecular interactions that classical computers cannot handle efficiently. Such capabilities could fast-track the development of more efficient batteries, green hydrogen catalysts and carbon capture materials. Quantum sensing is already providing precise tools for monitoring greenhouse gas emissions, and quantum communication has the potential to secure the critical digital infrastructure of future electricity grids. Available evidence indicates that, while the EU is investing seriously in quantum research, it currently lacks a coordinated strategy linking these technologies explicitly to decarbonisation. With the European Commission expected to adopt a quantum act in 2026, policymakers have a unique window of opportunity to address this gap. By integrating long-term decarbonisation objectives into the research and innovation framework, the EU can leverage its scientific leadership to drive the next generation of clean technologies.



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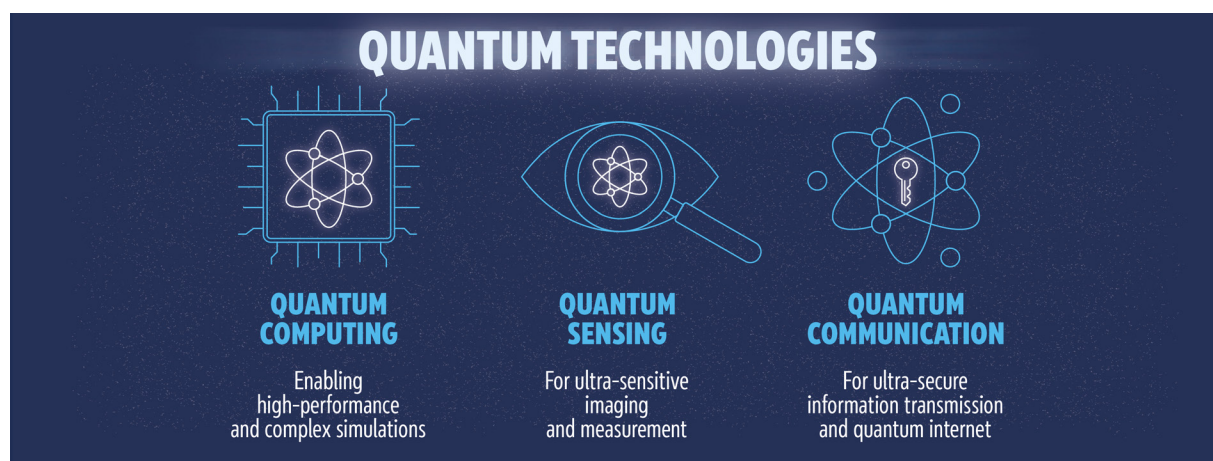
Introduction

Quantum technologies (QT) are seen as one of the most transformative innovations of the 21st century, as recognised in the 2023 [European Declaration on Quantum Technologies](#). Reflecting the importance assigned to QT, 2025 has been designated by the United Nations as the International Year of Quantum Science and Technology. Furthermore, investment and research are increasing significantly, with the quantum market expected to reach [€87 billion](#) within a decade. Global efforts to [harness the potential of quantum](#) technologies are underway.

Cybersecurity concerns, particularly the need for quantum-resilient [encryption](#), underscore the disruptive potential of these technologies. Therefore, policy coordination, a clear regulatory framework and the engagement of researchers and entrepreneurs are needed to shape standards and guardrails.

While QTs are still at different stages of maturity, experts have already identified promising applications of these technologies across various areas.

Figure 1 – Quantum technologies in a nutshell: Compute – sense – communicate



Source: Image by Samy Chahri, EPRS, based on the author's draft.

Yet, the role of quantum technologies in supporting decarbonisation has received little attention so far. In this context, decarbonisation should be understood not only as climate change mitigation, but as a strategic priority aimed at enhancing [energy independence](#), security, and technological resilience within the European Union.

Currently, it is widely recognised that existing technologies and policies, if fully deployed and effectively implemented, are sufficient to deliver the EU's 55 % reduction target for greenhouse gas (GHG) emissions by 2030. However, achieving climate neutrality (net-zero GHG emissions by 2050) poses a qualitatively different challenge. It requires further technological innovation to reduce costs and address sectors that are particularly challenging to decarbonise (such as heavy industry, long-distance transport, agriculture, and high-temperature industrial processes). As acknowledged by the [International Energy Agency](#), 'net zero by 2050 requires huge leaps in clean energy innovation'.

