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EDITORIAL

Quantum-ELSPI: A Novel Field of Research

Mauritz Kop[1]

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1 Introduction

Anticipating spectacular advancements in real-world quantum driven systems, products, materials, and devices, the time is ripe for governments, academia, and the market to prepare and develop strategies that balance their societal impact. This topical collection seeks to provide informed suggestions on how to maximize benefits and mitigate risks of the exotic family of applied quantum technologies. It intends to deliver insights and actionable recommendations on how and when to address identified opportunities and challenges, which can then be refined into plausible, evidence-based policy decisions by stakeholders across the world, fostering responsible quantum innovation (RQI).

Like any new and emerging technology, QT brings with it ethical, legal, social, and policy implications (Quantum-ELSPI). This introductory article depicts Quantum-ELSPI as a nascent research field with a metaparadigmatic character. On the one hand, the term Quantum-ELSPI is used to describe research activities focused on the societal aspects of QT. On the other hand, Quantum-ELSPI serves as a metaparadigm that sets an interdisciplinary research agenda. The aim of this article is to sketch, both descriptively and normatively, the emergence of this new research field dedicated to the ethical, legal, social, and policy implications of QT.

In the first section, the emergence of Quantum-ELSPI as a research field is described. After providing a brief introduction into QT and its potential applications, ELSPI research is explained as a field of study that centers around the impact of new and emerging technologies. Due to progress in second-generation (2G) QT that directly harness quantum mechanical effects such as superposition, entanglement, tunneling, and energy quantisation, there is now reason for such impact focused research in the context of QT. An overview is given of pioneering research activities in this area that demonstrate the emergence of a Quantum-ELSPI research field. In specific, the article highlights the three contributions to this topical collection, each providing a useful perspective on the impact of QT.

✉ Mauritz Kop
mkop@stanford.edu

1 Stanford Law School, Stanford University, Stanford, USA

In the second section, Quantum-ELSPI is redefined as a metaparadigm. It is argued that, as a metaparadigm, Quantum-ELSPI connects research on QT inextricably with research on the issues that arise with its introduction within society. In doing so, it communicates an inherently interdisciplinary approach for understanding and approaching the development and utilization of 2G QT in our society. In this way, the Quantum-ELSPI metaparadigm can help to inform and actively guide research and development, design, implementation, use, and governance of QT across a wide range of applications. The final section features an exploration of the potential issues that may arise within the ethical, legal, social, and policy subdomains of Quantum-ELSPI. The article concludes with a proposed research agenda, calling for the research community to engage with the Quantum-ELSPI field.

2 Quantum-ELSPI: An Emergent Research Field

2.1 Quantum Technology and its ELSPI

Quantum technology (QT) is a rapidly evolving field that holds great potential for transformative advances in areas such as computing, communication, cryptography, and sensing. For a more elaborate background of the field, see Dowling and Milburn (2003) and Kaye et al. (2007). By directly harnessing unique, counterintuitive quantum mechanical properties, second-generation quantum devices will disrupt multiple industries and impact society at large, just like electromagnetic theory did before in communication technology and the energy sector. By virtue of QT's many potential use cases, some of which are already being explored and developed, it can be revolutionary to many fields, from information technology to healthcare. Below are ten examples of how quantum technology can be applied, setting the stage for thinking about the societal impact of such applications.

1. *Quantum computing*
   Quantum computers can solve certain problems exponentially faster than classical computers, which can enable breakthroughs in cryptography, machine learning, drug discovery, and more.
2. *Cryptography*
   Quantum computers have the potential to break traditional encryption methods, but they can also be used to create unbreakable encryption based on the principles of quantum mechanics, ensuring the security of communication, facilitating decryption, and providing a secure key distribution method which is immune to eavesdropping.
3. *Optimization*
   By quantum annealing, a type of quantum computation, quantum computers can solve complex optimization problems more efficiently than classical computers can. This advantage can have applications in fields such as finance, supply line logistics, and transportation. Quantum computers can help model complex financial scenarios and analyze risk, which can have applications in

areas such as portfolio optimization, hedging, and risk management. Quantum computers could potentially optimize traffic flows in real-time, leading to reduced travel time, energy consumption, and emissions. Further, quantum computing could be used to optimize energy distribution and reduce waste in power grids.

4. *Quantum machine learning*

   Quantum machine learning uses quantum computers to speed up and improve machine learning algorithms. Truly parallel quantum machine learning algorithms can be used to train models and make predictions faster and more accurately than classical machine learning algorithms, improving AI applications.

