Regulating Transformative Technology in The Quantum Age: Intellectual Property, Standardization & Sustainable Innovation

Mauritz Kop [1]

Abstract

*The behavior of nature at the smallest scale can be strange and counterintuitive. In addition to unique physical characteristics, quantum technology has many legal aspects. In this article, we first explain what quantum technology entails. Next, we discuss implementation and areas of application, including quantum computing, quantum sensing and the quantum internet. Through a cross-disciplinary lens, we then focus on intellectual property ('**IP**'), standardization, ethical, legal & social aspects ('**ELSA**') as well as horizontal & industry-specific regulation of this transformative technology.*

*The Quantum Age raises many legal questions. For example, which existing legislation applies to quantum technology? What types of IP rights can be vested in the components of a scalable quantum computer? Are there sufficient market-set innovation incentives for the development and dissemination of quantum software and hardware structures? Or is there a need for open source ecosystems, enrichment of the public domain and even democratization of quantum technology? Should we create global quantum safety, security and interoperability standards and make them mandatory in each area of application? In what way can quantum technology enhance artificial intelligence ('**AI**') that is legal, ethical and technically robust?*

Regulating technology is a continuous effort. It is a dynamic, ongoing process that follows the life-cycle of the technology and the application. The article argues that the pervasiveness of quantum technology asks for a holistic view on a regulatory framework, that balances the interests of stakeholders and that of society at large. It demands for an agile legislative system that can adapt quickly to changing circumstances and societal needs.

How can policy makers realize these objectives and regulate quantum computing, quantum sensing and the quantum internet in a socially responsible manner? Regulation that addresses risks in a proportional manner, whilst optimizing the benefits of this cutting edge technology? Without hindering sustainable innovation, including the apportionment of rights, responsibilities and duties of care? What are the effects of standardization and certification on innovation, intellectual property, competition and market-entrance of quantum-startups?

Moreover, which culturally sensitive ethical issues play a role in these regulations? Would it be a good first step to link the governance of quantum & AI hybrids to the Trustworthy AI principles? Do quantum's different physical properties call for additional core rules? Is it wise to embed our

---

[1] Mauritz Kop is Stanford Law School TTLF Fellow at Stanford University and is Managing Partner at AIRecht, Amsterdam, The Netherlands. Correspondence: advies@airecht.nl. The author is grateful to Mark Lemley (Stanford Law School), Maran van Heesch (TNO, The Hague, Netherlands, CEN-CENELEC Focus Group on Quantum Technologies), Juha Vesala (Stanford Law School) and Suzan Slijpen (Slijpen Legal) for valuable comments. The author owes gratitude to the ECP | Platform for the Information Society, TU Delft and TNO for organizing the 2019 Quantum Computing & Quantum Internet meeting at QuTech Delft and to the AI4EU 2020 webinar 'The future of AI' presented by Wouter Denayer (CTO IBM Belgium). An earlier version of this article has been published in the Stanford Law School Newsletter on Transatlantic Antitrust and IPR Developments, Issue No. 2/2020, https://www-cdn.law.stanford.edu/wp-content/uploads/2015/04/2020-2.pdf.

democratic values into the architecture of quantum systems, by way of Trustworthy Quantum Technology by Design? The article explores possible answers to these tantalizing questions.

Particles and energy at the subatomic level do not follow the same rules as the objects we can detect around us in our everyday lives. In addition to universal, overarching guiding principles of Trustworthy & Responsible Quantum Technology that are in line with the unique physical characteristics of quantum mechanics, the article advocates a vertical, differentiated industry-specific legislative approach regarding innovation incentives (based on the innovation policy pluralism toolkit), externalities and risks (based on the pyramid of criticality, which should include a definition of high-risk quantum technology applications).

The article demonstrates that strategically using a mixture of IP rights to maximize the value of the IP portfolio of the quantum computer's owner, potentially leads to IP protection in perpetuity. Overlapping IP protection regimes can result in unlimited duration of global exclusive exploitation rights for first movers, being a handful of universities and large corporations. The ensuing IP overprotection in the field of quantum computing leads to an unwanted concentration of market power. Overprotection of information causes market barriers and hinders both healthy competition and industry-specific innovation. In this particular case it slows down progress in an important application area of quantum technology, namely quantum computing.

In general, our current intellectual property framework is not written with quantum technology in mind. Intellectual property should be an exception -limited in time and scope- to the rule that information goods can be used for the common good without restraint. Intellectual property cannot incentivize creation, prevent market failure, fix winner-takes-all effects, eliminate free riding and prohibit predatory market behavior at the same time. To encourage fair competition and correct market skewness, antitrust law is the instrument of choice.

The article proposes a solution tailored to the exponential pace of innovation in The Quantum Age, by introducing shorter IP protection durations of 3 to 10 years for Quantum and AI infused creations and inventions. These shorter terms could be made applicable to both the software and the hardware side of things. Clarity about the recommended limited durations of exclusive rights -in combination with compulsory licenses or fixed prized statutory licenses- encourages legal certainty, knowledge dissemination and follow on innovation within the quantum domain. In this light, policy makers should build an innovation architecture that mixes freedom (e.g. access, public domain) and control (e.g. incentive & reward mechanisms).

Regulating transformative technology in The Quantum Age requires synergetic relationships between legislation, standardization, certification and government institutions. The article suggests that quantum products and services made within the EU or elsewhere in the world should adhere to EU safety and security benchmarks, including not limited to the high technical, legal and ethical standards that reflect Trustworthy quantum technology core values, before they qualify for a CE-marking and are eligible to enter the European markets.

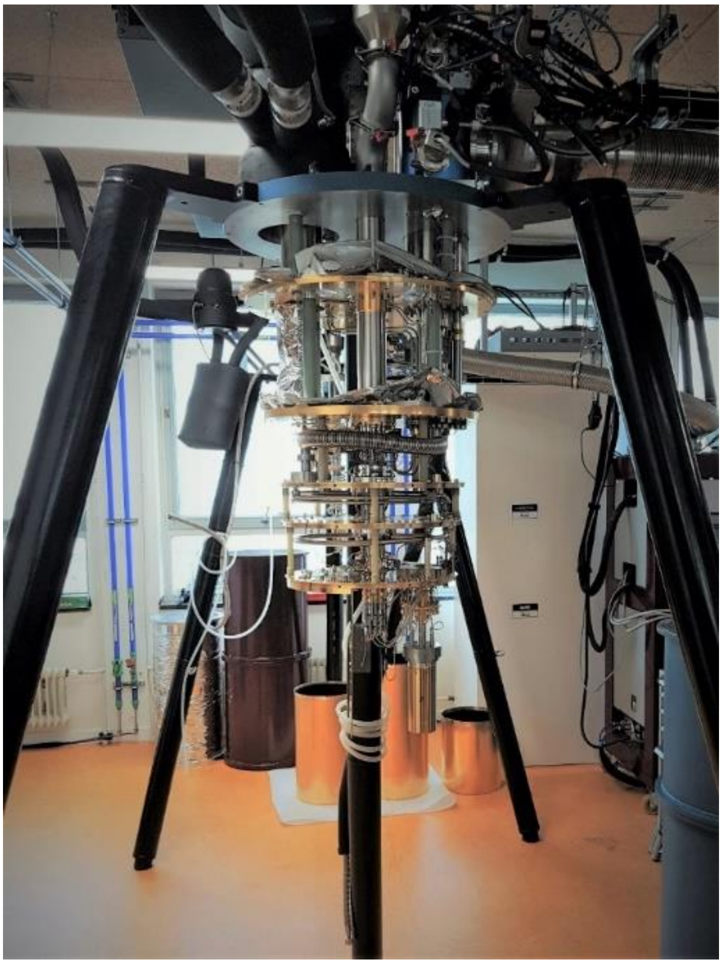
The article concludes that anticipating spectacular advancements in quantum technology, the time is now ripe for governments, research institutions and the markets to prepare regulatory and intellectual property strategies that strike the right balance between safeguarding our fundamental rights & freedoms, our democratic norms & standards, and pursued policy goals that include rapid technology transfer, the free flow of information and the creation of a thriving global quantum ecosystem, whilst encouraging healthy competition and incentivizing sustainable innovation.

Introduction

The behavior of nature at the smallest scale can be strange and counterintuitive. In addition to unique physical characteristics, quantum technology has many legal aspects. In this article, we first explain what quantum technology entails. Next, we discuss implementation and areas of application, including quantum computing, quantum sensing and the quantum internet. Through an interdisciplinary lens, we then focus on intellectual property (‘**IP**’), standardization, ethical, legal & social aspects (‘**ELSA**’) as well as horizontal & industry-specific regulation of this transformative technology.

The Quantum Age raises many legal questions. For example, which existing legislation applies to quantum technology? What types of IP rights can be vested in the components of a scalable quantum computer? Are there enough innovation incentives for the development of quantum software and hardware structures? Or is there a need for open source ecosystems, a thriving public domain and even democratization of quantum technology? Should we create global quantum safety, security and interoperability standards and make them mandatory in each area of application? In what way can quantum technology enhance artificial intelligence (‘**AI**’) that is legal, ethical and technically robust?

