

Towards an Ecosystem Approach to Quantum Computing Ethics: Implications for the Global Majority

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Introduction

Quantum Computing (QC) represents a class of technologies that harness fundamental principles of quantum mechanics, particularly superposition and entanglement, to process, transmit, and secure information in ways unattainable by classical systems [1]. Positioned at the core of Quantum Information and Communication Technologies (QICT) [2], QC is central to the ongoing Second Quantum Revolution, driving innovation infrastructures and redefining capabilities in computation, networking, and secure information exchange at fundamental levels [3]. Unlike the first quantum revolution, which focused on physics and laboratory experiments, today's Quantum technology (QT) applications are inherently digital, dependent on and deeply integrated within the digital stack, relying on cloud platforms, high-performance computing, advanced telecommunications, and potentially converging with other emerging digital technologies (EDT) such as artificial intelligence (AI), blockchain, big data, the Internet of Things (IoT) [4], [5], offering new paradigms for the digital economy and society [6]. While there remains considerable uncertainty regarding their practical, scalable applications, the disruptive potential of QC is increasingly recognized [7]

with profound ethical, legal, social, and policy implications [8] and a need for practical approaches to their governance [9]. QC is not a standalone technology, but operates as a complex innovation ecosystem where research, policy, markets, and ethics co-evolve [10].

Rationale for an Ethics-Based Approach

As an EDT, QC cannot be regarded as intrinsically good or bad; their impacts are determined by how they are conceived, developed, and applied within specific social, cultural, and political settings [5], [11]. Innovation ecosystem outcomes are not neutral but reflect the values, governance frameworks, and power structures embedded in their design and deployment [12], [13]. In this respect, QC should be understood as sociotechnical systems, where technical capabilities and societal contexts co-evolve and mutually shape one another [4], [11]. Therefore, an ethics-based approach is essential to guide governance across the QC innovation ecosystem. Ethics for innovation ecosystems must not be treated as an external constraint, but rather as an embedded element of research, design, and policymaking, ensuring that QC development and deployment align with societal goals such

as accountability, justice, and intergenerational responsibility [5], [9], [10], [11].

Navigating Ethics from Human-Centered Computing (HCC) towards a Responsible Research and Innovation (RRI) Ecosystems approach

Human-Centered Computing (HCC) emphasizes inclusivity, usability, and fairness in human–machine interaction. HCC has provided effective frameworks for addressing design-level shortcomings in emerging technologies and ensuring that systems are accessible and responsive to diverse user needs to address complex entangled systems [13]. However, given the systematic risks and complexity of dimensions associated with QC [10], [14], HCC provides a limited scope when applied to QC; threats of QC extend far beyond interface-level concerns [15] and require transdisciplinary knowledge integration across disciplinary, institutional, and societal boundaries [16]. For example, the potential breaking of public-key cryptography would disrupt financial infrastructures, communication systems, and governance mechanisms worldwide, challenges that cannot be solved only through user-centered design principles alone [4], [10].

To address broader challenges, QC ethics requires a shift from HCC to Responsible Research and Innovation (RRI). RRI provides a framework that embeds anticipation, inclusion, reflexivity, and responsiveness into ethics-related discourse on information systems and broader innovation ecosystems for EDT [5], [15], [17]. RRI offers a systemic approach that expands ethics beyond artefacts or interfaces to

encompass research agendas, commercialization pathways, infrastructures, power, regulation, and policy frameworks [9], [10], [15], [18]. For QC, this means ethics must be integrated across its entire lifecycle that shapes cryptographic standards, telecommunications integration, and international internet governance processes, to name a few [6], [9], [10].

Recent scholarship highlights the need for responsible innovation in QC, since RI approaches remain underdeveloped, with ethical concerns often sidelined in favor of technical progress [13], [18]. Similarly, there is consensus that failing to embed ethics at the innovation ecosystem level risks exacerbating inequalities, geopolitical asymmetries, and legitimacy crises associated with EDT [15]. By embedding RRI principles, ethical considerations for QC evolve from being a constraint to becoming a constitutive element of innovation quality control, ensuring that QC serves societal well-being, sustainability, and justice rather than narrow technical or commercial interests [9], [13], [18].