This briefing identifies relevant EU and global quantum initiatives, with a special focus on innovations that support the decarbonisation of the EU economy. It aims to provide a policy-relevant overview of emerging applications and use cases in clean energy, chemistry, materials science and energy system optimisation.

The briefing suggests that QT may serve as accelerators rather than as primary decarbonisation tools. Quantum computing, for instance, has the potential to revolutionise the design of catalysts for green hydrogen production, support the development of next-generation batteries, and enable more efficient carbon capture and methane conversion. Quantum sensors could enhance the monitoring of emissions, while quantum communication may support secure operations of the

electricity grid. With some exceptions, these applications remain at early stages of technological development but may hold long-term strategic value for the EU.

Relevant EU quantum initiatives

According to the [Draghi report](#), QT might contribute up to €850 billion to the EU economy over the next 15–30 years. The Commission's strategic framework for EU competitiveness and innovation – the [Competitive Compass for the EU](#) – identifies quantum as one of the innovative technologies that could be key for the EU's future. QT are also prioritised under the Digital Decade, Horizon Europe, EuroQCI, and the Quantum Flagship, all of which are key EU-level policy frameworks and funding initiatives supporting quantum research, infrastructure development and industrial uptake. In 2018, the Quantum Technologies Flagship was launched with the aim of positioning the EU as a leading global player in quantum, with €1 billion allocated over a decade.

Horizon Europe and the Quantum Flagship are funding a [range of projects](#) aimed at scaling and applying quantum technologies, including projects addressing problems related to climate change mitigation and adaptation. For instance, the [CARIOQA](#) project is developing quantum gravimeters to improve monitoring of climate change. The EU is also planning to launch a space quantum gravimeter after 2030 for Earth observation purposes.

The EU is building quantum infrastructure within the [EuroHPC Joint Undertaking](#), a secure communications network under the [European Quantum Communication Infrastructure](#) (EuroQCI) and quantum chip manufacturing pilots under the Chips Act, with the support of the [Chips Joint Undertaking](#). Under the EuroHPC Joint Undertaking, [eight quantum computers](#) have been procured across Europe and integrated into EuroHPC supercomputers. The aim is to enhance high-performance data processing, including in materials simulations and meteorology. Under the [EQUALITY](#) consortium, scientists and industrial players are developing quantum computing algorithms to solve key industrial problems, including battery and materials design. Under EuroQCI, the European Space Agency (ESA) is expected to launch the first prototype [EuroQCI satellites](#) in early 2026.

In addition, several Member States have released their own national quantum strategies, many of which link quantum to decarbonisation. Finland, a leading country in quantum, identifies use cases in terms of batteries and climate change modelling in its [quantum strategy](#). Likewise, Spain's first [quantum technologies strategy](#), worth €808 million, acknowledges that quantum technologies can help decarbonise the economy, including through optimising electricity grids and developing sustainable fertiliser catalysts.

Most recently, the 2025 [EU quantum strategy](#) outlines a vision for Europe to become a 'quantum continent'. The [strategy](#) recognises a broad range of promising applications for quantum, including those related to battery materials and to the improvement of the energy efficiency of computation. However, it also identifies three challenges: i) the EU is lagging behind in translating its innovation capabilities into real market opportunities; ii) EU efforts are fragmented across Member States, limiting the ability to build critical mass and scale; and iii) the emerging EU quantum ecosystem lacks sustainable financial support and clear market perspectives. The [Joint Research Centre \(JRC\) report](#) entitled 'Future directions for quantum technology in Europe' states that while 32 % of global quantum companies are based in the EU, the EU accounts for only 6 % of patents, highlighting the need to move from research and development (R&D) to innovative commercial products.