How should we regulate quantum computing, quantum sensing and the quantum internet in a socially responsible manner? Which culturally sensitive ethical issues play a role in these regulations? Is it wise to embed our democratic values into the architecture of quantum systems, by way of Trustworthy Quantum Technology by Design? In the following, we explore possible answers to these tantalizing questions.



1. What is Quantum Computing?

First, let us zoom in on quantum computing. Quantum computing derives its constituent elements from principles of quantum mechanics (superposition and entanglement), the theory of the very small. Quantum mechanics describes the interaction between matter and energy and the building blocks of atoms at the subatomic level, beyond classical physics. Subatomic particles such as protons, neutrons and electrons. The human body is composed of atoms and molecules, some of which are as old as the universe.[2] On a micro level, these atoms connect us to each other, to our planet and to the cosmos.[3] Einstein's general theory of relativity on the other hand, is the theory of the very large, and describes the operation of laws of physics, including gravity, speed of light, time, space, mass and energy (E = mc squared)[4].

Quantum Bits or Qubits

Quantum bits or qubits are the quantum version of classic (binary) bits.[5] A qubit can be a 1 or a 0, or both. We call this superposition.[6] A qubit represents a quantum particle in superposition of all possible quantum states.[7]

In addition to superposition, quantum particles can be in several places at the same time, while they remain "aware" of each other. This is known as entanglement.[8] For us humans this is a counterintuitive quantum state. True quantum entanglement requires superluminal data transfer, or transfer of information that is many times faster than light.[9] Here, general relativity theory - which assumes that particles cannot travel faster than light in the space-time continuum - and quantum mechanics collide.[10] String theory attempts to unify both Einstein's relativity theory and quantum physics.[11]

Quantum Computing Methods

Several implementations of quantum computing exist today.[12] By implementations we mean the methods by which the qubits are actually created. Two promising models, or architectures are

[2] Carl Sagan, Cosmos, Published October 12th 1980 by Random House (NY) Random House, https://www.goodreads.com/book/show/55030.Cosmos.

[3] See also: Robbert Dijkgraaf, Hoe jij, Julius Caesar en een dinosaurus met elkaar verbonden zijn, NRC, 2 October 2020, https://www.nrc.nl/nieuws/2020/10/02/hoe-jij-julius-caesar-en-een-dinosaurus-met-elkaar-verbonden-zijn-a4013077.

[4] Albert Einstein, On the Electrodynamics of Moving Bodies, by Annalen der Physik, 17, 1905. Reprinted in The Principle of Relativity, Dover Pub. E = Energy, M= Mass, C= Speed of light.

[5] See for example: Xiang Fu, Quantum Control Architecture: Bridging the Gap between Quantum Software and Hardware, (2018), https://doi.org/10.4233/uuid:8205cc34-30df-45f0-b6eb-8081bdb765b8.

[6] Fu, *supra* note 5.

[7] See: https://docs.microsoft.com/en-us/quantum/overview/understanding-quantum-computing.

[8] Fu, *supra* note 5

[9] In quantum teleportation based on classical communication, quantum information cannot travel faster than the speed of light.

[10] There are also a number of phenomena -mainly occurring at extremely low temperatures- which can only be explained by quantum mechanics, such as superconductivity and the Meissner effect, ferromagnetism and atomic spectral lines. See: https://qutech.nl/2020/03/02/the-magnet-that-didnt-exist/.

[11] See for example: Kevin Wray, An Introduction to *String Theory*, (2009).

[12] See also: https://airecht.nl/quantum-computing-software-superconducting-qubits-parallel/.

superconducting quantum computing[13] and trapped ion quantum computing.[14] Based on these methods we can distinguish two different types of quantum bits: superconducting qubits[15] and trapped ion qubits.[16] Moreover, spin qubits exist.[17] Several smart real-world implementations of quantum computing power in the cloud, that can be accessed by conventional computers, have been successfully developed.[18] The next step is utilizing a network of gate-based quantum computers in the cloud.[19]

Quantum Supremacy

Quantum supremacy is the moment when quantum computers can perform a certain computational task better than (or impossible for) the fastest classical exascale supercomputers.[20] It is expected that (task specific) quantum supremacy will be achieved with gate-based chips with at least 100 stable qubits (i.e. the computing power) in combination with a very low margin of error.[21] Such systems must be able to demonstrate quantum benefit, or at least quantum advantage.[22] Cloud computing is practical here, because of costs, required cryogenic temperatures and the many terabytes (TB) of RAM required for 1000 operating qubits chip systems.[23] While task specific quantum supremacy is well within reach, it is estimated that a properly functioning, programmable 'general purpose'

---

[13] See for example: Jonathan Hui, QC — How to build a Quantum Computer with Superconducting Circuit? January 17 2019, Medium, https://medium.com/@jonathan_hui/qc-how-to-build-a-quantum-computer-with-superconducting-circuit-4c30b1b296cd.

[14] See also: https://qutech.nl/demonstrators/.

[15] See for example: Peter Jurcevic et al., Demonstration of quantum volume 64 on a superconducting quantum computing system, August 19 2020, https://arxiv.org/abs/2008.08571.

[16] The Quantum Internet and Quantum Computers: How Will They Change the World? TUDelft, OpenCourseWare, https://ocw.tudelft.nl/courses/quantum-internet-quantum-computers-will-change-world/?view=lectures&paging=1.

[17] See: Zhu, X., Tu, T., Guo, A. *et al.* Spin-photon module for scalable network architecture in quantum dots. *Sci Rep* 10, 5063 (2020). https://doi.org/10.1038/s41598-020-61976-2 and Hendrickx, N.W., Lawrie, W.I.L., Petit, L. *et al.* A single-hole spin qubit. *Nat Commun* 11, 3478 (2020). https://doi.org/10.1038/s41467-020-17211-7. Particles like photons and electrons have a property called 'spin', which can be up or down, when measured. Before measuring, a particle can be in superposition of up and down. Therefore photons and electrons can act as qubit using its spin property.

[18] See for example the first Dutch quantum computer in the cloud: https://www.quantum-inspire.com/ and the IBM Quantum Experience: https://quantum-computing.ibm.com/.

[19] See: https://qt.eu/understand/underlying-principles/gate-based-qc/.

[20] For a discussion between Google and IBM after Google's quantum supremacy claim, see: https://www.quantamagazine.org/google-and-ibm-clash-over-quantum-supremacy-claim-20191023/ and https://www.qusoft.org/christian-schaffner-on-bnr-radio-about-quantum-supremacy/.

[21] Scientists expect to achieve quantum supremacy in the quantum chemistry domain, such as simulating penicillin, within 3 years. See: https://www.bcg.com/publications/2019/quantum-computers-create-value-when.

[22] See: https://en.wikipedia.org/wiki/Quantum_supremacy.

[23] See also: https://www.linkedin.com/pulse/quantum-computing-mauritz-kop/.

quantum computer requires millions of qubits.[24] The amount needed depends on the quantum computing method and the type of qubits used in the system.[25]

What Can We Do with a Quantum Computer?

In general, quantum computing is ideally suited for solving mathematical optimization problems, solving some of the computationally hard problems on which we build current cryptography,[26] and simulating the behavior of atoms and elementary particles. Quantum computers are useful when modelling nature[27] or searching large amounts of data using parallel quantum query algorithms.[28] They excel when complex systems have to be simulated. Quantum machines also have limits. Quantum computers can help finding approximate solutions to computational complexity NP-hard and NP-complete problems, such as the travelling salesman problem.[29] They can however not solve them by delivering exact answers.

Practical Obstacles for Scalable Quantum Computing

There are still some practical hurdles to the practical, physical realization of scalable, commercially available quantum computers.[30] For example, current quantum computers require refrigerated qubits i.e. very heavy cooling to operate near absolute zero (15 milli-Kelvin). The point where atoms almost come to a standstill.[31] QuTech Delft researchers recently managed to build silicium qubits that can operate at higher temperatures, together with the conventional electronic parts of the machine that control the qubits, instead of having to separate components through a vacuum freezer. [32] This paves the way for quantum integrated circuits that contains millions of qubits.[33]

---

[24] See: Jarosław Adam Miszczak (2012). High-level Structures in Quantum Computing. ISBN 9781608458516; Bertels, K.; Almudever, C. G.; Hogaboam, J. W.; Ashraf, I.; Guerreschi, G. G.; Khammassi, N. (2018-05-24). "cQASM v1.0: Towards a Common Quantum Assembly Language". arXiv:1805.09607v1 and Smith, Robert S.; Curtis, Michael J.; Zeng, William J. (2016), A Practical Quantum Instruction Set Architecture, arXiv:1608.03355

[25] This means for example that if Microsoft's topological qubits become a success, less are needed to build a general purpose quantum computer. See: https://cloudblogs.microsoft.com/quantum/2018/09/06/developing-a-topological-qubit/.

[26] For quantum-safe cryptography using an advanced security proxy (ASP), see: https://www.tno.nl/en/focus-areas/information-communication-technology/roadmaps/trusted-ict/quantum/quantum-safe-crypto/.

[27] See: https://www.ias.edu/ideas/2014/ambainis-quantum-computing. Quantum information can lead to a better understanding of the principles of quantum systems.