An innovation ecosystem approach is central to the ethical analysis in this paper for several reasons [23]; First, QC raises unique and amplified ethical challenges, at a systems level, particularly in relation to privacy, security, inequality, and responsible QC [7], [10], [11], [13]. Second, QC's unprecedented computational capacity directly threatens classical encryption systems, raising urgent concerns around large-scale privacy breaches, data protection, and the security of critical infrastructures [4]. Third, as QC requires significant financial, technical, and human

capital investments, access will likely be restricted to advanced nations and global corporations, a dynamic that risks deepening digital divides unless more equitable innovation ecosystems are fostered [5]. Fourth, QC could enable new forms of surveillance and profiling, intensifying the need for ethical and legal safeguards to prevent misuse and protect human rights in [19]. Finally, the energy intensity and specialized hardware demands of QC highlight pressing sustainability and environmental ethics considerations that must inform its development [20].

Beyond technical milestones, transitioning towards the quantum advantage (QA) carries profound ethical and geopolitical implications. The reality where QC can solve specific problems faster or more efficiently than the best available classical supercomputers could disrupt global cybersecurity, reshape industrial competitiveness, and widen digital divides if access is limited to a small number of powerful actors [4], [9]. This paper proposes positioning QC as an urgent and illustrative focal point for evolving from HCC approaches to RRI ecosystems discourses for informing ethics-related research to ensure that digital transformation towards QA remains human-centric and rights-oriented [13], [15].

In addition, the existing frameworks for assessing technological opportunities and risks are often insufficient and require substantial re-evaluation to effectively address the novel challenges and possibilities associated with QC [16]. Furthermore, QC will not operate independently but will be closely integrated with classical computing technologies and information systems which may amplify existing

challenges found in classical computing such as cybersecurity risks, system compatibility, and resource demands [9], [13], [21]. Another critical consideration is that QC demands considerable investments in resources and infrastructure, raising issues of equitable access and distribution of benefits and risks, which are particularly acute for under-resourced nations and stakeholder groups [4], [6].

Emerging Risks: Focus on the Global Majority

QC decryption risks are uneven across Global Majority regions due to differences in digital infrastructure, governance, and reliance on foreign providers [22].

Emerging QC ELSPI and governance frameworks reflect Global North priorities [14], with limited consideration of the Global Majority. While these initiatives illustrate strong political will and significant investment in QC governance, they reflect the priorities of high-income economies and risk marginalizing the Global Majority, where infrastructures are fragmented, and policy frameworks remain underdeveloped [22].

Imposing Global North sociotechnical imaginaries risks misalignment where local priorities differ such as prioritizing broadband access or regional cloud sovereignty [22], [23], the imbalance of priorities raises ethical concerns about reinforcing global asymmetries, particularly if powerful states dominate the early design of QC standards and infrastructures, thereby shaping global governance trajectories in ways that may not reflect the priorities of lower- and

middle-income countries. From an ethical standpoint, the concentration of power risks entrenching digital dependency and undermining data sovereignty in the Global Majority. Ethical considerations, therefore, demand that QC governance frameworks move beyond narrowly defined national security imperatives to address inclusivity, justice, and equity at global scales [5], [9], [24].

RRI offers a framework to counter by embedding anticipation, inclusion, reflexivity, and responsiveness into transnational governance [5]. In practice, this means engaging citizens and civil society in discussions of quantum security, ensuring that post-quantum cryptography (PQC) is accessible across different economies, and aligning QC strategies with regional priorities [10], [15]. By reframing QC ethics through RRI, ethics becomes a constitutive part of ecosystem resilience in the Global Majority. This approach ensures that QC innovation pathways not only mitigate ethical risks but also advance self-determined digital futures, sustainable development, and intergenerational justice [5].

Future Implications and Conclusion

Lessons from AI offer key insights that highlight risks of reactive regulation, the need for multi-stakeholder governance, and the importance of international cooperation. An ethical approach to QC innovation ecosystems must balance innovation with security while maintaining public trust. HCC methodologies ensure policies remain transparent and accessible, while RRI offers a framework to counter by embedding anticipation, inclusion,

reflexivity, and responsiveness into transnational governance.

By reframing QC ethics through RRI at an ecosystem level, ethics becomes a constitutive part of ecosystem resilience for the Global Majority and offers a powerful lens to rethink innovation ecosystems, particularly how we design, who we design with, and whose expertise is valued in developing QC innovation ecosystem pathways, not only to mitigate risks but also to advance self-determined digital futures, sustainable development, and intergenerational justice.

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