The Commission's proposal for the EU's [2028–2034 multiannual financial framework](#) also recognises that quantum capabilities are central to building secure digital infrastructures and next-generation computing ecosystems. It suggests that quantum research, infrastructure and skills complement efforts in artificial intelligence and space technologies, ensuring that Europe remains at the technological frontier. The next Horizon Europe, which will be tightly connected to the European Competitiveness Fund, is expected to support the development of 'moonshot projects' (large-scale, high-risk innovation projects aimed at systemic breakthroughs), among which quantum

technologies are shortlisted. According to the Commission, a [quantum moonshot](#) is conceived as a flagship initiative designed to realise the ambition to 'make Europe the first continent with fully integrated quantum computing in daily life', developing applications 'from medicine to climate, solving previously impossible problems for 450 million citizens'.

In 2026, the [Commission](#) is expected to adopt a quantum act to support quantum computing, communication and sensing infrastructure, and to consolidate EU quantum initiatives. However, it is unclear if the legal act will specifically include specific actions to support the decarbonisation of the economy using these innovative technologies.

Relevant global quantum initiatives

The UK [national quantum strategy](#) from 2023 states that QT will 'help us tackle climate change', including by improving the efficiency of renewables, optimising traffic flows and monitoring emissions. The strategy sets out a 10-year plan for quantum technologies and commits to [£2.5 billion](#) (€2.8 billion) in spending to boost quantum technologies, but does not include a ringfenced budget for decarbonisation applications.

The United States (US) released a national strategy for quantum in 2018, as part of the [National Quantum Initiative Act](#), focusing on accelerating R&D. While it does not explicitly acknowledge links to decarbonisation efforts, the US is investing in quantum applications relevant to decarbonisation. For instance, in 2024 the US Department of Energy announced a [US\\$30 million](#) (€26 million) investment in the Quantum Computing for Computational Chemistry (QC³) programme, under the ARPA-E initiative, to develop quantum algorithms for energy research, including the design of sustainable catalysts and superconductors, as well as improvements in battery chemistry. The bulk of US investment in QT comes from the private sector. Companies like IBM, Google and Microsoft are actively focusing their quantum computing research programmes on decarbonisation and energy-related challenges.

Australia's [national quantum strategy](#) connects quantum technologies to decarbonisation, noting that quantum can both 'support emissions reduction' and 'help us transition to a net zero economy'. The Australian government recently committed [US\\$620 million](#) (€580 million) in support of PsiQuantum, an Australian quantum computing company building the world's first utility-scale, fault-tolerant quantum computer in the country. PsiQuantum is also part of the [Queensland Quantum Decarbonisation Alliance](#), a public-private partnership seeking to drive innovation in quantum applications for decarbonisation, supported by the [AU\\$10 million](#) (€6.1 million) [Quantum Decarbonisation Mission](#). Key research themes include green hydrogen, batteries and carbon sequestration.

India is also investing in QT through both public and private sector initiatives, including an emerging startup ecosystem, and government funding of more than INR6 003.65 crore (€580 million) through the [National Quantum Mission](#). Explicit linkages to decarbonisation are still at an early stage of development. Similarly, South Korea's [national quantum science and technology strategy](#) pledges a significant investment of US\$2.3 billion (€2 billion), shared between the government and the private sector, and although there are references to clean energy, the strategy is primarily driven by technological sovereignty and security objectives.

Japan's [Vision of Quantum Future Society](#) identifies 'contribution to a carbon neutral society' as one driver for quantum development, particularly for materials science and energy-grid optimisation. By contrast, [China's](#) approach embeds quantum within broader technological competitiveness frameworks, focusing on near-term QTs that are closer to market readiness, notably in quantum communications and sensing.

Quantum applications for decarbonisation

Quantum computing

Universal quantum computers are expected to become operational in the coming decade. By their capacity to overcome computational bottlenecks, quantum computers could [enable scientific breakthroughs](#) in clean technologies. Quantum computers may be able to solve previously intractable problems in materials science and chemistry involving complex materials and phenomena, and to help optimise energy systems. [McKinsey](#) estimates that quantum computing could enable the development of technologies that could deliver a reduction of carbon emissions by around 7 gigatons a year by 2035 – or over 150 gigatons in the coming 30 years. This assumes that quantum simulations lead to better technologies, and that quantum computers will be a better and cheaper alternative for large-scale materials discovery. Improved calculations could, in the worst case, simply confirm current technologies as optimal or the only viable options, while classical computers could remain the cheaper alternative for low-level high-throughput screening.