[28] See: Jeffery, S., Magniez, F. & de Wolf, R. Optimal Parallel Quantum Query Algorithms. Algorithmica 79, 509–529 (2017). https://doi.org/10.1007/s00453-016-0206-z.

[29] See: https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-845-quantum-complexity-theory-fall-2010/.

[30] See Van Meter, Rodney & Devitt, Simon. (2016). The Path to Scalable Distributed Quantum Computing. Computer. 49. 31-42, https://ieeexplore.ieee.org/document/7562346; C. G. Almudever et al., Towards a scalable quantum computer, 2018 13th International Conference on Design & Technology of Integrated Systems In Nanoscale Era (DTIS), Taormina, 2018, pp. 1-1, https://ieeexplore.ieee.org/document/8368579.

[31] An atom consists of negatively charged electrons, positively charged protons and neutrons.

[32] For technologies that rival quantum computing, see: Dmitri Nikonov, Stochastic magnetic circuits rival quantum computing, Nature 573, 351-352 (2019), https://www.nature.com/articles/d41586-019-02742-x

[33] See also: https://ocw.tudelft.nl/course-lectures/2-2-2-many-quits-computer/?course_id=28465.

Electrical Interference, Error Correction and Noise-less Qubits

Today's machines cannot withstand shocks and electrical interference very well. Once disturbed, they start making too many mistakes. In addition, coherent quantum states have a limited lifespan. Solutions for these challenges can be found in noise-less qubits[34] that are isolated from any electrical interference, robust fault tolerance implementation and quantum error correction.[35] On top of that, present-day machines contain a powerful magnet. When this magnet is on, it is unpleasant and even unhealthy to stay around for a long time.

Anno 2020, quantum computers are becoming increasingly powerful but prone to unreliability because of interference. Sourcing exotic, high-quality parts for quantum computers is a challenge.[36] It is essential for quantum computing scalability that both hardware and software are reliable, safe and easy to upgrade.[37]

Quantum & Artificial Intelligence Hybrids

The combination of artificial intelligence, machine learning and functioning quantum computers & simulators can theoretically solve mathematical, physical and chemical optimization problems. Technological synergies can disentangle problems that are currently not soluble with the help of binary computers. Synergies such as AI & quantum computing hybrids consisting of bits, neurons and qubits. Combining powerful AI algorithms using classical computers together with quantum algorithms that utilize the quantum mechanical principles, have the potential to revolutionize bio engineering - including synthetic cells[38] - and nano engineering. Quantum will enhance AI. In the coming years, interaction between quantum technology and AI will give a new perspective of science itself to the world. It is expected that quantum computing and quantum software will play an important role in the development of autonomous artificial beings, and in the awakening of Artificial Super Intelligence ('**ASI**'). A downright paradigm shift.

2. Application Areas of Quantum Technology

Quantum technology has various application areas.[39] Each area, or domain, has its own, separate line of development. In some cases, these domains intersect. Take, for example, Quantum Key Distribution ('**QKD**'), a secure communication method that uses quantum cryptography.[40] QKD is an application of quantum internet, that does not depend on the development of quantum computers. In the future, quantum internet will make (advanced) networked quantum computing possible,

---

[34] Yuichiro Fujiwara, Quantum error correction via less noisy qubits, 20 Feb 2013, https://arxiv.org/abs/1302.5081.See also: https://news.mit.edu/2019/non-gaussian-noise-detect-qubits-0916
[35] See also Fu, *supra* note 5.
[36] Martin Giles, "We'd have more quantum computers if it weren't so hard to find the damn cables". MIT Technology Review, 17 January 2019, https://www.technologyreview.com/2019/01/17/137811/quantum-computers-component-shortage/.
[37] For example, using germanium quantum dots instead of silicon is essential to scale up qubits. See: https://qutech.nl/story/it-all-comes-together/. See also: https://phys.org/news/2020-07-wiring-path-scalable-quantum.html and https://cloudblogs.microsoft.com/quantum/2018/05/16/achieving-scalability-in-quantum-computing/.
[38] See: https://www.genome.gov/about-genomics/policy-issues/Synthetic-Biology.
[39] See TUDelft, *supra* note 16.
[40] See: https://qiskit.org/textbook/ch-algorithms/quantum-key-distribution.html.

which includes QKD.[41] This way, in networked quantum computing, two lines of development come together.

We can distinguish the following six application areas of quantum technology:

1. Quantum computing, including optimization problems among which package delivery route optimization and the travelling salesman problem, prime factorization, and chemistry, such as next generation batteries, fluid mechanics, medicines, nutrition, fertilizers and novel materials;
2. Quantum communication, such as the quantum internet that includes quantum-safe encryption based on the uncertainty principle[42];
3. Quantum sensing, including quantum nanoscience and metrology, for instance advanced, high-resolution distance measuring, quantum MRI, brain-machine interfaces and atomic clocks, automotive, navigation, imaging;
4. Quantum simulation, such as weather forecasting, water management, carbon removal technology, self-driving cars, modelling behavior of molecules and even single electrons;[43]
5. Fundamental quantum science, studying the fundamental laws of quantum physics;
6. Artificial intelligence, which includes machine learning and neural networks.

In our current NISQ ('**Noisy Intermediate State Quantum**') era[44], each of these six quantum domains requires dedicated hardware infrastructures and software ecosystems including algorithms, API's and apps.

Quantum Computing complements Classical Computing

Apart from hybrids of quantum and AI, it is expected that quantum technology will stand out in the above-mentioned application areas. AI will retain its own application areas, but it will be enriched and boosted by quantum. One of the reasons for this is that quantum and AI have different physical characteristics. Quantum computing will therefore complement, instead of replace conventional computing in the foreseeable future. The same applies to quantum sensing, quantum simulation and the quantum internet.

From a legal perspective, the economic sectors in which quantum technology is used often determine the vertical, industry-specific regulations that apply to quantum, such as the Medical Device Regulation[45] in the health sector, or the Machinery Directive[46] in the case of Robotics. Sectors and industries are a key starting point for the applicability of product liability regimes, and for proprietary or third-party IP rights.

---

[41] See: https://tu-delft.foleon.com/tu-delft/quantum-internet/the-six-stages-of-quantum-networks/.
[42] See: Tujner, Zsolt & Rooijakkers, Thomas & van Heesch, Maran & Önen, Melek. (2020). QSOR: Quantum-safe Onion Routing. 618-624, https://www.researchgate.net/publication/343183996_QSOR_Quantum-safe_Onion_Routing.
[43] It is even possible that we ourselves live in a quantum simulation.
[44] See: John Preskill, Quantum Computing in the NISQ era and beyond, January 2 2018, https://arxiv.org/abs/1801.00862.
[45] Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC) No 178/2002 and Regulation (EC) No 1223/2009 and repealing Council Directives 90/385/EEC and 93/42/EEC (MDR).
[46] Directive 2006/42/EC of The European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (Machinery Directive).

3. IP on the Components of Quantum Computers

Let us return to quantum computing and link it to intellectual property law. Quantum computers can be protected by different types of intellectual and industrial property rights, such as chip rights (semi-conductor topography protection), patents, copyrights, trade secrets, design rights and trademarks. Per component, we discuss which IP rights can be established. We also discuss whether there are gaps / loopholes in protection or whether there are overlaps. Although IP rights are territorial rights, we make these qualifications as much as possible from the perspective of an international IP acquis.[47] There may be regional differences in formal and material requirements, flexibilities, scope and term of protection in the EU, China, India or the US.

The Components

Quantum computers, depending on their specific application in the domains listed above, and depending on their precise implementation method, may contain the following layers of components[48]: the technology building blocks (qubits), quantum gates & multipliers, quantum integrated circuit chips, the various types of quantum processors such as spin qubits and superconducting[49] transmon qubits[50], quantum interference devices[51], compiler engines (i.e. optimizers, translators, mappers)[52], decoders, a simulator and an emulator, a circuit drawer, the microarchitecture (quantum execution (‘**QEX**’) block & quantum error (‘**QEC**’) block), the quantum-classical interface, the quantum instruction set architecture, quantum memory, quantum software[53], smart quantum algorithms[54], the API’s (application programming interface),[55] quantum arithmetic unit (quantum addition, subtraction, multiplication, and exponentiation), runtime assertion & configuration, quantum computing platforms, program paradigm & languages, the Bacon-Shor stabilization code, three dimensional color codes[56], and surface codes.

---

[47] See also: Paul Goldstein & Bernt Hugenholtz, *International Copyright: Principles, Law, and Practice* (4rd edn, OUP 2019), and Maciej Szpunar, Territoriality of Union Law in The Era of Globalisation, in: « Evolution des rapports entre les ordres juridiques de l'Union européenne, international et nationaux » Liber Amicorum Jiří Malenovský, D. Petrlík, M. Bobek, J. Passer et A. Masson (dir.), Bruylant 2020.

[48] 5 Essential Hardware Components of a Quantum Computer." National Academies of Sciences, Engineering, and Medicine. 2019. *Quantum Computing: Progress and Prospects*. Washington, DC: The National Academies Press. doi: 10.17226/25196, https://www.nap.edu/read/25196/chapter/7#114.

