Communities of Quantum Technologies: Stakeholder Identification, Legitimation, and Interaction

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Abstract

This paper focuses on stakeholder identification as per the value sensitive design (VSD) approach applied to the context of quantum technologies (QT) and contributes to a better understanding of the complex and dynamic nature of the QT landscape. We provide two comprehensive lists of stakeholders as starting points for VSD researchers and practitioners. These lists encompass a diverse range of organizations, including private companies, government agencies, NGOs, partnerships, and professional/trade organizations. Our aim is to facilitate the recognition, legitimation, and understanding of stakeholder interactions in the development of QT. These stakeholder lists lay a foundation for designing and implementing policies and strategies that promote the ethical and responsible development of QT, considering the values and interests of various stakeholders. Furthermore, these lists enable empirical and technical studies on specific QT innovations using an ethics-by-design approach like VSD.

Keywords: stakeholders, quantum technologies, quantum computing, value sensitive design

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1. Introduction

Numerous industries, including healthcare, banking, energy, and others, stand to benefit from quantum technologies (QT). QT refer to a spectrum of innovations and tools developed based on the principles of quantum mechanics. At the core, they leverage the unique behaviors of particles at the quantum level, such as superposition (where a quantum system can exist in multiple states simultaneously) and entanglement (where particles become interlinked and the state of one instantly affects the state of the other, regardless of distance). These technologies include but are not limited to:

- Quantum Computing which exploits quantum principles to process information in ways that classical computers cannot, offering potentially exponential speed-ups for certain computational problems.
- Quantum Communication, where quantum mechanics is used to secure communication, is a notable example of quantum key distribution ensuring the secrecy of transmitted information.
- Quantum Sensing, Metrology, and Imaging encompass a range of technologies that leverage quantum principles to push the boundaries of accuracy and sensitivity in various fields. Quantum Sensing and Metrology utilize quantum principles to develop sensors with unparalleled accuracy, applicable in areas such as gravitational wave detection and precision time-keeping. Simultaneously, Quantum Imaging employs quantum properties like entanglement to devise imaging techniques that transcend classical limits, further expanding the potential of QT in diverse applications.

QT have a plethora of possible uses, from developing novel materials to more effective batteries (Giustino et al., 2021), enhancing medicine discovery (Gupta et al., 2023), and transforming cryptography (Fernandez-Carames & Fraga-Lamas, 2020). The number of businesses engaged in the development of QT is increasing along with the field (Cusumano, 2018). These organizations originate from a variety of industries, including private businesses, governmental institutions, non-governmental organizations, partnerships, and professional/trade associations. Each has its own objectives and ideals.

For understanding and guiding the development of QT it is important to comprehend who these organizations are, how they interact, and what their individual responsibilities are in the QT environment. The ethical and responsible development of QT can be augmented by identifying stakeholders, validating their interests, and figuring out how they interact (Friedman & Hendry, 2019). This is done while taking into account the values and interests of various stakeholders.

In order to investigate the goals, formation, and motivations of the numerous organizations working in the field of QT, this paper provides a classificatory matrix of the various organizations currently engaging in QT research and innovation. This article offers insights into the various stakeholder roles and responsibilities in the development of QT to help facilitate researchers to determine how their interactions can influence the field's future, using tools and insights from the value sensitive design (VSD) approach. At a cursory glance, the technological landscape might be replete with usual stakeholders. However, the uniqueness of QT necessitates a fresh perspective. Beyond the fascinating science, there's an intricate web of organizations, objectives, and ideals. The stakes are high, and the values these entities hold can be the bedrock on which QT thrive or the hurdles that stifle innovation. The results of this study provide a conceptual analysis of the complex and dynamic nature of the QT environment, which can be used in further empirical investigations to determine important stakeholder engagement and collaboration dynamics that will shape the development of those systems.

Few studies (WEF, 2022; Perrier, 2022) have performed a thorough examination of the various organizations involved in the development of QT, despite the rising body of research on the ethical, social, and legal implications of these technologies (e.g., see Vermaas, 2017; Perrier, 2021; Kop, 2021; Kop et al., 2023). By providing a conceptual investigation of for-profit businesses, governmental organizations, non-governmental organizations, partnerships, and trade associations active in QT, this work adds to the body of literature.