Still, universal quantum computers are expected to outperform classical computers on [certain tasks](#). In a demonstration of quantum supremacy, Google [unveiled](#) a quantum computer in 2024 that solved a calculation in five minutes, a task that would have taken a classical supercomputer 10 septillion (10^{25}) years to accomplish. However, the current limitations of quantum algorithms and quantum devices constrain their applicability. Furthermore, the research literature assessing promising applications of quantum computing is often based on [quantum simulators](#), which run on classical computers. In fact, practical deployments of quantum computing often leverage hybrid quantum-classical systems, where quantum processors tackle exponentially complex subproblems while classical computers handle error correction, thereby combining the strengths of both approaches effectively.

Quantum computers could play a significant role in making [computation less energy intensive](#). For instance, Google's quantum supremacy experiment computer [ran on 26 kilowatt \(kW\)](#), compared to the supercomputer, which consumed 500 times more power, running on 14 megawatt (MW). Quantum computing could also contribute to more energy-efficient AI training, reducing the [energy required to power AI data centres](#). However, there are concerns that quantum computing could be [highly energy intensive](#), not least due to the cooling required. As the technologies are still emerging, developing energy-efficient quantum systems will be of great importance in determining whether they can help to contribute meaningfully to decarbonisation targets. This is acknowledged by the [Quantum Energy Initiative](#), a community of experts and industry partners launched in 2022, committed to making quantum technologies energy efficient.

Materials science and chemistry

Quantum computers are expected to be able to simulate highly complex problems and therefore help accelerate [decarbonisation efforts](#) by identifying and designing new and improved materials and catalysts. For example, by simulating natural processes of nitrogen fixation using water, quantum computers could drive innovations in [sustainable fertilisers and green hydrogen](#). Today, nitrogen-based fertilisers are produced using natural gas through the century-old Haber-Bosch process, accounting for around [2 % of global CO₂ emissions](#). On the other hand, green hydrogen costs are still well above cost-parity with natural gas, but quantum computing could help reduce these costs by advancing the development of more efficient and durable catalysts and membrane materials.

Simulating how different materials interact with CO₂ molecules using quantum computers could also help identify materials that enable more [effective carbon capture](#). According to the Intergovernmental Panel on Climate Change ([IPCC](#)), direct air capture will be necessary to achieve net-zero targets, yet it remains too costly to deploy at scale. Quantum computing and quantum software company [Quantinuum's](#) partnership with [TotalEnergies](#) presents an example of quantum

computing applied to carbon-capture-technology development. The collaboration developed quantum methodologies for modelling carbon dioxide binding with metal-organic frameworks (MOFs), materials that are critical for efficient [carbon capture](#). This work is expected to accelerate the understanding and optimisation of carbon capture materials and, consequently, support industrial decarbonisation efforts.

It has been suggested that quantum computing could also help reduce emissions from the cement industry by simulating chemical reactions of alternative materials. The [International Energy Agency](#) (IEA) states that the main ingredient in cement, known as clinker, is the main cause of rising CO₂ emissions in recent years in a sector responsible for 8% of total global emissions. Quantum simulations can help discover [alternative clinker formulations](#) with lower calcination temperatures or carbon content.

Another promising application of quantum computing relates to improving energy-storage technologies, particularly batteries. Researchers are exploring how quantum computers can more accurately simulate molecular interactions in [battery electrolytes](#). For example, [Daimler AG, in collaboration with IBM](#), is leveraging quantum computing to accelerate the development of lithium-sulphur (Li-S) batteries. This is an advanced battery chemistry offering higher energy density and longer lifespan compared to current lithium-ion technology. Battery technology is key to the electrification and decarbonisation of the economy. As a result, these advances can accelerate the transition to a low-carbon, electrified energy system.

Applications of quantum computing in materials and chemistry supporting cleantech development do not end here. Researchers claim that it can also help improve [solar-panel efficiency](#), [optimise wind-farm layout](#), deepen understanding of [fusion energy](#) and advance [superconductivity](#).