[49] See also: Glennda Chui, Stanford physicist’s quest for the perfect keys to unlock the mysteries of superconductivity, September 10, 2020, https://news.stanford.edu/2020/09/10/unlocking-mysteries-superconductivity/.

[50] See: https://qutech.nl/demonstrators/.

[51] See: Loft, N.J.S., Kjaergaard, M., Kristensen, L.B. *et al.* Quantum interference device for controlled two-qubit operations. *npj Quantum Inf* 6, 47 (2020). https://doi.org/10.1038/s41534-020-0275-3.

[52] See: Epiqc, New compiler makes quantum computers two times faster, University of Chicago, October 11 2019, https://phys.org/news/2019-10-quantum-faster.html.

[53] 6 Essential Software Components of a Scalable Quantum Computer." National Academies of Sciences, Engineering, and Medicine. 2019. *Quantum Computing: Progress and Prospects*. Washington, DC: The National Academies Press. doi: 10.17226/25196, https://www.nap.edu/read/25196/chapter/8#137.

[54] See: Montanaro, A. Quantum algorithms: an overview. *npj Quantum Inf* 2, 15023 (2016). https://doi.org/10.1038/npjqi.2015.23 and "3 Quantum Algorithms and Applications." National Academies of Sciences, Engineering, and Medicine. 2019. *Quantum Computing: Progress and Prospects*. Washington, DC: The National Academies Press. doi: 10.17226/25196, https://www.nap.edu/read/25196/chapter/5.

[55] See for example: https://en.wikipedia.org/wiki/Quantum_programming.

[56] See: Aleksander Kubica, Michael E. Beverland, Fernando Brandão, John Preskill, and Krysta M. Svore, Three-Dimensional Color Code Thresholds via Statistical-Mechanical Mapping, Phys. Rev. Lett. 120, 180501 – Published 4 May 2018, https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.120.180501.

Furthermore, the actual casing (the dilution refrigerator) of a quantum computer contains -*inter alia*- a cryoperm shield, quantum amplifiers, cryogenic isolators, a mixing chamber, superconducting coaxial lines[57], input microwave lines and a qubit signal amplifier.

In addition, a conventional computer is used to be able to access the output of the quantum computer in human and machine-readable formats. This means there is a certain amount of 'classical control', through the quantum-classical interface. In case we are dealing with quantum & AI hybrids (or hybrid quantum-classical co-processing systems) we have to add all the parts of the AI system to this list of components, including the inference engine that processes the rules.[58]

Creations & Inventions

Only novel, useful, inventive and non-obvious inventions made by a human inventor, can be patented. Copyrights generally require a minimum of creativity, originality and a human author.[59]

Technical discoveries that have been developed and embedded into hardware, can be patented. Software can be copyrighted. From the perspective of IP rights, we can group the components of a quantum computer by hardware (chip rights, design and utility patents), software (copyrights, creative commons), and algorithms (open source[60] or public domain). The protection term for patents is 20 years, compared to 70 years for software. One of the reasons for this difference, is that the copyright system and the patent system both have distinct objectives.[61] In general, quantum computing hardware is much more difficult to develop and replicate than the accompanying software and algorithms. It requires more investments to make than writing the code. As a result of this, computer chips can become subject to geopolitical conflicts and export control reforms[62], as observed in today's trade war between the US and China.[63]

Patents

The patent system aims to incentivize inventors to disclose, produce and market their invention with the prospect of return on investment.[64] It intends to encourage the detailed disclosure of innovative ideas and optimize the allocation of R&D capacity, by granting exclusive rights to the inventor. At the same time, it incentivizes inventors to improve and build upon earlier patents.[65]

---

[57] See also: Yufan Li, Xiaoying Xu, M.-H. Lee, M.-W. Chu, C. L. Chien, Observation of half-quantum flux in the unconventional superconductor β-Bi_2Pd, https://science.sciencemag.org/content/366/6462/238 *Science,* 11 Oct 2019 : 238-241 and Johns Hopkins University, New Superconducting Material Discovered That Could Power Quantum Computers of the Future, October 11 2019, https://scitechdaily.com/new-superconducting-material-discovered-that-could-power-quantum-computers-of-the-future/.

[58] Mauritz Kop, *AI & Intellectual Property: Towards an Articulated Public Domain*, 28 Tex. Intell. Prop. L. J. 297, 2020, http://tiplj.org/wp-content/uploads/Volumes/v28/Kop_Final.pdf.

[59] See also Kop, *supra* note 58.

[60] See for example the Qiskit Open-Source Quantum Development, https://qiskit.org/. Qiskit is an open source SDK for working with quantum computers at the level of pulses, circuits and algorithms.

[61] Menell, Peter S. and Lemley, Mark A. and Merges, Robert P. and Balganesh, Shyamkrishna, Intellectual Property in the New Technological Age: 2020 (Clause 8 Publishing, 2020).

[62] See: https://merics.org/en/report/export-controls-and-us-china-tech-war and https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI%282019%29644187.

[63] See for example: https://www.bbc.com/news/business-45899310.

[64] Menell et al., *supra* note 61.

[65] Kop, *supra* note 58.

The following components are eligible for patent protection:

The technology building blocks (qubits), quantum gates & multipliers, quantum integrated circuit chips, the various types of quantum processors such as spin qubits and superconducting transmon qubits, quantum interference devices, compiler engines (i.e. optimizers, translators, mappers), decoders, a simulator and an emulator, a circuit drawer, the microarchitecture (quantum execution (QEX) block & quantum error (QEC) block), the quantum-classical interface, the quantum instruction set architecture, quantum memory. The 'quantum computing process' can be protected by patent as well. The dilution refrigerator as a whole, including its individual cryoperm shield, quantum amplifiers, cryogenic isolators, a mixing chamber, superconducting coaxial lines, input microwave lines and a qubit signal amplifier component, are also eligible for patenting.

Copyrights

Copyright intends to incentivize and maximize creativity, cultural diversity, technological progress and freedom of expression. An important objective of copyright is to stimulate creation and dissemination of diverse cultural expression by enabling successive generations of authors to draw freely on the works of their successors.

According to TRIPs and WTC, creative aspects of software source code and firmware can be protected by copyright, as where they literary works. Expression of computer software is protected, not its functionality.[66] The idea/expression dichotomy prescribes that ideas are not protected by copyright. Algorithms, functionality, principles and ideas on the other hand, are not protected.[67] These are part of the public domain. Before the expression of an idea is captured in a tangible medium, it can be time-stamped by an i-Depot. Ideas can also be protected contractually, by an NDA.

The following components are eligible for copyright protection:

Quantum software, the API's (application programming interface), quantum arithmetic unit (quantum addition, subtraction, multiplication, and exponentiation), runtime assertion & configuration, quantum computing platforms, program paradigm & languages, the Bacon-Shor stabilization code, color codes, and surface codes. These components fall within the scope of copyrightable subject matter.

It is possible that certain applied program languages, such as eDSL in Python[68], will be open sourced instead of copyright protected, or licensed for use via Creative Commons.[69] As with classical computing, it is expected that both commercial and open source operating systems will come onto the markets.

[66] See for example: Directive 2009/24/EC of the European Parliament and of the Council of 23 April 2009 on the legal protection of computer programs (EU Software Directive).
[67] Daniel Gervais and Estelle Derclaye, 'The scope of computer program protection after SAS: are we closer to answers?' 34(8) European Intellectual Property Review, 565 (2012) (pp. 565-572)
[68] See: https://github.com/topics/edsl.
[69] See: https://creativecommons.org/.

A few uncrystallized areas require specific attention and perhaps some legal pioneering. Functionality for instance, is not protected by copyright.[70] This raises the question whether software and API functionality should be protected by patents. Arguments for and against patentability of software functionality and computer implemented inventions can be made.[71] Legal uncertainty about IP protection, whether concerning copyrights or patents, usually results in a shift to trade secrets, which generally stifles innovation.[72]

Input & Output Data

Depending on the application area, current quantum computing systems input consists of problem definitions. It is also possible to feed input data from a classical computing device into a quantum circuit, via the quantum-classical interface.

In case of AI hybrids that utilize machine learning training datasets, clearance of the input information is needed in the event this data represents IP subject matter.[73] Besides a rainbow of potential IP rights potentially vested in the data that need to be licensed under current law, including a *sui generis* database right on the training corpus itself (in territory Europe), the main roadblocks for the uptake of AI & data are privacy and GDPR concerns, and uncertainty about ownership of data.[74] There is a lack of trust in the existing rules, because they are complex and abstract and not written specifically for AI and machine learning training data. database EU. As for AI, there needs to be a broad exemption, or even a superior right to process data for quantum computing purposes, that respects privacy and other fundamental rights.[75]

In case quantum computing output represents IP subject matter, this output is eligible for IP protection. It can then be licensed or sold. If desired, IP rights on the output can also be waived and pushed into the public domain.