5. *Quantum sensing and metrology*

   Quantum sensors can detect and measure small changes in magnetic fields, electric fields, and other physical properties, which can have applications in areas such as medical imaging, precision metrology, geological and mineral exploration, environmental monitoring, defense, and astronomy. Quantum imaging can be used for enhanced resolution in medical imaging, improving diagnostics and for imaging objects that are otherwise difficult to see. Quantum metrology can be used to measure extremely small changes in physical systems, such as gravitational waves or magnetic fields, and could have applications in fields like GPS-free navigation and atomic clocks.

6. *Quantum communication*

   Quantum communication and networking protocols can provide secure data communication channels via fiber or satellite that are invulnerable to eavesdropping, interception, or tampering, eventually resulting in the Quantum Internet. It can facilitate remote and distributed quantum computing. Quantum technology can be used to teleport quantum states from one location to another, which has potential applications in communication and information processing.

7. *Quantum simulation*

   Quantum simulation uses quantum computers to simulate complex physical systems that are hard to simulate with classical computers, such as the behavior of molecules and materials. Quantum simulators can mimic the behavior of complex physical systems that are difficult to study or simulate using classical methods, such as high-temperature superconductors or quantum magnets. Quantum computational chemistry can help simulate the behavior of molecules at the quantum level, which can lead to faster and more accurate drug discovery and design. Quantum technology can be used to study biological systems and processes at the quantum level, which could lead to new insights and applications in fields like medicine and agriculture.

8. *Fundamental quantum physics*

   Quantum technology, in specific quantum simulation, could assist physicists to better understand the exceptional nature of gravity at the quantum level and help reconcile quantum mechanics with general relativity.

9. *Materials science and engineering*

   Quantum computing can be used to model and predict the behavior of materials and their properties, which could lead to the discovery, design, and engineering of new materials with specific properties.

10. *Weather forecasting*

    Quantum computers can simulate the behavior of weather systems more accurately than classical computers, which can lead to more accurate weather forecasting and better disaster preparedness. Quantum computers could help improve the accuracy of weather forecasting by simulating complex climate models with greater accuracy and speed.

As the field continues to evolve, this list will expand exponentially. As with any emerging technology, there are significant interrelated ethical, legal, social, and policy implications of QT that must be considered. Moreover, the novel, imperceptible nature of QT poses novel challenges as to managing its consequences. Research into the societal aspects of new and emerging technologies (NEST) has traditionally been referred to as ELSI (US) or ELSA (EU), highlighting the ethical, legal, and social *implications* or *aspects*, respectively. Acknowledging the distinct issues in the realm of policy, it is important to explicitly extend these acronyms and speak of "ELSPI" to refer to the area of research that investigates the societal impact of NEST.

Now that the applications of QT become more concrete and closer to realization, an urgency evolves to consider its ELSPI. The topical collection thematizes this development under the header of "Quantum-ELSPI." This term can be used to denominate the study of QT from the perspectives of disciplines within the social sciences. However, as the disciplinary implications of QT will in practice be highly intertwined, it is more useful to consider Quantum-ELSPI as an inherently interdisciplinary and integrated research field that crosses the boundaries among ethics, law, socioeconomics, policy, and quantum technology.

The rise of Quantum-ELSPI as a research field that is dedicated to the ethical, legal, social, and policy implications of QT can be observed by an increasing attention for the subject matter from a societal perspective. It was only quite recently that the impact of QT on society became a topic in academic work. The work of Hoofnagle and Garfinkel (2022), Perrier (2022), Johnson (2018), Coenen and Grunwald (2017), Ten Holter et al. (2021), De Wolf (2017), Vermaas (2017), Seskir et al. (2023), Roberson (2023), De Jong (2022), and (Kop et al., 2023a, b), all in their own way explore Quantum-ELSPI and propose possible responses, laying the groundwork for further research. The articles that this topical collection features are among the most recent efforts within this field.

2.2 Topical Collection

Aiming to shape our collective interdisciplinary thinking about balancing the societal impact of spectacular advancements in real-world quantum driven systems, products, and services, *Digital Society* launched this Special Issue, "Quantum ELSPI: ethical, legal, social and policy implications of quantum technology." It includes three articles plus this introductory article. The contributors consist of both rising stars and established scholars working in the intersection of law, ethics, philosophy, quantum physics, cybersecurity, data governance, public policy, and society. Each article offers a unique perspective to investigate Quantum-ELSPI considerations on both national and international agendas. Combined, their findings advance the Quantum-ELSPI research field and offer tangible recommendations to governments, academia, and the market on how to maximize benefits and mitigate risks of applied quantum technologies, which can then be refined into plausible, evidence-based policy decisions by stakeholders across the world.