This study offers insights into the various stakeholders influencing the development of QT by examining the goals, formation, purposes, and values of these organizations. Additionally, by taking into account the values and interests of stakeholders, the VSD approach utilized to identify these stakeholders in this paper can assist in the creation of policies and strategies that support the moral and responsible development of QT. As a result, this research contributes usefully to the literature by emphasizing the significance of stakeholder involvement and cooperation in determining the course of QT (Seskir et al., 2023a).

In order to do this, this paper is organized in the following way. In the next section, we outline the various theoretical tools that emerge from VSD that are apt to identify the various stakeholders, legitimate[1] them, and determine how they interact with one another in potentially meaningful ways. Section 3 lays out the methodology used in this study to classify the numerous organizations involved in QT research and innovation. Section 4 provides some initial insights given this classification project, detailing how further conceptual as well as empirical investigations can benefit from this preliminary stakeholder identification. Section 5 discusses some of the limitations of this research and potentially fruitful avenues for further investigation. The final section provides conclusions.

2. Tools for Stakeholder Identification, Legitimation, and Interaction

The VSD method is a framework for creating technologies that are aligned with and embody stakeholders' values and interests. The approach acknowledges that the creation of new technologies is not value-neutral and that these developments may have both intentional and unforeseen effects on people, organizations, and society as a whole. In order to make sure that technologies reflect users' beliefs, interests, and needs, VSD aims to involve stakeholders in the design process.

In the 1990s, Batya Friedman and Peter Kahn, Jr. created the VSD approach (Friedman et al., 2002). They understood that the design process for developing technologies needed to be more sensitive to the requirements and values of stakeholders because it was common for these technologies to be developed without taking ethical, social, or environmental concerns into account. They argued that in order to better understand stakeholders' beliefs and incorporate them into the design process, designers needed to interact with them. For this reason, the VSD approach to technology development is crucially

[1] Legitimation, in the context of stakeholder identification, refers to the process of acknowledging, validating, and justifying the relevance and importance of various stakeholders in a given domain or field. This process not only recognizes the existence and roles of stakeholders but also endorses their rightful place in the discussion, decision-making, and development processes. It involves an understanding of the interrelationships, power dynamics, and value propositions of different entities, ensuring that their voices and interests are appropriately represented and considered.

dependent on stakeholder *identification*, *legitimation*, and *interaction* tools. Identification of all parties with an interest or stake in the development of the technology, as well as those who may be impacted by it, is known as stakeholder analysis (Friedman et al., 2006; Nathan et al., 2008). This technique enables designers to comprehend the variety of viewpoints and interests that could affect the technology's conception, application, and use.

After stakeholders have been identified, legitimation strategies are employed to guarantee that their interests are regarded as valuable and genuine during the development process (Borning et al., 2005). By highlighting the significance of stakeholders and their connections to the technology, the stakeholder analysis tool, for instance, is a potent means to legitimize stakeholder interests. Prioritizing which stakeholders in the development process should receive greater attention or resources can also be helpful.

Then, interaction tools are employed to encourage stakeholder engagement and communication. One such tool is the stakeholder tokens tool. According to Yoo (2018), the stakeholder tokens tool provides a tangible or digital representation of individual stakeholders or stakeholder groups. These tokens can be used in collaborative settings such as workshops, brainstorming sessions, or decision-making meetings. Stakeholder tokens offer a mechanism to track and record stakeholder contributions over time, ensuring that a comprehensive record of their inputs, concerns, and suggestions is maintained. Additionally, these tokens serve as an avenue for stakeholders to express their values, opinions, interests, and preferences, thus promoting transparency, inclusivity, and active participation in the development process.