---

[70] Pamela Samuelson, 'Functionality and Expression in Computer Programs: Refining the Tests for Software Copyright Infringement' (January 31, 2017). Berkeley Technology Law Journal, Forthcoming. Available at SSRN: https://ssrn.com/abstract=2909152 and Peter Menell, Rise of the API Copyright Dead?: An Updated Epitaph for Copyright Protection of Network and Functional Features of Computer Software (January 18, 2017). 31 Harvard Journal of Law & Technology 305 (2018), UC Berkeley Public Law Research Paper No. 2893192, Available at SSRN: https://ssrn.com/abstract=2893192.

[71] For case law on this subject, see: Péter Mezei, Dóra Hajdú, Luis Javier Capote-Pérez and Jie Qin, Comparative Digital Copyright Law (Vandeplas publishing 2020).

[72] Kop, *supra* note 58

[73] See: Mauritz Kop, *Machine Learning & EU Data Sharing Practices*, TTLF Newsletter on Transatlantic Antitrust and IPR Developments Stanford-Vienna Transatlantic Technology Law Forum, Stanford University 2020, Volume 1, https://www-cdn.law.stanford.edu/wp-content/uploads/2015/04/2020-1.pdf. See also Kop, *supra* note 58.

[74] *id.*

[75] Mauritz Kop, The Right to Process Data for Machine Learning Purposes in the EU (June 22, 2020). Harvard Law School, Harvard Journal of Law & Technology (JOLT) Online Digest 2021, Forthcoming, Available at SSRN: https://ssrn.com/abstract=3653537. See also: Christophe Geiger, Giancarlo Frosio, & Oleksandr Bulayenko, *The Exception for Text and Data Mining (TDM) in the Proposed Directive on Copyright in the Digital Single Market - Legal Aspects*, Centre for International Intellectual Property Studies (CEIPI) Research Paper No. 2018-02 (March 2, 2018). See also: Sean Flynn, Christophe Geiger & João Quintais et al., *Implementing User Rights for Research in the Field of Artificial Intelligence: A Call for International Action,* European Intellectual Property Review 2020, Issue 7 (April 20, 2020). Available at SSRN: https://ssrn.com/abstract=3578819.

IP Ownership: Legal Subjectivity and Public Domain

Output created or invented by autonomous quantum/ AI systems without human upstream or downstream intervention should be public domain. The output lacks human creativity and inventiveness and society benefits from a robust public domain. Besides that, IP rights can only be owned by legal subjects, such as people, universities or corporations. Autonomous systems lack legal subjectivity or legal personhood needed to own rights and carry responsibilities. Machine generated Quantum/AI Creations & Inventions should be *Res Publicae ex Machina*.[76] These belong in an articulated public domain.

Trade Secrets & Trademarks

On top of copyrights and patents, virtually each component can contain trademarks (and in some circumstances trade-dress) and trade secrets[77], with potentially unlimited duration of IP protection. Further, cybersecurity law and national security considerations could, beyond the scope of the IP toolkit, play a role in keeping technological breakthroughs a state secret. As is the case with AI system, legal uncertainty about the patentability of quantum computing systems together with the unlimited duration of trade secret rights, could ultimately cause a shift towards trade secrets, in order to protect assets and commodify quantum computing applications. This trend might ensue in a disincentive to disclose ideas and impedes dissemination of information, technology transfer to the market[78] and follow on innovation.[79]

Note that a trade secret right does not protect against reverse engineering. This IP loophole can be filled by concluding contracts that prohibit unwanted reverse engineering. [80]

Additionally, both a quantum computer's looks, brands and functional design can be protected. Product design, artwork, logos, software interfaces, layouts and hardware modelling can, depending on the territory for which protection is sought, be protected by an arrangement of IP instruments such as design rights, tradename rights and trade dress.

IP Overlap & Overprotection

Strategically using a mixture of IP rights to maximize and protect the value of the IP portfolio of the quantum computer's owner, can result in an unlimited duration of global exclusive exploitation rights for first movers, absent compulsory licensing of standard essential patents (SEP) in certain territories. Thus, there are no consequential loopholes in IP protection possibilities. Far from it. Instead, there is an overlap of IP protection regimes.[81] At this time, new layers of rights do not seem appropriate.

---

[76] Kop, *supra* note 58.
[77] See also: Drexl, Josef, 'Designing Competitive Markets for Industrial Data - Between Propertisation and Access' (October 31, 2016).
[78] See for example: https://www.tno.nl/en/focus-areas/techtransfer/.
[79] Wachter, Sandra and Mittelstadt, Brent, 'A Right to Reasonable Inferences: Re-Thinking Data Protection Law in the Age of Big Data and AI' (October 05, 2018). Columbia Business Law Review, 2019(1).
[80] Kop, *supra* note 58.
[81] *id.* See also Deltorn, Jean-Marc and Macrez, Franck, Authorship in the Age of Machine learning and Artificial Intelligence (August 1, 2018). In: Sean M. O'Connor (ed.), The Oxford Handbook of Music Law and Policy, Oxford University Press, 2019 (Forthcoming); Centre for International Intellectual Property Studies (CEIPI) Research Paper No. 2018-10. Available at SSRN: https://ssrn.com/abstract=3261329.

Other quantum technology applications, among which quantum sensing, quantum simulation and the quantum internet are equally eligible for IP protection, using the same amalgam of IP rights. From a beyond IP innovation law perspective, future quantum internet functionality[82] ought to be public domain and net neutrality should exist. Its constituting, enabling components, however, could in theory be protected by an array of IP rights. With each right protecting something different. The same applies to quantum sensors, quantum simulation, engineered/synthesized plants and novel materials invented with the help of quantum technology.

In general, our current intellectual property framework is not written with quantum technology in mind. Intellectual property should be an exception -limited in time and scope- to the rule that information goods can be used for the common good without restraint. From a dogmatic sustainable innovation policy perspective, IP rights holders should not be legally entitled to internalize the full social benefits of their creations and inventions.[83] There is no need to limit uncompensated positive externalities in a well-structured quantum technology market place, nor is there a need to internalize such positive spillovers in intellectual property, after initial investment costs have been retrieved.[84] Positive quantum technology creation and invention externalities do not need to be remedied by IP regulations, taxes or subsidies, beyond the break-even-point. Furthermore, there is no tragedy of the commons in IP on quantum technology knowledge goods.[85] Information cannot be overused.

Intellectual property cannot incentivize creation, prevent market failure, fix winner-takes-all effects, eliminate free riding and prohibit predatory market behavior at the same time. To encourage fair competition and correct market skewness, antitrust law is the instrument of choice.[86]

The question is whether the identified overlap in regimes benefits business dynamism and accelerated innovation.[87] The subsequent IP overprotection may create barriers for market entrants and raise concerns regarding fair competition, freedom of expression and the creation of new jobs.[88] Overprotection might hinder industry-specific innovation. In this particular case it slows down progress in an important application area of quantum technology, namely quantum computing.

A solution tailored to the exponential pace of innovation in The Quantum Age, is to introduce shorter IP protection durations of 3 to 10 years for Quantum and AI infused creations and inventions. These shorter terms could be made applicable to both the software and the hardware side of things. Clarity about the proposed limited durations of exclusive rights -in combination with compulsory licenses or fixed prized statutory licenses- encourages legal certainty, knowledge dissemination and follow on innovation within the quantum domain.[89] In this light, policy makers should build an innovation

[82] See also: https://ec.europa.eu/digital-single-market/en/news/quantum-technologies-and-advent-quantum-internet-european-union-brochure.
[83] See also: Lemley, Mark A., Property, *Intellectual Property, and Free Riding*. Texas Law Review, Vol. 83, p. 1031, 2005. Available at SSRN: https://ssrn.com/abstract=582602.
[84] *id.*
[85] Kop, *supra* note 58.
[86] To *inter alia* ensure that dominant online platforms can be challenged by new market entrants and existing competitors, so that consumers have the widest choice and the Single Market remains competitive and open to innovations, the European Commission recently introduced the Digital Services Act package, as part of the European Digital Strategy. See: https://ec.europa.eu/digital-single-market/en/digital-services-act-package.
[87] See also: See also Deltorn, Jean-Marc and Macrez, Franck, Authorship in the Age of Machine learning and Artificial Intelligence (August 1, 2018). In: Sean M. O'Connor (ed.), The Oxford Handbook of Music Law and Policy, Oxford University Press, 2019 (Forthcoming) ; Centre for International Intellectual Property Studies (CEIPI) Research Paper No. 2018-10. Available at SSRN: https://ssrn.com/abstract=3261329.
[88] Kop, *supra* note 58.
[89] *id.*

architecture that mixes freedom (e.g. access, public domain) and control (e.g. incentive & reward mechanisms).

On November 25th 2020 the European Commission presented its IP Action Plan, which promises an '*overhaul of the intellectual property system to strengthen Europe's ability to develop next generation technologies and reflect advances in data and AI*'.[90] The EC aims to set global standards in IP. The Action Plan announces Action announces measures in five key areas[91]:

1. Improving the protection of IP
2. Boost the uptake of IP by small and medium-sized companies (SMEs)
3. Facilitate the sharing of IP
4. Fight counterfeiting and improve enforcement of IP rights
5. Promote a global level playing field

IP Alternatives

With regard to innovation incentives and allocation mechanisms, IP rights are not the only answer - and not automatically the best answer. Policy makers could apply innovation policy pluralism (i.e. mix, match and layer IP alternatives such as anti-trust law, contract law, consumer privacy protection, tax law, standardization & certification, as well as prizes, subsidies, public-private funding, competitions, penalty's and fines) to enable fair-trading conditions, remedy externalities and balance the effects of exponential innovation within the markets.[92] Because innovation incentive & reward mechanisms, externalities and safety/security risks vary per industry and per technology, policy makers should differentiate more unequivocally between economic sectors, when designing regulatory solutions. Further, IP rights might be less necessary in a quantum and AI driven world where creation, reproduction, and distribution have become inexpensive.[93]

4. Regulating Quantum Technology

Regulating technology is a continuous effort. It is a dynamic, ongoing process that follows the life-cycle of the technology and the application.