The first article by Miriam Wimmer and Thiago Guimarães Moraes titled "Quantum Computing, Digital Constitutionalism, and the Right to Encryption: Perspectives from Brazil" explores the potential effects of quantum computing on proposals surrounding the digital right to encryption in the context of digital constitutionalism (Wimmer & Moraes, 2022). The article raises the important issue of how one should protect fundamental human rights and freedoms in the digital sphere, particularly given the likelihood of the development of quantum capabilities occurring unevenly between developed and developing countries, against the background of an increasing disconnection between regulation and innovation. The article is divided into three sections: firstly, it provides an overview of the right to encryption debates within digital constitutionalism initiatives, with a particular focus on Brazil. Secondly, it examines the potential impact of quantum technologies on encryption, exploring both technical and geopolitical implications of the race for quantum supremacy. Finally, the authors evaluate the potential consequences, opportunities, and risks of quantum computing for the enjoyment of fundamental rights in the digital environment, considering three different approaches: (1) the development of post-quantum cryptography standards, (2) the adaptation of domestic policies and legal frameworks, and (3) international cooperation through binding and non-binding legal instruments. The article concludes with discussing the challenges faced by developing countries such as Brazil in connecting the debate on exercising fundamental rights to emerging technical and legal issues posed by new technologies, while promoting an equitable distribution of the benefits that these technologies may bring.

The second article by Eline De Jong titled "Own the Unknown: An Anticipatory Approach to Prepare Society for the Quantum Age" posits that quantum technology has the potential to impact society *systemically* (De Jong, 2022). Its promise to expand our abilities to gather, process, and communicate information means that nearly every aspect of society may be profoundly affected. De Jong argues that it is crucial that we start considering the ethical, legal, social, and policy implications of this system technology now that we can still effectively direct its course. One way to prepare for the uncertain future impact of quantum technology is by studying the historical analogies of how society has dealt with other similar system technologies in the past. The Netherlands Scientific Council for Government Policy (WRR) has developed a framework (co-authored by De Jong) for embedding system technologies into society based on such an analysis. De Jong's current article reinterprets and adapts the WRR's framework into an anticipatory strategy for preparing society for quantum technology and vice versa. The proposed strategy has five dimensions: (1) countering unrealistic perceptions (*demystification*), (2) creating a facilitating socio-technical environment (*contextualization*), (3) including stakeholders and civil society (*engagement*), (4) developing adequate regulatory frameworks (*regulation*), and (5) strategically relating to others in the international domain (*positioning*). By actively engaging in these processes, society can enable the development of quantum technology while mitigating its potential negative impacts, proactively guiding the co-evolution of quantum technology and society towards purposeful destination.

The third article by Elija Perrier, titled “The Quantum Governance Stack: Models of Governance for Quantum Information Technologies”, showcases how the emergence of quantum information technologies — potentially among the most profound set of technologies ever created with broad potential applications in various industries and domains — has highlighted the need for practical approaches to governing their development and use (Perrier, 2022). Effective technology governance must balance multiple objectives, including supporting and facilitating technological progress while meeting legal requirements, societal expectations, and managing risks. The article explores multiple idealized governance models and approaches that can synthesize these complementary yet sometimes competing objectives. Perrier carries out a comparative analysis of quantum governance in the context of existing models of technological governance. The article presents an actor-instrument model for quantum governance, called the “quantum governance stack”, which outlines key characteristics that quantum governance should exhibit at each level of governance hierarchy, from states and governments to public and private institutions. The model emphasizes the importance of identifying stakeholder rights, interests, and responsibilities impacted by quantum technologies, as well as appropriate policy instruments — from best practices to hard laws - to manage such impacts. The article argues that quantum governance must be responsive and adaptable to the state of the technology at the time, resource and economic requirements for research and development, and assessments of near-term and future impacts. In addition, it offers a practical introduction to quantum governance by providing a taxonomy of governance actors and instruments and examples of how different stakeholders within the hierarchy might implement governance responses to quantum information technologies. This introduction to quantum governance is intended for pragmatic and systematic use by stakeholders in government, industry, academia, and civil society to help inform their governance response to the quantum technology revolution. The article concludes that regulating nascent technology such as QIT requires a delicate anticipatory balancing act in anticipatory framing of uncertain outcomes and risks while fostering innovation and QIT development as an explicit inherent governance objective.