QT can be developed in ways that are in line with the significant values of stakeholders by using the VSD approach and its accompanying tools. More broadly speaking, VSD can be used in at least the following ways concerning QT:

- *Identification of stakeholders*: it is crucial to identify all parties who could be impacted by the development of QT, including investors, users, regulators, and advocacy groups. To make sure that these stakeholders' viewpoints are taken into account during the design process, VSD can help identify these stakeholders and their interests. In this study, we will primarily focus on the question of how to formulate a core list of relevant stakeholders. This often takes on the form of a literature review to create a preliminary list of stakeholders that is then revised given subsequent empirical investigations.
- *Stakeholder legitimation*: when stakeholders have been identified, VSD can be used to validate their viewpoints and interests. The stakeholder analysis tool, for instance, can assist developers in determining the significance of various stakeholders and their connections to the technology (c.f., Watkins et al., 2013). This can make sure that during the design process, the interests of all stakeholders are taken into consideration.
- *Stakeholder interaction*: due to the complexity of QT, a number of stakeholders with various specialities may need to work together. By the use of tools like stakeholder tokens, VSD may assist in fostering collaboration and communication between stakeholders. This tool can aid in organizing and facilitating stakeholder interactions, making sure that everyone involved has the chance to voice their opinions (c.f., Hendry et al., 2021).
- *Values*: QTs have the potential to have a big impact on society, including ethical, societal, and environmental issues (Coenen and Grunwald, 2017; Satanassi, 2020). To make sure that these values are taken into account during the design process, VSD can be used to identify and

prioritize them. For instance, ethical problems with the collecting and use of private information in quantum sensing can be found using VSD.

3. QT Stakeholders in the Literature

The emerging literature on the ethical, legal and societal aspects (ELSA) already discuss to some extent the role of stakeholders in the development of QT. In this section we survey this literature, collecting the presented views on the identification, legitimation of and interaction with stakeholders.

3.1. Literature Search Method

To identify the relevant literature, we initially adopted a bibliometric approach (Linnenluecke, et al., 2020), utilizing the Scopus database with the following query[2] on 10 October 2022 and ended up with 11 articles. After reading the abstracts of each article, we only found five of them to be relevant to QT. Next, we tried relaxing the query conditions by removing the “AND ("responsib*" OR "stakeholder*")” part. This led to 160 articles; however, a majority of these articles were technical papers, mainly on quantum key distribution due to the keyword “legal” being used in a different context. Removing this keyword reduced the results to 53, and after reading the titles and abstracts, we identified 15 of them as relevant literature.[3] From previous literature (Wolbring, 2022), we knew that there should be somewhere around at least 20 articles. At this point, we ran co-citation and bibliographic coupling analysis on the 15 articles we have, which identifies articles that were cited by multiple articles in our dataset, and which articles were cited together in the references section of the articles in our dataset. This led to the identification of four more relevant articles. At this point, we checked the list and realized that some papers known by the authors are not present in the list.

Next, we manually investigated the references sections of the papers at hand and also the articles known by the authors. We realized two key points: (i) some of the articles were published in new journals, meaning they couldn’t be discovered via a Web of Science (WoS) or Scopus literature research because the journal is not indexed yet (one example is the journal *Digital Society*, which published its first issue in July 2022), (ii) any attempt to cover all the ELSA keywords together with relevant quantum keywords would eventually lead to orders of magnitude more false positives than true positives, this is mainly due to the difference in the size of literatures in QT versus the ELSA of QT. The QT literature has more than 84.000 scholarly works in Scopus-indexed journals (utilizing the keyword from Seskir & Aydinoglu, 2021), while ELSA of QT has less than 50.

After all the steps above, we ended up with a list of 39 scholarly works indexed by Scopus. Next, we downloaded each paper/book and ran searches for keywords “Responsib*” and “Ethic*”, and read the paragraphs and sections to identify in which contexts these words were present in the text. We identified 18 from the list containing the concept of responsibility/responsible, and 19 contained the concept ethics/ethical in the contexts we were aiming for, 14 of the concepts contained both works. Therefore,

[2] Query: (("quantum tech*" OR "quantum comput*" OR "quantum sensing" OR "quantum sensor*" OR "quantum simulation" OR "quantum cryptograph*" OR "quantum communication") AND ("ethic*" OR "legal" OR "societal")) AND ("responsib*" OR "stakeholder*")

[3] We searched for the terms "ethic*" and "responsib*", and selected those papers that employ these words in a meaningful manner, not just a mere passing mention or used in a different context (especially for the term "responsib*".

we focused our attention on these 14. In each, we searched for the keyword "stakeholder" and highlighted the relevant section. Our highlights of these sections and the following takeaway messages are below, provided in chronological order depending on the publication years. The summary of the information on these articles can be found in Table 1.