Systems optimisation

Quantum machine learning, combined with neural networks, offers significant promise in optimising power system operations, enhancing grid stability and efficiency. Grid operators currently depend on classical supercomputers for planning, scheduling energy production and balancing supply and demand. However, as power grids become more complex, these [classical methods face significant computational challenges](#).

Quantum computers can handle these [complexity hurdles](#) by simulating large-scale grid dynamics and [optimising power flows](#) to minimise waste, reduce blackout risks and facilitate renewable energy integration. Advanced quantum optimisation algorithms are being deployed in hybrid quantum-classical systems to solve energy scheduling and [unit commitment problems](#) beyond classical limits. Quantum hardware and algorithms can also be used to enhanced energy demand forecasting for smart electric vehicle charging. French quantum computing company [Pasqal and EDF](#), France's state-owned electricity utility, are demonstrating this real-world quantum application in energy systems optimisation.

It is also important to highlight that quantum technologies can be integrated with artificial intelligence and Internet of Things (IoT) systems to enhance energy system optimisation, grid management and predictive maintenance. These synergies are likely to create a multi-technology ecosystem.

Quantum sensing

Quantum sensing is currently the most [mature](#) quantum technology. [Quantum sensors](#) can transform climate and environmental monitoring and modelling. [Quantum sensing](#) allows more sensitive and precise detection and measurement of, for instance, [electromagnetic energy](#), [gravity](#), pressure, temperature and GHG emissions. These capabilities can improve climate forecasts and climate risk scenarios and thereby inform adaptation strategies. Together with quantum computers simulating complex climate systems, quantum sensors can enable more accurate climate forecasting models and an improved understanding of climate tipping points. Through their capacity to detect

tiny changes, quantum sensors can be used to improve environmental monitoring, including the detection of air pollution.

Quantum sensors can also be used in [industry, transportation and electricity systems](#). In particular, quantum sensors can improve the efficiency of power grids and battery performance by [monitoring temperatures in grids](#) more accurately and minimising energy losses. Through their ability to detect underground features with great precision, quantum sensors might also help to identify [promising geothermal energy sources](#), speeding up exploration and deployment of geothermal energy, as well as enable the tracking of glacier loss and groundwater depletion.

Quantum communication

[Quantum communication](#) could help secure communication networks crucial for [energy infrastructure](#) and data flows essential to decarbonised economies. This is because encryption keys based on quantum bits make hacking them much more difficult, due to their extreme sensitivity to external influences. Quantum therefore has the potential to secure and support the operation of critical infrastructure, including transportation and energy systems. By increasing the [security of energy infrastructure](#) through quantum cryptography, it can help ensure the integrity of communications and protect critical facilities from cyber threats.

Technological readiness level

In assessing quantum technologies for decarbonisation, it is important to distinguish between what already exists, what is being developed, and what is currently far from being commercialised.

There is significant uncertainty regarding the availability of scalable quantum computing, but it could arrive [within the next five to seven years](#). This has implications for quantum computing for materials science, which is still at an early stage of development. The validation, certification and industrial standardisation of quantum-engineered materials present distinct challenges. Classical materials benefit from decades of established standards (ISO standards for tensile strength, thermal properties, etc.) and proven supply-chain certification protocols. By contrast, quantum materials require novel validation frameworks to certify that quantum properties are preserved through manufacturing, scaling and deployment – frameworks that do not yet exist at the EU or international level.

Pilot projects have demonstrated practical capabilities of quantum sensing. For example, as presented above, quantum magnetometers and gravimeters are operational in field trials for environmental monitoring. In contrast to quantum computing for materials science, quantum sensing technology integrates directly into existing frameworks and data standards (such as ISO environmental management standards and Copernicus Earth-observation protocols), and quantum sensors simply meet established environmental monitoring requirements.

Quantum communications for cryptographic security occupies a distinctive middle position. Quantum key distribution (QKD) has achieved operational deployment in pilot networks across EU Member States and internationally, with systems handling live data exchanges. However, readiness is constrained by fundamental deployment limitations: QKD requires dedicated fibre optic or satellite infrastructure, and it cannot simply integrate into existing security architectures as a software update. Accordingly, it is appropriate to regard post-quantum cryptography (PQC) as the near-to-medium-term priority, as presented in the Commission's [roadmap for the transition to post-quantum cryptography](#), with quantum communications serving as a long-term strategic asset.