3 Quantum-ELSPI: A Metaparadigm

3.1 High-Level Models

A metaparadigm can be understood as a common model of thought that is guiding for a (scientific) domain, setting general parameters for understanding and organizing a discipline. Metaparadigms thus contain the central perspective on a domain and define its central issues. The metaparadigm that unifies the field of nursing, for example, consists of four key concepts: person, environment, health, and nursing (Meleis, 2011). These concepts are interrelated and interdependent, and together they provide a holistic view of nursing and healthcare. Such comprehensive understanding of a scientific discipline, entailing a certain way of approaching reality, is the essence of a metaparadigm (Kuhn, 1996). In this sense, a metaparadigm can serve as a structured method to clarify our thoughts about the broader societal implications of research, development, and innovation within a certain scientific domain, and the systematic framing of such implications can help guiding one to the desired outcome. Metaparadigms are the most abstract of thought models and can be interpreted on lower levels of abstraction in the form of more specific and actionable approaches.

Besides describing a both multidisciplinary and interdisciplinary research field, Quantum-ELSPI can also be taken as a metaparadigm. In that way, the Quantum-ELSPI metaparadigm communicates the idea that the field studying the impact of QT has four key aspects: the ethical, legal, social, and policy dimension. These aspects are inherently connected and should be understood and studied within their interconnection and interdependence. As such, the Quantum-ELSPI metaparadigm forms a normative view on how this research field should function. The rationale of this metaparadigmatic approach is to steer QT developments actively and deliberately towards equitable societal outcomes while incentivizing innovation and mitigating risks. It does so by bringing together disciplines beyond research silos to create rich, synergetic insights, and effects. In such an exercise, creativity, imagination, and lateral thinking are pertinent (Lehmann & Gaskins, 2019; Loeb, 2021). Under the heading of this metaparadigm, more specified and concrete approaches can be developed to guide research efforts. If the Quantum-ELSPI metaparadigm is at the highest abstraction level, mid-level approaches will provide more specific frameworks to those active in the field, and lower-level approaches will offer the most concrete guidance. Such developments, including the formation of a specialized (research) community, indicate the maturation of the Quantum-ELSPI metaparadigm.

3.2 Mid- and Lower-Level Models

At the mid-level, the idea of Responsible Quantum Technology (RQT), the SEA-framework, and Principles for RQI have been developed within the Quantum-ELSPI metaparadigm (Kop et al., 2023a, b). The RQT approach, for example, aims to ensure that quantum technologies are developed and used in ways that are safe, secure, sustainable, and equitable and that the potential benefits of quantum technology are distributed fairly across society, while mitigating potential threats and risks. Such an approach will naturally contribute to people's trust in QT and thereby to its wide adoption. Responding to the key dimensions of Responsible Research and Innovation (RRI) (Stilgoe et al., 2013), the RQT approach maps out the characteristics of responsible innovation in the realm of QT, eventually yielding quantum applications that align with our core values. The RQT approach is further specified by means of the SEA-framework, explicating what RQT amounts to in practice: safeguarding society against risks, engaging society with the development of QT, and advancing QT and society jointly. The SEA-framework can be operationalized by means of specific principles, aiming to provide concrete guidelines for acting and directing towards societally desirable outcomes.

The example of the RQT approach and its corresponding framework and principles shows how such mid- and lower-level thought models seek to provide the field with more specific guidelines for how to study and direct the societal impact of QT. At the most concrete level, rules, tools, and techniques will have to be developed to provide practical guidance, including hard regulatory instruments in the form of an international treaty; convention or regional quantum governance act with risk-based product safety and liability regimes, including enforcement and oversight bodies for certification and accreditation; benchmarking and validation—conveying trust in verifiable results; production and market authorization; and standardization, as well as tangible soft law tools such as quantum impact assessments, dual use assessments, testing, benchmarking and validation metrics, moral guidelines, quantum R&D best practices, checklists, protocols, directives, and ex ante, ex durante, and ex post conformity and compliance audits.

Each of these concepts, methods, and instruments has their place within the Quantum-ELSPI domain. The Quantum-ELSPI research field produces and studies these central elements and their interconnectedness, all the way from conceptual and philosophical frameworks (Floridi, 2011) down to real-world actionable perspectives, ultimately transferring the conceptual models and methods into a standardized style of analysis and intervention (Fawcett, 1984). The mid-level and lower-level elements will be tailored and applied in individual quantum domains such as computing, simulation, sensing and networking, materials and devices, quantum–classical interactions, as well as to currently known use cases, applications, and industries such as chemistry, energy, health, defense, logistics, and cleantech, each with its own characteristics, needs, and requirements. Thus, the Quantum-ELSPI metaparadigm unfolds, providing a high-level framework for understanding the broader implications of the development and application of quantum technology in society. This understanding, in turn, can inform and direct decision-making and behavior in R&D, application, and adoption of quantum technology and provides a basis for the design and implementation of policies, regulations, and strategies that promote the responsible and ethical use of quantum technology — eventually fostering beneficial societal outcomes on the highest, planetary level.