Table 1: Title, in-text citation, year, and link to the publication for the 14 articles identified.

Title of the article	**In-text citation**	**Year**	**Link to publication**
QT and Society: Towards a Different Spin	(Coenen, Grinbaum, Grunwald, Milburn, & Vermaas, 2021)	2022	https://doi.org/10.1007/s11569-021-00409-4
Auditing the 'Social' of QT: A Scoping Review	(Wolbring, 2022)	2022	https://www.mdpi.com/2075-4698/12/2/41
Ethics education in the quantum information science classroom: Exploring attitudes, barriers, and opportunities	(Meyer, Finkelstein, & Wilcox, 2022)	2022	https://arxiv.org/abs/2202.01849
QT and human rights: an agenda for collaboration	(Krishnamurthy, 2022)	2022	https://iopscience.iop.org/article/10.1088/2058-9565/ac81e7
Q-turn: changing paradigms in quantum science	(Sainz, 2022)	2022	https://iopscience.iop.org/article/10.1088/2058-9565/ac82c4
Intellectual property in quantum computing and market power: a theoretical discussion and empirical analysis	(Kop, Aboy & Minssen, 2022)	2022	https://doi.org/10.1093/jiplp/jpac060
Digital justice in 2058: Trusting our survival to artificial intelligence, quantum and the rule of law	(Ritter, 2021)	2021	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3778678
Reading the road: challenges and opportunities on the path to responsible innovation in quantum computing	(Ten Holter, Inglesant, & Jirotka, 2021)	2021	https://www.tandfonline.com/doi/full/10.1080/09537325.2021.1988070
Asleep at the wheel? Responsible Innovation in quantum	(Inglesant, Ten Holter, Jirotka, & Williams, 2021)	2021	https://www.tandfonline.com/doi/full/10.1080/09537325.2021.1988557
Talking about public good for the second quantum revolution: analysing QT narratives in the context of national strategies	(Roberson, Leach, & Raman, 2021)	2021	https://doi.org/10.1088/2058-9565/abc5ab
The Potential Impact of Quantum Computers on Society	(de Wolf, 2017)	2017	https://link.springer.com/article/10.1007/s10676-017-9439-z
Responsible research and innovation (RRI) in QT	(Coenen & Grunwald, 2017)	2017	https://link.springer.com/article/10.1007/s10676-017-9432-6
The societal impact of the emerging QT: a renewed urgency to make quantum theory understandable	(Vermaas, 2017)	2017	https://link.springer.com/article/10.1007/s10676-017-9429-1
Quantum computing and cloud computing: Humans trusting humans via machines	(Grodzinsky, Wolf, & Miller, 2011)	2011	https://ieeexplore.ieee.org/document/7160598

3.2. Literature summary and general points

Vermaas (2017) argues that for a societal debate on QT to be effective, stakeholders need to have a reasonable understanding of the technologies in question. Quantum theory is notoriously difficult to understand, but philosophers of physics can help provide stakeholders with the necessary understanding to participate in the debate. He suggests that current responsible research and innovation approaches need to be expanded to include all stakeholders in the debate on QT. He also recommends organizing the debates in a manner which should distinguish between issues that arise during the transitional phase of introducing new QT and those that have a more permanent impact on society. By engaging in open dialogue and considering a range of perspectives, stakeholders can work together to guide the development of QT in a direction that is beneficial for all.