Table 1 – Technological readiness level

QT	Readiness level (TRL ¹)	Supporting evidence and key uses
Quantum computing for materials simulation and chemistry	3-6	Prototype devices and algorithms enabling molecular and catalytic simulations for green hydrogen, carbon capture materials and battery chemistry. Advances noted in the IonQ and Daimler-IBM projects.
Quantum computing for systems optimisation and energy forecasting	3-6	Hybrid quantum-classical algorithm applications in power flow optimisation, unit commitment and smart EV charging, as demonstrated by EDF-Pasqal collaboration.
Quantum sensing (magnetometers)	8-9	Commercially viable with multiple products on the market; climate and environmental monitoring; greenhouse gas detection.
Quantum communication	7-8	Real-world pilot projects securing energy infrastructure communications via QKD; ² improving cybersecurity critical for decarbonised economies.

Source: 'A quantum technologies policy primer', OECD [working paper](#), 28 January 2025.

Conclusion and next steps

QT may offer an opportunity for the European Union to bridge the innovation gap – a step needed to achieve climate neutrality (net-zero GHG emissions) by 2050. Unlike conventional clean technologies already embedded in existing industrial policies, quantum-enabled solutions could unlock innovations in cement production, batteries, solar and green hydrogen. However, for that to happen, the development of dedicated quantum-for-climate research capabilities should be considered now.

Additionally, different quantum technologies are at different maturity levels and therefore require differentiated policy support approaches. For quantum computing, policy should focus on coordinated multidisciplinary research initiatives, standards development for quantum-designed materials and integrated training programmes. By contrast, for quantum sensing, the pathway to deployment is primarily an adoption and scaling challenge. For quantum communications, policy should clarify infrastructure investment requirements and align timelines with cybersecurity imperatives, which are then linked to electricity infrastructure operation.

National quantum strategies across leading countries consistently recognise the technology's potential for decarbonisation and identify the optimisation of energy grids and the improvement of battery chemistry as the most promising applications, yet dedicated funding for decarbonisation applications remains minimal.

In contrast, the EU's quantum investment, while substantial, lacks a clear focus on decarbonisation. Current EU quantum projects under Horizon Europe and the Quantum Flagship include climate-relevant research, but these remain scattered initiatives rather than forming a coordinated strategic priority and tend to focus primarily on environmental monitoring. This risk of fragmentation may allow other geographies to establish technological and market leadership in quantum-enabled clean technologies.

The European Commission's forthcoming proposal for a quantum act (expected Q2 2026) provides an opportunity to integrate decarbonisation into the EU's quantum governance framework, for example by:

- establishing quantum-for-decarbonisation as a focus area within EU quantum infrastructure and research funding, equivalent to cybersecurity;
- establishing a 'quantum-for-decarbonisation' initiative, in addition to general quantum research, under Horizon Europe, that explicitly targets: a) quantum computing for materials discovery in green hydrogen, carbon capture and batteries; b) quantum sensing for environmental monitoring and climate forecasting; and c) quantum-classical hybrid systems for energy grid optimisation;
- the quantum act aiming to transform TRL 3-6 quantum software, algorithms and hardware into commercially viable solutions by linking quantum innovation to existing EU industrial policy frameworks (such as the Net-Zero Industry Act);
- enhancing coordination between quantum research, chemistry, materials science and climate and energy policy communities, while promoting joint training and education programmes.

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ENDNOTES

- ¹ Technology readiness levels (TRLs) – TRL 1: Basic principles observed; TRL 2: Technology concept/application formulated; TRL 3: Analytical and experimental proof of concept; TRL 4: Technology validated in lab; TRL 5: Technology validated in relevant environment; TRL 6: Technology demonstrated in relevant environment; TRL 7: System prototype demonstration in an operational environment; TRL 8: System complete and qualified; TRL 9: Actual system proven in an operational environment.
- ² Quantum key distribution (QKD) is a method that uses principles of quantum mechanics to generate and distribute secure cryptographic keys between two parties, ensuring that any attempt to eavesdrop can be detected.

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