The pervasiveness of quantum technology askes for a holistic view on a politically feasible regulatory framework. It also demands for lawmakers and their staff to acquire interdisciplinary competences. Knowledge and skills pertaining to application areas like the quantum internet, quantum computing methods and use cases, allow policy makers to communicate more effectively about governing

[90] See: https://ec.europa.eu/commission/presscorner/detail/en/IP_20_2187 and https://ec.europa.eu/docsroom/documents/43865/attachments/2/translations/en/renditions/native.

[91] *id.*

[92] See: Daniel J. Hemel & Lisa Larrimore Ouellette, *Innovation Policy Pluralism*, 128 YALE L.J. (2019), Available at: https://digitalcommons.law.yale.edu/ylj/vol128/iss3/1 and Mauritz Kop, Beyond AI & Intellectual Property: Regulating Disruptive Innovation in Europe and the United States – A Comparative Analysis, https://law.stanford.edu/projects/beyond-ai-intellectual-property-regulating-disruptive-innovation-in-europe-and-the-united-states-a-comparative-analysis/.

[93] Lemley, Mark A., IP in a World Without Scarcity (March 24, 2014). Stanford Public Law Working Paper No. 2413974. Available at SSRN: https://ssrn.com/abstract=2413974.

quantum technology.[94] A thorough understanding of quantum mechanics gives context to multifaceted challenges surrounding quantum technology, including its impact on society.[95] Defining legal requirements requires interdisciplinary skills and must be informed by a solid grasp of relevant quantum technologies and the way technology, humans and the law interact.[96]

Policy makers should construct a legal framework that balances the interests of stakeholders and that of society at large.[97] A framework that offers legal certainty, a favorable investment climate and an innovation optimum, while respecting democratic rights, fundamental freedoms, ensuring inclusive societal outcomes, protecting citizen's wellbeing and safeguarding our joint humanist moral values.[98] In addition to standards, certification and consensus on codes of ethics[99], we need an agile legislative framework that can adapt quickly to changing circumstances and societal needs.[100]

Legislative Framework

Let us link quantum to the Trustworthy AI principles. Right now, the European Commission ('**EC**') is drafting its Law of AI, to stimulate the commitment to Trustworthy AI in the European economy.[101] Trustworthy AI has 7 key requirements: Human agency and oversight, Technical robustness and safety, Privacy and Data Governance, Transparency, Diversity, Non-discrimination and fairness, Societal and environmental well-being, and Accountability.[102] The EC is also designing a legislative framework for data governance: The Data Governance Act.[103] Both the Law of AI and the Data Governance Act are expected to be adopted next year.[104] This will make access to data easier and provides clarity about the rules for AI like liability, insurance and risks.[105] It is expected that the scope

---

[94] For more interdisciplinary roadblocks surrounding emerging tech, see: Susan Athey & Guido W. Imbens, *Machine Learning Methods that Economists Should Know About*, ANNUAL REVIEW OF ECONOMICS, VOL. 11, pp. 685-725, 2019. Available at SSRN: https://ssrn.com/abstract=3445877.

[95] See also: Pieter E. Vermaas, The societal impact of the emerging quantum technologies: a renewed urgency to make quantum theory understandable, Ethics Inf Technol (2017), https://dl.acm.org/doi/abs/10.1007/s10676-017-9429-1.

[96] See also Kop, *supra* note 92.

[97] See also Mauritz Kop, Shaping the Law of AI: Transatlantic Perspectives, TTLF Working Papers No. 65, Stanford-Vienna Transatlantic Technology Law Forum (2020), https://law.stanford.edu/publications/no-65-shaping-the-law-of-ai-transatlantic-perspectives/.

[98] Kop, *supra* note 92.

[99] See also: Principled Artificial Intelligence: Mapping Consensus in Ethical and Rights-Based Approaches to Principles for AI, Berkman Klein Center Research Publication No. 2020-1, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3518482; World Economic Forum, White Paper Digital Policy Playbook 2017: Approaches to National Digital Governance, http://www3.weforum.org/docs/White_Paper_Digital_Policy_Playbook_Approaches_National_Digital_Governance_report_2017.pdf and Kop, *supra* note 97.

[100] See also: World Economic Forum *supra* note 99.

[101] See: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12527-Requirements-for-Artificial-Intelligence.

[102] See: https://ec.europa.eu/digital-single-market/en/artificial-intelligence.

[103] The Data Governance Act is part of the European Strategy for Data, see: https://ec.europa.eu/digital-single-market/en/news/proposal-regulation-european-data-governance-data-governance-act and https://ec.europa.eu/digital-single-market/en/policies/building-european-data-economy.

[104] For further reading on AI regulation, see: Hoffmann-Riem, Wolfgang. (2020). Artificial Intelligence as a Challenge for Law and Regulation. 10.1007/978-3-030-32361-5_1, in Regulating Artificial Intelligence, Editors: Wischmeyer, Thomas, Rademacher, Timo (Eds.) (Springer 2020).

[105] For a groundworks analysis of the different notions of data interoperability, see: Hoffmann, Jörg and Gonzalez Otero, Begoña, Demystifying the Role of Data Interoperability in the Access and Sharing Debate (September 29, 2020). Max Planck Institute for Innovation & Competition Research Paper No. 20-16, Available at SSRN: https://ssrn.com/abstract=3705217.

of these new laws will also extend to technological synergies such as AI & quantum computing hybrids.

Overarching Core Quantum Technology Rules

The first regulatory step should be for countries to adopt a holistic set of overarching core quantum technology rules.[106] Universal, horizontal rules that apply across all industries, and that protect our democracy and our fundamental human rights & freedoms in the Information Age.[107] These core rules should build upon the principles we embraced for AI. They have to cover development and introduction of quantum-based applications, products and services, software and hardware paradigms, the supply chain as well as enabling factors that include quantum computing ecosystems, quantum communications infrastructure[108], talent development and related technologies.[109]

Particles and energy at the atomic level do not follow the same rules as the objects we can see in our everyday lives. Similarly, quantum laws do not work well in the macro cosmos. As quantum technology and AI have different physical properties, we need additional overarching core rules. Imagine Ten Quantum Technology Commandments, consisting of tables or Prime Directives[110] similarly to "Thou shall not distort the space-time continuum", and "Thou shall not interfere with the history of mankind in its current simulation of the universe, during time-travelling." Another core rule should be that quantum computing is equally available to everyone, via desktop or cloud.[111] A quantum divide should be avoided.[112] According to the quantum scientists from QuTech Delft, governance of quantum computing and the quantum internet needs to be construed around at least the following public values: Security, Safety, Resilience, Trust Privacy, Equal Access and Net Neutrality.[113]

Differentiated Industry-Specific Approach

In addition to universal, overarching guiding principles of Trustworthy & Responsible Quantum Technology that are in line with the unique physical characteristics of quantum mechanics, we advocate a vertical, differentiated industry-specific legislative approach regarding innovation incentives (based on the innovation policy pluralism toolkit)[114] and risks (based on the pyramid of

---

[106] *Cf.* Paul Nemitz & Matthias Pfeffer, Prinzip Mensch. Macht, Freiheit und Demokratie im Zeitalter der Künstlichen Intelligenz, https://prinzipmenscheu.wordpress.com/. See also: Kop, *supra* note 97.

[107] For a detailed description of ethical, legal and social guiding principles for quantum technology, see: Mauritz Kop, *Establishing a Legal-Ethical Framework for Quantum Technology*, (February 28, 2021), Yale Journal of Law & Technology (YJoLT) The Record 2021, Forthcoming. For horizontal rules in general, see: https://ec.europa.eu/competition/state_aid/legislation/horizontal.html.

[108] See also: https://ec.europa.eu/digital-single-market/en/faq/frequently-asked-questions-quantum-communication-infrastructure.

[109] NWO, National Agenda on Quantum Technology - Key technologies as a solution to societal challenges, 16 September 2019, https://www.nwo.nl/en/news-and-events/news/2019/09/national-agenda-on-quantum-technology-the-netherlands-as-an-international-centre-for-quantum-technology.html.

[110] See: https://memory-alpha.fandom.com/wiki/Prime_Directive.

[111] Export controls implemented on quantum technology, AI and 3D printing will stand in the way of this pursuit of equality. See: https://www.kirkland.com/publications/article/2020/01/anticipating-turning-point-us-export-controls-tech.

[112] Vermaas, *supra* note 88.