Coenen and Grunwald (2017) propose the implementation of a "strong" responsible research and innovation (RRI) approach to ensure the responsible development and commercial viability of QT. This approach involves linking core policy processes to stakeholder dialogues, decision-supporting public engagement, and a wide variety of other public communication activities. The authors emphasize the importance of engaging with a wide range of stakeholders at an early stage, including industry, early adopters, and key stakeholders, as well as the general public, in order to ensure that the development of QT aligns with societal values and interests. They also stress the need for proactive engagement with stakeholders throughout the lifecycle of QT, not just closer to the market. They caution against using uncertainties surrounding QT as an excuse to delay or avoid dialogue, as this could allow others to shape the narrative in unhelpful ways. Instead, the authors advocate for mutually informative dialogue with all stakeholders to give a broader picture of public perception and foster a shared narrative that is widely recognized and welcomed. In summary, Coenen and Grunwald (2017) argue for a societal debate on QT that involve open dialogue and consideration of a range of perspectives. This can help guide the development of QT in a direction that is beneficial for all and ensure that the research delivers results that are socially desirable and undertaken in the public interest, while helping to avoid large parts of the general public learning about QT via unfounded and potentially frightening speculations.

Roberson, Leach, and Raman (2021) argue that the concept of "public good" in research should focus on the diversity of stakeholders and their engagement to ensure that research outcomes benefit society as a whole. The authors propose a "public good test" that includes three elements: research agendas, social orders, and research-society networks. These elements should be diverse to pre-empt narrow outcomes that may harm certain groups, and stakeholders should be involved in exploring different agendas and outcomes. In their article, they emphasize that research funding, institutions of research utilization, and public communication of science play a crucial role in shaping research's capacity to address the public good for all stakeholders.

Holter, Inglesant, and Jirotka (2021) argue that responsible innovation (RI) requires engagement with stakeholders in the development of QT. Their case studies suggest that identifying stakeholders is not limited to ultimate users but also includes peers within the research team and similar fields. In their article, they also emphasize the importance of managing expectations and representing QT in a non-hyperbolic way to stakeholders, including funders and policymakers as well as the general public. Widening the pool of stakeholders consulted is necessary to develop a better understanding of the possible effects and impacts of quantum-based technologies. Engagement should not only happen with the public but with all interested stakeholders, including regulators, contingent industries, and other branches of the academy. Overall, their work emphasizes that identifying and engaging with stakeholders is critical for developing and implementing QT responsibly.

Wolbring (2022) argues that involving stakeholders is crucial in building literacy in the societal impacts of QT. Some quantum policy documents indicate the need to involve stakeholders in reviewing the potential impacts of QT on society (QuantERA, 2020; WEF, 2022), and some countries have already carried out public consultations on their quantum strategies (Brennen, et al., 2021). Since QT research is still a relatively recent topic for many governments, the discussion among stakeholders is still ongoing, and several European countries have yet to develop social, ethical, and legal parameters (QuantERA, 2020). Wolbring suggests that mapping out the 'social' within a differentiated map of the applications allows for social risk to be mapped out in a meaningful way as well as to build literacy in the societal implications. He argues that a mapping exercise could also be used as a pedagogical tool in EDI curricula content and other courses, engaging with the concept of stakeholder and citizen engagement in society. He highlights the importance of involving stakeholders and building their understanding of QT to support meaningful societal debate and decision-making.

Ritter (2021) highlights the rarity of open dialogue among technology and legal stakeholders regarding how to innovate and govern. Krishnamurthy (2022) stresses how governments can create the conditions for successful self-regulatory and multi-stakeholder initiatives in order to address the human rights impacts of QT. Finally, Meyer, Finkelstein, and Wilcox (2022) point out that QIS researchers and stakeholders from technical backgrounds, although accepting that ethical issues undeniably emerge in QT, they believe these issues do not diverge significantly from those of other areas of engineering and technology and are perhaps better suited for philosophy departments rather than the public domain.

In summary, from the previous literature in the articles published in Scopus-indexed journals, we can list the following points to be taken into account when getting involved in stakeholder identification and engagement:

- Involving stakeholders in reviewing the potential impacts of QT on society to support meaningful societal debate and decision-making.
- Mapping out the 'social' within a differentiated map of the applications to allow for social risk to be mapped out in a meaningful way, build literacy in the societal implications, and be used as a pedagogical tool in EDI curricula content and other courses.
- Providing stakeholders with a reasonable understanding of the technologies in question through engagement with philosophers of physics and open dialogue that considers a range of perspectives.
- Implementing a "strong" responsible research and innovation (RRI) approach that involves engaging with a wide range of stakeholders at an early stage and throughout the lifecycle of QT to ensure the development aligns with societal values and interests.
- Focusing on the diversity of stakeholders and their engagement to ensure research outcomes benefit society as a whole through a "public good test" that includes research agendas, social orders, and research-society networks.