4 Exploring the Field of Quantum-ELSPI: A Research Agenda

In the former sections, the novel domain of Quantum-ELSPI was characterized and discussed in its totality. This final section zooms in on its subdomains and explores the issues that may arise there.

4.1 Ethical Implications

The ethical domain focuses on the moral principles and values that are involved in the development and application of QT. Such principles and values are contextual, culturally sensitive, and dynamic in the sense that these may change over time. Quantum ethics includes ensuring that QT is developed and used in ways that align with our principles and values, yielding “responsible” QT, not least to ensure that potential benefits of quantum technology are distributed equitably. Before looking at the ethical issues that the development and use of QT raises, two general remarks are important. First, many ethical issues that come with QT will be the result of its dual-use character: QT can be used for good, but the very same techniques can also be used maliciously. Often, the use of QT will encompass the possibility of misuse. Second, the source of some ethical issues will spring quantum technological hybrids. When creating technological hybrids with other technologies such as AI and bioengineering, QT has the potential to amplify existing ethical issues present in such fields. In that sense, quantum can have a multiplier effect on both benefits and risks. A preliminary exploration of other quantum ethical issues includes the following:

1. *Privacy*

   Quantum computing has the potential to break current encryption standards, which could lead to a loss of privacy for individuals and businesses. Moreover, while quantum computers will be able to break existing encryption, potentially compromising sensitive data, quantum safe communication can be used as a privacy enhancing technique. This could create conflicts between the right to privacy and the need for security, utilizing various QT domains. When it comes to quantum sensing, applications can be used to create powerful surveillance capabilities, posing a serious threat to privacy.
2. *Security*

   The potential of quantum computers to break encryption that is currently used to secure sensitive information does not only threaten privacy, but also the security of military information and government secrets, resulting in concerns for national security.
3. *Responsibility and accountability*

   QT can be used to create new weapons and cause widespread destruction, leading to questions of responsibility and accountability and ethical use.
4. *Inequality and distributive justice*

   The development of QT may lead to the creation of new inequalities, as access to this technology may be limited to certain groups. QT may thus exacerbate existing social inequalities by widening the gap between those who have access to it and those who do not. On a global level, the imminent quantum Internet could, for example, exacerbate global inequalities by an access divide between the Global North and Majority World Countries or disadvantaged minorities having less access, or higher entry barriers, to its benefits than the elite.
5. *Fairness and equality*

   QT could increase the efficiency of financial markets, but it could also enable faster and more accurate trading algorithms. This could potentially create a more unfair and unequal system since without sector specific QT regulation; QT will be controlled by a powerful elite. In addition, unfair quantum-machine learning could lead to systemic bias (Perrier, 2021).
6. *Morality*

   Quantum computers could enable faster and more accurate simulations of complex systems, including biological processes, and eventually nature as a whole. This could enable researchers to manipulate and control biological processes, with the aim of curing diseases and enhance human abilities, raising ethical questions about the limits and risks of scientific experimentation, such as human enhancement, and fair competition between enhanced and untweaked human beings.

7. *Gender Imbalance*

   The hard science part of the quantum community is predominantly male, and this raises concerns about diversity and inclusivity.

The ethical implications of QT are even more complex given its potential to impact various domains of human life. For example, quantum computing combined with AI and quantum machine learning has the potential to revolutionize healthcare by enabling faster and more accurate diagnosis and treatment of diseases. However, such application also raises ethical concerns about bias, informed consent, privacy, confidentiality, and security of personal health information. To ensure that these technologies are used in an ethically responsible manner, the Quantum-ELSPI meta-paradigm requires that ethical considerations like these should be proactively considered in the development and use of QT. Similarly, sectors such as energy, defense, and cleantech each have their own quantum ethics issues, which should be actively confronted. Studying the implications of QT generally or of its applications within specific domains, as well as developing strategies to respond to them, is the focus of the ethics subdomain. Often, although not exclusively, such ethical investigations and considerations inform legal interventions and regulatory strategies.

