Key Performance Indicators for Quantum Technologies in Europe

October 2022

Abstract

This document is a recommendation of the Strategic Advisory Board of the European Quantum Flagship and the European Commission to monitor and evaluate the progress of quantum technologies in Europe. It thereby does not merely focus on the Quantum Flagship itself but takes all initiatives and measures into account.

The document is divided into the following topical and technological pillars: **Ecosystem, Quantum Communication, Quantum Computing, Quantum Simulation, Quantum Sensing and Metrology,** and **Education.**

Within those pillars, Key Performance Indicators (KPIs) are formulated to have a perspective towards 2030 and reflect overall research and innovation goals as set forth in the Strategic Research Agenda*. It assumes that there is consistent and continued support for fundamental research and basic science which forms the foundation of all further innovations, in order to ensure that we continue to maintain open approaches and excellence in scientific expertise which lead to creating the best conditions for future breakthroughs.

The KPIs were compiled with the best present knowledge of what could be achieved by the quantum community, combining reasonable and attainable results with a healthy dose of ambition. However, the global impact of COVID-19 on innovation of quantum technologies and other potential future impediments to progress, necessitate that this paper remains a living document, which must undergo periodic review and adjustment.

The full set of KPIs will be used as a tool to benchmark Europe's overall progress, therefore deviations for single KPIs may occur, naturally.

This document is a result of collaboration between the academic, public, and private sector representatives from the Strategic Advisory Board (SAB), the Science and Engineering Board (SEB), the Quantum Community Network (QCN), the European Quantum Industry Consortium (QuIC), and the Flagship coordination office. Multiple rounds of feedback from those bodies were collected to define the KPIs, set appropriate target values for the year 2030, and estimate the annual progress required to reach those targets.

The KPI values for 2021 were measured at the end of that year by surveying the members of the SAB, the SEB, the QuIC and the Flagship coordination office. The plausibility of the collected results was verified by the SAB. References and explanations are given at the end of this document.

* https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=65402

KPI Scorecard

KEY

- Ahead of schedule | >>10%
- On schedule | ~10%
- Needs progress | <10%
- Behind schedule | <<10%

KPI Ecosystem	2021 value	2030 target	progress (%)
Investment *(b€)*	n.a.	1	
Lab-to-market	79	250	31,6
Lab-to-fab	1	10	10,0
Job Creation	n.a.	n.a.	
Patent Creation/IP Retention *(rank)*	n.a.	top 2	
Supply Chain & Strategic autonomy	0	10	0,0

KPI Quantum Communication	2021 value	2030 target	progress (%)
Performance	2	20	10,0
European Technical Leadership *(km)*	1,3	500	0,3
Deployment *(areas; nodes)*	1; 8	10; 50	10,0
Adoption	5	30	16,7

KPI Quantum Computing	2021 value	2030 target	progress (%)
Performance	0	3	0,0
European Technical Leadership *(q volume)*	32	655	4,9
European Impact Leadership	70	500	14,0
Accessibility	0	10	0,0

KPI Quantum Simulation	2021 value	2030 target	progress (%)
Performance	0	8	0,0
Market Readiness	0	12	0,0
European Technical Leadership	200	200	100,0

KPI Quantum Sensing and Metrology	2021 value	2030 target	progress (%)
Market Readiness	3	20	15,0
Next-generation Technologies	0	7	0,0

KPI Education	2021 value	2030 target	progress (%)
Outreach	7	100	7,0
Education	0	180	0,0
Adopting	1	225	0,4
Diversity and Equity	0	90	0,0

KPIs Ecosystem

1. Investment

Total amount of EC investment in the form of venture capital (EU quantum start-ups), corporate seed-funding (EU incubators & accelerators), and EU public investment (EU public-private ventures).

2021 value	tbc
progression/year	+90m€
2030 target	1b€

2. Lab-to-market

Number of quantum start-ups, spinoffs, incubators, accelerators, as well as public private joint ventures in Europe (given for all pillars, including established EU companies that enter the field).