- Engaging with stakeholders, including peers within the research team and similar fields, regulators, contingent industries, and other branches of the academy, to develop a better understanding of the possible effects and impacts of quantum-based technologies.
- Managing expectations and representing QT in a non-hyperbolic way to stakeholders, including funders and policymakers as well as the general public.
- Collaboration between certain stakeholder groups are seen as more important or necessary by some authors, the role of governments as facilitators is stressed upon, and no consensus on where discussions on ethical issues arising from QT should be tackled is hard to locate.

Further condensing these points raised in the literature into the basis of a framework for identifying, legitimating, and interacting with QT stakeholders, we identified the following elements covered in the literature:

1. **Early and continuous engagement:** Implement a responsible research and innovation approach that involves diverse stakeholders throughout the lifecycle of QT, ensuring alignment with societal values and interests.
2. **Stakeholder literacy and social impact mapping:** Provide stakeholders with a reasonable understanding of QT, manage expectations, and create a differentiated map of QT applications to identify social risks and build societal implications literacy.
3. **Inclusive engagement and collaboration:** Encourage collaboration across sectors and emphasize the role of governments as facilitators in the stakeholder engagement process, fostering a comprehensive understanding of QT impacts and addressing ethical issues.

3.3. Ethical Orientations and Interests of Stakeholders in QT

Understanding the roles and interests of stakeholders is foundational. However, to create a comprehensive framework that addresses both stakeholder identification and ethical considerations, we must dive into the ethical orientations, interests, and potential conflicts that stakeholders might harbor regarding QT.

- **Industry Players**: These stakeholders primarily aim for technological advancement and commercial viability. However, their interests might sometimes prioritize profit over broader societal benefits, leading to ethical concerns like data privacy, monopolization, or the rapid deployment of under-tested technologies.
- **Philosophers of Physics**: They focus on the foundational understanding of QT. Ethically, they strive for accurate, non-hyperbolic representations of QT's capabilities and implications, ensuring that society has a realistic view of what QT can and cannot achieve.
- **General Public**: Their ethical concerns center around the direct and indirect effects of QT on daily life. This includes potential surveillance concerns, implications for employment (like job losses due to automation), and the societal consequences of major technological shifts.

- **Government Bodies**: While they aim to foster innovation, they must also protect citizens from potential harm. Ethically, their position is often a balancing act between facilitating technological growth and ensuring societal safety and equity.
- **Research Teams and Academia**: Their primary objective is knowledge expansion. Ethical concerns for this group include ensuring research integrity, avoiding hyperbolic claims, and considering the broader societal implications of their findings, beyond just the academic realm.
- **Early Adopters**: They are often excited about the possibilities of new technologies. However, their enthusiasm might overlook potential ethical pitfalls, such as adopting systems that might later prove to have privacy concerns or other unintended consequences.
- **Regulators**: They play a crucial role in creating a safe landscape for QT deployment. Their ethical considerations revolve around ensuring that new regulations protect society without stifling innovation.

By examining these ethical orientations, we can identify potential conflicts. For instance, industry players might be in disagreement with regulators about the speed at which a new QT should be rolled out. Philosophers of physics might challenge research teams on their claims about the potential of QT, advocating for more grounded and realistic public communications. Understanding these ethical positions is crucial not just for effective stakeholder engagement, but also for anticipating potential challenges and conflicts as QT continues to evolve and permeate society. Future research should focus on developing strategies and frameworks to navigate these ethical concerns, ensuring a holistic and responsible advancement of QT.

In the following section, we delve into the topic of identification of stakeholder groups that are directly or indirectly affected by the development and deployment of QT. By identifying the wide diversity of the stakeholder groups, we aim to emphasize the necessity of a multi-faceted approach to address the diverse range of ethical, social, and environmental issues that arise from the development and implementation of QT.