4.2 Legal Implications

The legal subdomain of Quantum-ELSPI refers to the laws, regulations, and policies that govern the development, application, and trade of QT. The legal concept encompasses issues such as intellectual property (IP) and licensing, export controls, insurance and liability, and regulation, for example, in the form of hard law market authorization. QT can challenge existing legal framework. Quantum computing, for example, presents several legal challenges related to IP rights, data ownership, data privacy, data protection, safety and security issues, and liability for quantum computing errors. Moreover, as quantum computing advances, new patents must be developed to protect these innovations. In addition, the ownership and control of quantum data may become a contentious issue. Quantum sensing also raises a number of legal issues, including human rights infringements. Quantum communication and networking furthermore demands for interoperability standards that embody our liberal democratic norms, principles, and values, as codified in international treaties such as the Universal Declaration for Human Rights (DeNardis, 2022). A special case is the quantum-AI hybrid, which are associated with high TRL levels that will quickly find their way to the markets. Such hybrids could create new risks and liabilities in fields like chemistry and material design. There is, however, currently a lack of clear legal frameworks for their development and use. Legal considerations such as intellectual property, liability, and regulation of quantum-AI hybrids should be taken into account to ensure that the development and use of quantum-AI hybrids is in compliance with existing laws and regulations. Five examples of quantum legal issues include the following:

1. *Fair competition and antitrust*

   As most quantum innovation is created by a handful of multinationals and leading universities, unwanted market behavior and winner-takes-all dynamics can become problematic. Pro-quantum antitrust law enforcement aiming for fair competition in and equal access to a thriving quantum ecosystem could mitigate the risks of market skewness, while fostering sustainable innovation.
2. *Liability and insurance*

   Quantum technology is complex, and it may be difficult to assign liability in the event of an accident, malfunction, or other detrimental impacts. Similarly, quantum technology raises novel questions of personal, professional, and product liability insurance. As quantum technology continues to advance, liability for potential damages must be considered.
3. *Cybersecurity*

   The potential for quantum technology to breach cybersecurity systems calls for a legal response. As QT could enable new forms of cyberattacks, it becomes necessary to establish new legal frameworks to protect against them.
4. *Intellectual Property*

   QT, not least in the form of AI-hybrids, could enable faster and more accurate modeling of chemical and biological systems, making it easier to design new drugs, designer molecules, and novel nano and quantum materials. This could raise questions about the ownership of intellectual property (IP), patent rights, and trade secrets (Aboy et al., 2022) particularly when generated by autonomous quantum-AI hybrids or in case of AI-assisted inventions and creations. QT may spark new inventions, but it may be difficult to determine who or what owns the IP rights, potentially leading to a surge of patent applications and legal disputes, overflowing Patent Offices and Courts.
5. *Product safety and certification*

   Hard laws beyond self-regulation should instigate product safety guardrails, for example, in the form of production and market authorization and lifecycle auditing, benchmarking, and validation by means of well-established CE-marking quality control protocols.

   As a metaparadigm, Quantum-ELSPI requires that the legal considerations of QT be considered in the development and application of QT. It is important to note that a technological revolution often requires recalibration of legal frameworks, ecosystems, and infrastructure. In other words, it demands an evolution of law. The trick here is to set technologically neutral rules as much as possible, without being too abstract and ambiguous. This is to prevent regulations from being overtaken by technological innovations in the near future. Legislative interventions for QT should be in line with the concepts of proportionality, subsidiarity, and effectiveness. Also, new laws must fit into existing horizontal and sector-specific legislative structures and not conflict or contradict them. Lastly, the question whether QT introduces novel problems or just new iterations of existing ones, whether general or sector-specific, should be carefully studied, not least to avoid reinventing the wheel, and strengthens justification for the Quantum-ELSPI research field (Quantum Law, 2018).

4.3 Social Implications

Social implications refer to issues related to equity, access, and affordability, but also relate to workforce development, education and talent development, and the potential impact of QT on the different domains within society, including effects on employment and the economy (Coenen et al., 2022; Vermaas, 2017). Although the technology is still in its early stages, there are concerns that wide-spread adoption of QT could lead to job losses through automation and contribute to economic inequality, especially if combined with AI. On the other hand, new jobs will be created as well. Additionally, access to quantum technology may be limited, leading to unequal distribution of benefits and wealth, and potentially exacerbating global power imbalances. When taking the healthcare sector as an example, the social implications of QT applications can be both positive and negative at the same time. Although quantum simulation can contribute to improvements in healthcare on topics such as diagnostics, personalized medicine, and drug design, we should make sure that access to such benefits is equitable. Similarly, quantum computing has the potential to create economic growth in healthcare, but also raises concerns about the potential impact on the healthcare workforce and the potential for economic inequality in access to healthcare-specific QT. Examples of potential social issues related to QT include the following:

1. *Employment*
   The rise of quantum technology may lead to job loss or require new skills, creating social inequality (but also opportunities), shifting workplaces. Quantum empowered AI as well could lead to the automation of many jobs, potentially creating significant unemployment across many sectors and industries.
2. *Education*
   The development of quantum technology will require a highly skilled workforce, leading to questions about education and training.
3. *Inequality*
   Quantum technology could exacerbate existing inequalities in access to technology and education, and in the distribution of positive and negative effects, potentially creating new forms of disadvantage.
4. *Trust*
   Quantum technology could be difficult to understand and explain to the public, potentially eroding trust in science and technology, which could hinder wide adoption.
5. *Environmental impact*
   Quantum technology requires large amounts of energy, and its impact on the environment needs to be considered.

The social implications of QT are equally significant as their ethical and legal counterparts, exactly because existing inequalities can be exacerbated, and the digital divide be widened. The Quantum-ELSPI metaparadigm requires to critically examine the impact of QT on different groups in society and proactively address potential unfairness.

4.4 Policy Implications

The policy domain of Quantum-ELSPI mostly concerns what is called public policy, including governance and regulation. Considering the policy implications of QT not only includes analyzing its impact on existing policy, but also the development of new policy that can stimulate the development of the kind of QT that is desirable from a societal point of view. Policy implications of QT include ensuring ethical development and use of the technology, investing in research and development, and establishing international agreements to address concerns about quantum computing's potential military applications and dual use. When it comes to the realm of regulation, policy makers face a dilemma. As also discussed in the contribution of De Jong (2022), the Collingridge dilemma explains that the ideal timing, or area of intervention for implementing such policies is between the ideation and the adoption phase of the technology (Genus & Stirling, 2018). In the case of QT, we are dealing with a suite of domains varying from computing to sensing to networking, each characterized by their own technology readiness levels (TRL), making it even harder to predict when, how, and where QT becomes locked in. Preventing a gap between the emerging QT field and legal-ethical oversight while leaving room for and incentivizing innovation, this regulatory timing-question calls for a differentiated, industry, and quantum domain-specific approach that forges harmonious compromises between conflicting policy objectives. Below are some of the current policy issues regarding QT:

1. *Regulation*

   Governments must regulate the development and use of quantum technology to ensure ethical and legal standards are upheld. Further, quantum technology could require new regulations to ensure safety and security. Excessive winner takes all effects could call for tax reforms, leveling income equality.
2. *Investment*

   Quantum technology requires significant investment from governments and private industry to develop and commercialize and stay competitive globally. Policy decisions around public funding and investment in quantum technology will impact the speed of its development and adoption and should prioritize public funding schemes for beneficial social objectives, linked to sustainable development goals.
3. *International relations and cooperation*

   As QT advances, it may impact international relations, with potential consequences for diplomacy, security, and economic relationships. Moreover, as QT is a global phenomenon, international cooperation will be necessary to ensure that it is developed and used responsibly.
4. *(Inter)national security*

   Quantum technology has the potential to revolutionize national and economic safety and security, raising questions about how it should be regulated and controlled.

Responding to the Quantum-ELSPI metaparadigm, policy strategies must guide the development and application of QT. This stretches from a strategic innovation agenda to international cooperation, to steer towards a values-based QT ecosystem.

4.5 Proposal for a Research Agenda

The Topical Collection contains rigorous examinations, evaluations, and recommendations concerning the ethical, legal, social, and policy implications of QT. Together with this introductory article, these first steps in the field of Quantum-ELSPI should inspire and encourage authors to engage with this novel research field which is known to be difficult to grasp, even for specialists dedicating their careers to advancing it. Possible questions that could be addressed by Quantum-ELSPI scholars include — but are certainly not limited to — the following:

1. *Ethics*

   How should we deal with the dual use character of QT? What could be the future impact of applied principles of quantum mechanics on culture, democracy, and human rights such as privacy, identity, freedom of expression, and freedom of thought? How can we utilize QT to reverse the long-standing trend towards greater income inequality? How to implement ethically aligned design into QT's architecture and infrastructure? Would developing a Trustworthy Quantum Technology concept, similar to the EU's Trustworthy AI concept, be useful? What would be its strengths and limits? Would a risk-based approach such as used for AI be useful in whole or in part in the context of QT?
2. *Legal*