[113] See: Quantum Internet | The internet's next big step, TU Delft, June 3, 2019. https://issuu.com/tudelft-mediasolutions/docs/quantum_magazine_june_2019.

[114] See Hemel & Larrimore Ouellette, *supra* note 92.

criticality, which should include a definition of high-risk quantum technology applications).[115] This means that certain sector-specific quantum technology boundary setting requirements in hi-risk industries such as health, food, energy, security, finance and defense are stricter than rules in lower risk areas such as entertainment and art.[116] Rules must not hinder rapid sustainable exponential innovation[117], in the sense of opening up new horizons of knowledge in the scientific, technological, aesthetic, cultural and social areas.[118]

Specific risks for society identified in light of quantum technology, are:

1. Risk of increased inequality during the introductory phase;
2. Risk to the stability of the financial system;
3. Risks pertaining to data privacy, data security, legal certainty and trust;
4. Risks of fake news, disinformation and misinformation and their impact on democratic processes;
5. Risks associated with state surveillance and control;
6. Risks of altered geopolitical relations.

Synchronous to implementing of quantum technology specific laws and standards and making risk-based impact assessments mandatory, the European Commission should take citizens and businesses by hand, prepare the workforce for quantum and construct specialized institutions that provide guidance, certainty, guarantees and trust on the current possibilities regarding the development and use of quantum technology.[119]

Towards an International Quantum Technology Legislative Acquis

The uncodified territory of Quantum & Law represents a phenomenal opportunity to establish a harmonized core of internationally pursued, common principles.[120] Innovation policy developments in countries that produce leading, next level technological inventions may have a strong impact on the creation of such an international acquis.[121] Further, the ubiquitous nature of quantum technology, which could pose challenges to oversight and enforcement of related laws, demands for

---

[115] See also Kop, *supra* note 97. Exclusive rights are performing different roles in different economic sectors. See in this context: Dan Burk and Mark Lemley, *The Patent Crisis and How the Courts Can Solve It* (University of Chicago Press, 2009) 38, and Kop, *supra* note 58.

[116] See Kop, *supra* note 97.

[117] Kop, *supra* note 73.

[118] McKenna, Mark P. and Frischmann, Brett M., *Comparative Analysis of Innovation Failures and Institutions in Context* (December 11, 2019). HOUSTON LAW REVIEW, VOL. 57, NO. 2, 2019; NOTRE DAME LEGAL STUDIES PAPER NO. 191211. Available at SSRN: https://ssrn.com/abstract=3502528. See also: Camilla Hrdy, Challenging what we think we know about "market failures" and "innovation", https://writtendescription.blogspot.com/2020/03/challenging-what-we-think-we-know-about.html.

[119] See also Kop, *supra* note 73 and Kop, *supra* note 97.

[120] See also Kop, *supra* note 97.

[121] Pluralism or Universalism in International Copyright Law, Introduction, Edited by Tatiana Eleni Synodinou. Kluwer, 2019, and Griffiths, Jonathan, Universalism, Pluralism or Isolationism? The Relationship between Authors' Rights and Creators' Human Rights (July 28, 2019). Tatiana Eleni Synodinou (ed), Pluralism or Universalism in International Copyright Law (Kluwer Law International), Available at SSRN: https://ssrn.com/abstract=3427997.

an international approach. It goes without saying that an acquis in quantum technology legislation should also include special international private law provisions that prevent forum shopping.[122]

5. Standardization and Effects on Innovation, IP & Competition

Standardization is a pillar of innovation policy.[123] Key objectives of standardization are quality, safety, security and sustainability. Standards intend to promote the competitiveness of enterprises large and small, protect consumers, remove technical obstacles to trade, and enhance market access and international trade. [124]As such, standardization has a significant impact on society, ranging from the safety and wellbeing of workers and citizens, the environment, the circular economy, to innovation and overall prosperity. Standards are voluntary, while certification is often mandatory. Both can add value to the quantum technology ecosystem. ISO/IEC standards for quantum computing are currently under construction.[125]

CEN-CENELEC Focus Group, EU Flagship, US QIS

Important initiatives that strive to *inter alia* bring quantum technology and standardization together, are the CEN-CENELEC Focus Group on Quantum Technologies, an initiative supported by the EU Quantum Flagship, and the 5 US Quantum Information Science Research Centers. CEN-CENELEC has its own IP rights policy under the provision of the CEN-CENELEC Guide 8 "Standardization and intellectual property rights (IPR)".[126] The Focus Group will ensure the cooperation of relevant stakeholders, identify standardization needs in the field of Quantum Technologies and suggest further actions to warrant that standards support the deployment of quantum technology in industry.[127] Furthermore, the Focus Group will set up a High-Level Expert Group on Quantum Technology ('**HLEG QT**'), assigned by the European Commission. The EU Quantum Technologies Flagship initiative aims to place Europe at the forefront of the second quantum revolution, develop a solid industrial base for quantum technologies and create practical applications in many different fields, including coordinated research and funding efforts.[128] Many EU Member States have adopted national Agenda's on Quantum technology. In august 2020, the White House Office of Science and Technology Policy and the U.S. Department of Energy ('**DOE**') announced the formation of five new Quantum Information Science ('**QIS**') Research Centers led by DOE national laboratories across the

[122] See also: Graeme Dinwoodie & Rochelle Dreyfuss, 'An international acquis: Integrating regimes and restoring balance' in Daniel J. Gervais (ed), *International Intellectual Property: A Handbook of Contemporary Research* (Edward Elgar Publishing 2015) 121.
[123] See: Granieri, Massimiliano, Renda, Andrea, Innovation Law and Policy in the European Union, Towards Horizon 2020 (Springer 2012).
[124] CEN-CENELEC, Faces of Standardization, interview with Carla Sirocchi, Secretary of CEN/CLC/JTC 19, https://www.cencenelec.eu/news/brief_news/Pages/TN-2020-049.aspx. See also: United Nations, Transforming our world: the 2030 Agenda for Sustainable Development, https://sustainabledevelopment.un.org/post2015/transformingourworld.
[125] See: https://www.iso.org/standard/80432.html and https://www.iso.org/committee/45020.html. These are (very) early stage developments in quantum computing standardization.
[126] See: https://www.cencenelec.eu/standards/Guides/Pages/default.aspx.
[127] See: https://www.cencenelec.eu/standards/topics/quantumtechnologies/pages/default.aspx and https://www.cencenelec.eu/news/events/Pages/QuantumTechnology.aspx. To this end, the Focus Group will produce a roadmap.
[128] See: https://ec.europa.eu/digital-single-market/en/policies/quantum-technologies-flagship

country.[129] SLAC National Accelerator Laboratory and Stanford University are founding partners of Q-NEXT national quantum center, one of the national QIS centers.[130]

CE-Marking

Responsible Tech and sustainable innovation require synergetic relationships between standardization, certification, legislation and government institutions.[131] Standards can be used as a policy lever, ahead of the market.[132] Take for example Europe, a leader in the field of quantum technology. The European Commission should steer to 'mandatory' standards for interoperability and interconnectivity in the Quantum Internet, with associated IEC, ISO and NEN standards and certification schemes. Companies that supply parts for quantum computers and quantum sensing would also benefit from interoperability standards. Certification is all about conformity and guarantees. Quantum products and services made within the EU or elsewhere in the world should adhere to EU safety and security benchmarks, including not limited to the high technical, legal and ethical standards that reflect Trustworthy quantum technology core values, before they qualify for a CE-marking and are eligible to enter the European markets.[133]

Fair Competition

Both insufficient and excessive standardization and certification can have adverse effects on innovation, competition and consumer welfare.[134] The right balance should be struck for any key enabling emerging technology. This includes a risk-based, differentiated industry-specific approach. The effects of requiring all implementations of quantum technology across all domains to be benchmarked by law beforehand, before it can obtain a CE-marking and/or other forms of certification, must be assessed in light of innovation incentives and global competition. Besides that, competitive and innovative aspects of open standards for quantum technologies should be thoroughly investigated.[135]

Roadblocks for SME's

[129] See: https://www6.slac.stanford.edu/news/2020-08-26-slac-and-stanford-join-q-next-national-quantum-center.aspx.

[130] See: https://www.q-next.org/ China is also participating in the race to quantum supremacy, see: https://www.scmp.com/news/china/science/article/3101219/china-claims-quantum-leap-machine-declared-million-times-greater and https://www.globaltimes.cn/content/1198916.shtml.

[131] CEN-CENELEC, *supra* note 124.
https://sustainabledevelopment.un.org/post2015/transformingourworld

[132] See also: Mark Lemley interview at The Robots Are Coming podcast, July 21, 2020, https://anchor.fm/ken-and-michael/episodes/The-Robots-Are-Coming-10---Professor-Mark-Lemley-eh1sdv.

[133] Kop, *supra* note 97. For China that would be the China Compulsory Certification (CCC), the US uses the USA Compliance Marking.

[134] See: Zafrilla Díaz-Marta, Vicente and Ferrandis, Carlos Muñoz, Open Standards and Open Source: Characterisation and Typologies (May 15, 2020). Available at SSRN: https://ssrn.com/abstract=3632406 and see: Hovenkamp, Herbert J., "Is Antitrust's Consumer Welfare Principle Imperiled?" (2019). *Faculty Scholarship at Penn Law*. 1985.