2021 value	79
progression/year	+20
2030 target	250

3. "Lab-to-fab" infrastructure and value chains

Number of EU research institutions offering open application labs, test-beds, production cleanrooms, with testing, prototyping and calibration service facilities accessible to European SMEs, covering TRL 2-6.

2021 value	1
progression/year	+1
2030 target	10

4. Job creation

Number of jobs in quantum technologies.

2021 value	tbc
progression/year	tbc
2030 target	tbc

5. Patent creation and IP retention

Quantum-related European patents granted versus distribution of granted patents globally.

2021 value	tbc
progression/year	n/a
2030 target	Top 2 globally

6. Supply chain and strategic autonomy

Number of components (supply chain) of quantum technologies which were formerly imported to EU and are now produced in EU that are of strategic importance and needed for self-sufficiency.

2021 value	0
progression/year	+1
2030 target	10

KPIs
Quantum Communication

1. Performance

Number of complementary subsystems, advancing the state of the art, necessary for Quantum Communications networks or to build a quantum internet.

2021 value	2
progression/year	x1.2
2030 target	20

2. European technical leadership

Entanglement distance in a quantum network based on entanglement distribution and quantum processing, linking processing nodes in two metropolitan networks (average of 20 km) via a quantum repeater backbone (>500 km).

2021 value	1.3km
progression/year	2023: 20km; 2027: 100km; 2029: 400km
2030 target	500km

3. Deployment

Number of connected European metropolitan areas (and QKD nodes) integrated with a commercial telecom infrastructure, including both terrestrial and satellite QKD links with a secure key rate of at least 100 bit/s.

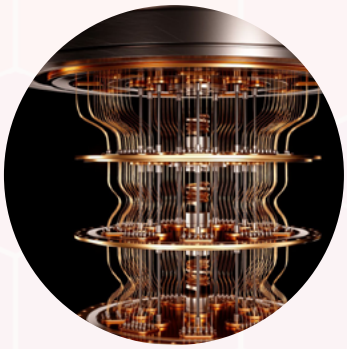
2021 value	1 metropolitan area; 8 nodes
progression/year	+1; +5
2030 target	10 metropolitan areas; 50 nodes

4. Adoption

Number of Quantum Communication services that enable commercial adoption for the public as well as private sector.

2021 value	5
progression/year	x1.2
2030 target	30

KPIs
Quantum Computing



1. Performance

The number of unique European quantum computing hardware stack systems/services demonstrating quantum advantage (i.e., outperforming a non-quantum hardware system/service in the solution of the same problem) by an ad-hoc benchmark created for proof.

2021 value	0
progression/year	aligned with progress European technical leadership KPI (see next)
2030 target	3 different QC stack systems demonstrating quantum advantage by ad hoc benchmark proof test

2. European technical leadership

Largest quantum computing capacity based on a European (or alternatively a widely adopted global) quantum volume benchmark.

2021 value	32
progression/year	(assuming QV=10 in 2023) - x1.6/year from 2023-2026 - x2.0/year from 2026-2030
2030 target	327 by end 2026 or 655 by end 2030

3. European impact leadership

Quantum algorithms and use cases created with clear impact orientation in basic science, applied science, industries, and the public sector (aligned with the UN and EU 2030 goals).

2021 value	70
progression/year	x1.2
2030 target	500

4. Accessibility

Number of entities providing public or private access from fully European quantum computing facilities (also based on fully European computing stack) to institutions, academia, research centers and companies.

2021 value	0
progression/year	+1
2030 target	10

KPIs
Quantum Simulation

1. Performance

Number of unique EU quantum simulators (services) outperforming the best-known algorithm running on the best classical computer on at least one relevant real-life computational problem.