   How should we design a differentiated horizontal-vertical legal-ethical framework vis-à-vis benefits and risks for quantum technology, which is both culturally sensitive and harmonized at the international level? How can a combination of antitrust rules and intellectual property laws safeguard a properly functioning market based on principles of fair trade and competition? How can winner take all effects and a quantum divide be prevented? What role should patents, trade secrets, copyrights, and trademarks on quantum software and hardware play to incentivize sustainable innovation that is as open as possible and as closed as necessary?
3. *Socioeconomics*

   Given the reality of a race for technological supremacy between systemic rivals with incompatible ideologies, it is not inconceivable that the development and uptake of transnational quantum principles will run along the lines of democratic and authoritarian technology governance models. Against that background, how can we embed liberal-democratic values in globally accepted human rights sensitive interoperability standards and protocols for this cutting-edge technology, including quantum-machine learning hybrids? How can we ensure cooperation on big picture trends such as climate change via quantum-empowered cleantech, energy and economy decarbonization, and space exploration? How can industries that face disruption by quantum computing, such as the cybersecurity industry and financial institutions, anticipate the use of quantum computers? How can one measure positive externalities, spillovers, and innovation rent caused by a thriving local, regional, and global quantum ecosystem? How can equal access to quantum technology, including quantum computing and the imminent quantum internet be encouraged? Should access to essential quantum technologies be democratized? By which private (open source) or public (government interventions) methods?

4. *Policy and regulation*
   How can policy makers learn from history when it comes to the regulation of QT? How can we, for example, build on the experience gained in the governance of artificial intelligence (AI), in managing dual use of nuclear fusion and fission, and on insights gained from adjacent fields such as nanotechnology (Lemley, 2005), virtual reality (Heller, 2021), and biotechnology (Slokenberga et al., 2023). How can we, via innovation policy and regulation, create a virtuous cycle for QT similar to that of the semiconductor industry? To what extent does governing classical computing (binary digits) differ from governing quantum computing (physical and logical qubits)? How could we experiment with agile, flexible regulatory frameworks in this context, without compromising legal certainty? How can one combine the best parts of precautionary and laissez-faire style systems to responsibly advance QT? What are the trade-offs of connecting intellectual property policy to national and economic security strategies? How can quantum technology impact assessments, audited by multidisciplinary teams, help to monitor, benchmark, and validate quantum infused platforms, products, and services during their lifecycle (upstream & downstream) (Greely, 2022)? Why should data driven research methods inform evidence based policy making and how can mixed empirical research reduce the risk of unintended counterproductive effects of policy interventions in the context of QT?

5 Conclusion

As an introduction to the topical collection on Quantum-ELSPI, this article provided an overview of the emergence of Quantum-ELSPI as a new research field dedicated to the ethical, legal, social, and policy implications of QT. Now that the applications of second-generation QT become more concrete and closer to realization, an urgency evolves to consider their impact within society. The term of Quantum-ELSPI depicts this emerging multidisciplinary and interdisciplinary research field. The articles in this topic collection are important contributions to the establishment of this novel research field.

On top of the descriptive use of the term, it was argued how Quantum-ELSPI can also be interpreted normatively, serving as a metaparadigm that sets general parameters for understanding and organizing research on the impact of QT. As a metaparadigm, Quantum-ELSPI promotes the idea that the field studying the impact of QT has four key aspects: the ethical, legal, social, and policy dimension. These aspects are inherently connected and should be understood and studied within their interconnection and interdependence. Under the heading of the Quantum-ELSPI metaparadigm, initial efforts are being made to translate the general thought model to mid-level and lower-level approaches, such as the RQT approach, the SEA-framework, and principles for RQI.

After characterizing Quantum-ELSPI as a descriptive and normative notion, the article zoomed in on the subdomains of the field. After briefly sketching the outlines of the ethical, legal, social, and policy domains, the article explored the emerging and potential issues that come with the development and adoption of QT. In addition to the identification of these issues, the article proposed a preliminary research agenda for the Quantum-ELSPI field, consisting of issues that should be carefully studied by the academic community, preferably in diverse, multidisciplinary settings.

While this topical collection is just a humble prelude to much needed deeply interdisciplinary research, combined our findings offer tangible early-stage recommendations to governments, academia, and the market on how to balance maximizing benefits and mitigating risks of QT. In that respect, it is important to emphasize that we are dealing with a moving target. QT as well as its ELSPI will both continue to evolve in the years to come. Research into Quantum-ELSPI and the design of responding strategies will thus be an ongoing effort, continuously attempting to bring new developments in harmony with the society that we desire.

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