[135] *id*. Marta *supra* note 134. See also Kop, *supra* note 73.

Lastly, it is crucial that small and medium enterprises ('**SME**') get the chance to effectively participate in the standards-making process.[136] Where incumbents have sufficient budget, SME's often lack awareness and resources to implement standards, which leads to competitive disadvantages including less access to foreign markets.[137] It encourages a winner-takes-all effect and associated declining business dynamism.[138] This is a main roadblock for building a thriving quantum technology ecosystem. It is vital that SME's have access to and comply with the latest internationally accepted standards, that allow them to benefit from the presumption of conformity with legal requirements.[139]

6. ELSA – Ethical, Legal & Social Aspects

As with other emerging technologies, ethical, legal and social aspects ('**ELSA**' or '**ELSI**') play a pivotal role in the uptake of quantum technology. Our societal values need to be in sync with the immense innovative power of quantum technology.[140] An ELSA approach aims to proactively anticipate on societal issues and possible controversies, encourages stakeholders and the general public to actively participate in co-designing interdisciplinary research agendas, and intends to bridge boundaries between research communities.[141] In Europe, the related term 'Responsible Research and Innovation' ('**RRI**') is used to express a focus on the societal impact of scientific research.[142] The RRI principles are being applied to quantum technology.

Awareness

An important part of syncing our norms, standards, principles and values with quantum technology is to raise awareness of its ethical, legal and social aspects. Stakeholders like decision makers, entrepreneurs and the general public need to be adequately taught and informed.[143] Other central topics that need to be addressed are human capital together with coordinated efforts to upgrade the workforce, and the knowledge and skills agenda including quantum education across all levels. The overall goal should be to make quantum theory understandable to key players in the quadruple helix innovation model i.e. government, industry, academia and citizens.

Quantum Technology Impact Assessment

---

[136] CEN-CENELEC, Standards: A gateway for SMEs to the Single Market, Interview with *Maitane Olabarria* Uzquiano, SBS Director, 29 June 2020, https://www.cencenelec.eu/news/publications/Publications/2020-0626-Publication_StandardsBuildTrust.pdf.

[137] *id.*

[138] Cunningham, Colleen and Ederer, Florian and Ma, Song, Killer Acquisitions (April 19, 2020). Available at SSRN: https://ssrn.com/abstract=3241707, and Lemley, Mark A. and McCreary, Andrew, Exit Strategy (December 19, 2019). Stanford Law and Economics Olin Working Paper #542, Available at SSRN: https://ssrn.com/abstract=3506919.

[139] CEN-CENELEC, *supra* note 136.

[140] TU Delft *supra* note 16.

[141] See for example: https://en.wikipedia.org/wiki/Ethical,_Legal_and_Social_Aspects_research and https://cordis.europa.eu/programme/id/FP4-BIOTECH-2_0901.

[142] See: Peckham, James "What is responsible innovation, and why should tech giants take it seriously?". TechRadar, 2018-08-27.

[143] See also: Mauritz Kop, What are the main requirements for AI systems in Healthcare? 10 December 2018, European AI Alliance, European Commission, https://ec.europa.eu/futurium/en/european-ai-alliance/what-are-main-requirements-ai-systems-healthcare

We could imagine a practical tool, based on the Dutch AI Impact Assessment[144] that would offer entrepreneurs, data scientists and software programmers a concrete code of conduct with which quantum technology can be safely implemented in their products and services. We could name it: the Quantum Technology Impact Assessment. It would provide a moral compass and nurture awareness. The Quantum Technology Impact Assessment could be a guide for the application of quantum computing, quantum sensing, quantum simulation and the quantum internet. It would use a practical checklist from a legal, technical and ethical point of view, in line with the European Trustworthy Quantum Technology principles. Quantum technology has to be safe, secure and resilient.

Further, quantum technology start-ups[145] and scale-ups should implement the Quantum Technology Impact Assessment in their workflow. An external audit ought be conducted by a multidisciplinary team that consists of a quantum technologist, an engineer, data scientist, an ai developer, a software programmer, lawyer, privacy specialist, ethicist, a manager and someone who has sector specific knowledge such as a doctor, to conduct the Quantum Technology Impact Assessment.[146] Going through this process can have a beneficial effect on insurance, duties & responsibilities of care, and liability issues. The successful implementation of the audit can, in addition to the presumption of legal conformity[147], be a decisive reason for multinationals to award a certain assignment to an SME, and vice versa.

As quantum technology and AI have different physical characteristics, additional requirements to balance its societal impact may be needed. Implementing change requires balancing the right combination of public and private incentives.[148] It is urgent that thorough, multidisciplinary research is carried out into the expected ELSA implications of this technology, plus the required funding. Society needs to be ready for a quantum future because it's coming.[149]

7. Trustworthy Quantum Technology by Design

The second quantum revolution is now underway.[150] Although atoms, neutrons and molecules are neutral, technology is not. Therefore, we should shape quantum technology for Good by embedding our norms, standards, principles and values into the architecture of our quantum systems, as much as possible.[151] This can be accomplished by pragmatically and responsibly building upon future overarching core quantum technology rules[152], which include the 7 key ethical, legal and technical

---

[144] AI Impact Assessment | Netherlands, December 6, 2018, https://airecht.nl/blog/2018/ai-impact-assessment-netherlands. See also: HLEG's Assessment List for Trustworthy Artificial Intelligence (ALTAI) for self-assessment and Council of Europe's Recommendations on the human rights impacts of algorithmic systems.

[145] Such as Dutch quantum computing start-up Orange Quantum Systems, see: https://thequantumdaily.com/2020/05/19/orange-quantum-systems-enabling-the-future-of-quantum-computing/.

[146] AI Impact Assessment, *supra* note 144.

[147] CEN-CENELEC, *supra* note 136.

[148] See also: Adapting policies that respond to today's challenges, https://news.stanford.edu/2020/09/28/2020-u-s-election-issues-challenges/.

[149] NATO Report "Science & Technology Trends: 2020-2040", D.F. Reding & J. Eaton, NATO Science & Technology Organization, March 2020 https://www.nato.int/cps/en/natohq/news_175574.htm. See also: https://www.economist.com/news/essays/21717782-quantum-technology-beginning-come-its-own.

[150] See: https://ec.europa.eu/commission/presscorner/detail/de/MEMO_18_6241.

[151] Kop, *supra* note 73 and Kop, *supra* note 97.

[152] As mentioned above in Chapter 4 Regulating Quantum Technology.

requirements set for AI.[153] Following this path, we can develop a Trustworthy Quantum Technology by Design paradigm.

Our society's norms, standards, principles and values need to be baked into our intelligent quantum systems[154] by means of sustainable Trustworthy Quantum Technology by Design, analogous to AI.[155] Technological crossovers can contribute to making the construction and configuration of quantum systems consistent with future key Trustworthy quantum technology requirements. For example, neurosymbolic computing together with genetic algorithms, distributed ledger technology ('**DLT**') and analogue computing paradigms can solve problems relating to black box (oracle) and explainability problems through the architecture of the hardware and the design of the code.[156] In addition, Trustworthy quantum technology can enhance artificial intelligence (AI) that is legal, ethical and technically robust, and vice versa, creating socially responsible synergetic effects. Moreover, adding analogue computing, memristors and nanomagnet chips to the mix can solve energy and sustainability challenges.

Quantum Technology Should Reflect Core Societal Values

Combining neural networks and symbolic reasoning is a promising method to optimize self-learning and self-reasoning of systems. Systems that have a richer understanding of context and concepts like ethics, deduction, causality and interpretation, without the need for large, hand-labelled training, testing and validation datasets during the learning process. Breakthroughs in information theory can help to create the much sought-after transparency and trust. Instead of *ex post* safety audits, automated checks & balances should be integrated in the process, including *ex ante* impact assessments. The architecture of systems equipped with quantum technology should articulate values that we consider important as a society.

Conclusion

Our current intellectual property framework is not written with quantum technology in mind. Anticipating spectacular technological advancements in quantum computing, quantum sensing and the quantum internet, the time is now ripe for governments, research institutions and the markets to prepare regulatory and intellectual property strategies that strike the right balance between safeguarding our democratic values, fundamental rights & freedoms, and pursue policy goals that include rapid technology transfer and the free flow of information, whilst encouraging healthy competition and incentivizing sustainable innovation.

**** fin ****

[153] See: Trustworthy AI 7 key requirements, *supra* note 102.

[154] See also: See also: Nemitz, Paul Friedrich, Constitutional Democracy and Technology in the age of Artificial Intelligence (August 18, 2018). DOI 10.1098/RSTA.2018.0089 - Royal Society Philosophical Transactions A, Available at SSRN: https://ssrn.com/abstract=3234336 and 20200917_IETC Hearing with Chairman Eric Schmidt: "Interim Review of the National Security Commission on AI" https://youtu.be/USEKVNSf4oI?t=862.

[155] Kop, *supra* note 73.

[156] For quantum technology related high-performance computing initiatives, see: https://ec.europa.eu/digital-single-market/en/content/high-performance-computing-and-quantum-technology-unit-c2.