2021 value	0
progression/year	+1 from 2023
2030 target	8

2. Market readiness

New unique industrial or societal real-life applications (products & services) introduced by EU companies, based on any quantum simulation

2021 value	0
progression/year	1 by 2023; +2/year thereafter
2030 target	12

3. European technical leadership

The number of qubits or simulated particles of Europe's most advanced non-gate-based quantum simulator.

2021 value	200
progression/year	x1.2
2030 target	200

KPIs Quantum Sensing and Metrology

1. Market readiness

Number of different (publicly known) product classes or service classes (or use cases) based on quantum sensors developed, implemented and sold by European companies or deployed in the EU.

2021 value	3
progression/year	+2
2030 target	20

2. Next-generation technologies

Number of demonstrated sensing technologies exploiting advanced quantum effects (entanglement, collective coherence etc.)

2021 value	0
progression/year	+0.5
2030 target	7

KPIs
Education

1. Outreach

Establish a successful communication and outreach program to raise awareness of quantum technologies: Number of outreach and training events promoted on the Quantum Flagship website (following the continually updated criteria laid out by the running Flagship Coordination and Support Action (CSA)).

2021 value	7
progression/year	+10
2030 target	100

2. Education

Developing an open-source ecosystem of validated and scalable QT education and training modules: Number of open source, curated (didactically validated) QT education modules accessible via the Quantum Flagship repository.

2021 value	0 (0 validated)
progression/year	+20 (+10 validated)
2030 target	180 (90 validated)

3. Adoption

Pan-European institutional adoption of the competence framework for planning, conducting and evaluating QT educational and training efforts: Number of entities (companies, universities and training institutions such as corporate training and vocational) actively using the competence framework in their workforce development and curriculum development efforts.

2021 value	1
progression/year	+25
2030 target	225

4. Diversity and equity

Fostering structural integration of equity and diversity initiatives into QT education and training: Number of entities (companies and educational institutions) contributing to the coordinated Quantum Flagship efforts following the guidelines developed in the Coordination and Support Actions (CSAs) (reported into the European Quantum Education Center (EQEC)).

2021 value	0
progression/year	+10
2030 target	90

References

Ecosystem

1. n/a
2. Defined as number of SMEs with QuIC membership.
3. Quantum Information Technology Testing Facility (QITT), TNO, NL
4. n/a
5. n/a
6. Zero by definition (list is defined for year 2021).

Communication

1. QIA subsystems at Delft and the Hague.
2. In QIA at TU Delft.
3. Austria-Croatia-UK cooperation (Bristol metropolitan area): 10.1126/sciadv.aba0959.
4. IDQuantique, Open QKD, Toshiba & BT, Airbus, Thales

Computing

1. Consensus of survey.
2. AQTION: 10.1103/PRXQuantum.2.020343
3. QuIC database for Computing and Simulation use-cases.
4. Consensus of survey. Worldwide only two vendors offering access to full-stack system, both non-EU: IBM, D-Wave.

Simulation

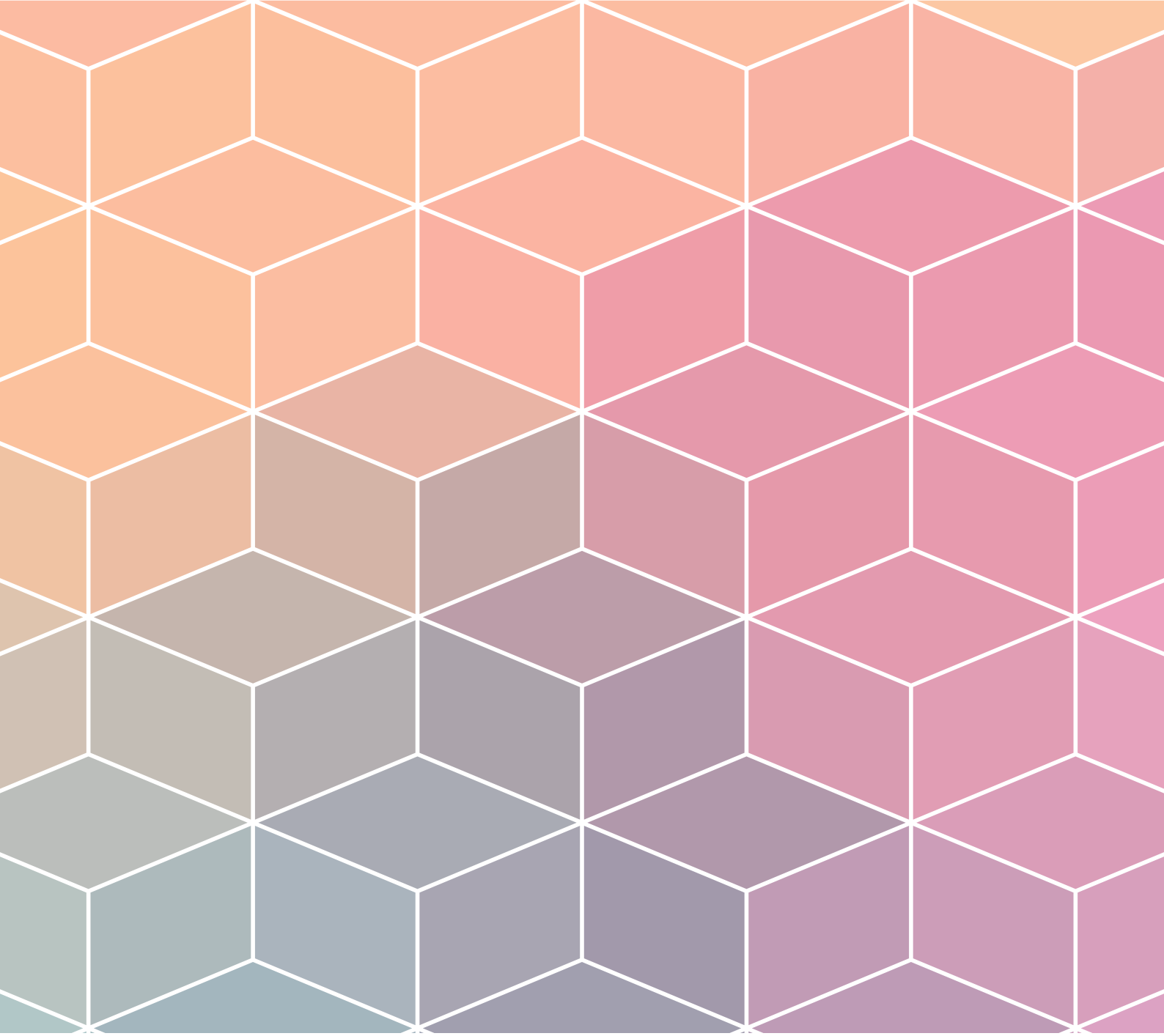
1. Consensus of survey. Current examples only work 'in principle', with no real-life problems solved yet.
2. Consensus of survey.
3. PASQAL (50-100); Max Planck Institute of Quantum Optics/LMU Munich (200)

Sensing & Metrology

1. Clocks; cold-atom gravitometers; NV-centre magnetometers.
2. Consensus of survey. Current technologies not yet at sufficiently high TRL.

Education

1. Listings on qt.eu website in 2021 [QTEdu Open Master (QTOM) Launch Event; NONGAUSS Winter School; QWorld Quantum Summer School; QWorld Quantum Programming Workshop QSilver; QTEdu Friday Networking Meetings; Start of Education Working Groups; Quantum Computing Workshop (QCW'21).]
2. Flagship repository
3. QuTech Academy, TU Delft
4. QTEdu



QUANTUM FLAGSHIP

European Commission

Compiled by the Strategic Advisory Board of the European Quantum Flagship

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