4. QT Stakeholder Communities

4.1. Existing listings of stakeholders

In the relevant literature only a few studies exist that explicitly emphasize who these stakeholders are. One such study is the *WEF Quantum Computing Governance Principles*. Authors identify seven key stakeholders in their report (2022, p. 7); (i) governments, (ii) academics and universities, (iii) international organizations, (iv) corporations and private entities that are using the technology, (v) corporations and private entities that are developing the technology, (vi) developers (individuals), and (vii) consumers (individuals).Another study, focusing on the quantum governance stack (Perrier, 2022, p. 2) identifies again seven key stakeholder groups; (i) states (governments) as the primary agents of regulation, and their role in (a) international and (b) national formal (legislative) regulation; (ii) multilateral institution(s); (iii) national instrumentalities, such as parliaments and administrative agencies; (iv) industrial and commercial stakeholders; (v) universities and academia; (vi) individual producers/consumers of QT and (vii) civil society and technical community groups. A different study focusing on the needs of the quantum industry (Hughes, et al., 2021, p. 2) identifies five stakeholders; (i) students, (ii) university educators and administrators, (iii) policy makers, (iv) funding agencies, and

(v) quantum companies. One final study that explicitly focuses on the list of stakeholders is a Delphi study conducted in the context of QT outreach and education (Seskir, et al., 2023b), where the stakeholders are asked to be identified and ranked by participants of the Delphi study. The resulting list contains (i) universities, (ii) research institutions, (iii) scientific associations, (iv) science centers, (v) high schools, (vi) companies/industry, (vii) student associations, (viii) museums, (ix) secondary schools, (x) professional associations, (xi) non-formal educational bodies, (xii) local communities, and (xiii) municipalities. These already extensive lists still omit some key stakeholders, such as investors, media and journalists, and affected communities, among possible others, either by omission or counting them under other categories (like civil society or industry).

Acknowledging that identifying stakeholders can be a challenging and sometimes arbitrary process is crucial for a more comprehensive understanding of the QT ecosystem. These studies provide a starting point, but the omission of certain obvious stakeholders highlights the complexity of this task. The dynamic nature of technology and its societal impacts requires continuous reassessment and adaptation of stakeholder lists to ensure inclusivity and effective collaboration. By recognizing the inherent difficulties in stakeholder identification and striving for a more encompassing approach, we can better address the multifaceted concerns and opportunities that arise in the development and application of QT.

Furthermore, stakeholder identification relies heavily on the context and the aimed model. A good example of this can be observed in a detailed previous work (Perrier, 2022) covering also the duties and rights-based approach of quantum governance. Stakeholder identification and engagement are explicitly included in this model (pp. 12-13), and an extensive table titled *Quantum governance stack* (Perrier, 2022, p. 41) with a detailed matrix for different quantum stakeholders versus types of governance instruments, denoting the category, agents, objectives/risks, instruments, rights/interests, powers/duties, and an example for each stakeholder can be found. However, media and journalists are only mentioned in this framework once (p. 37) and only as civil society stakeholders in their relation to setting agendas, highlighting risks, and drawing attention to issues requiring governance responses, as the model prioritizes governance-related relations over others. Different contexts and models highlight and constraint the roles and significance of potential stakeholder configurations.

4.2. Stakeholder Identification

In the context of VSD, a stakeholder can be defined as any individual, group, or entity that has a direct or indirect interest in, is affected by, or can influence the design, development, and use of technology, considering its ethical, social, and environmental implications (Nathan et al., 2008; Borning & Muller, 2012; Friedman & Hendry, 2019). As is typical in VSD conceptual investigations, we adopt both extant staholder groups that have previously been identified in the literature as well as ones that may be particular to QT more specifically. Such categorizations are then revised in light of subsequent empirical investigations. A revised list of stakeholders with their roles and significance highlighted, and with the reasoning for including them, is given in Table 2.

Table 2: Stakeholder groups, their role and significance, and the reasoning behind including them.

Stakeholder Group	**Role and Significance**	**Reasoning**

Researchers and developers	Individuals and organizations directly involved in the creation and advancement of QT; responsible for aligning their work with ethical, social, and environmental considerations.	Their work shapes the technology's design and development, and they need to consider the ethical, social, and environmental implications of their work to align with the values of other stakeholders.
Educators and training providers	Individuals and institutions responsible for teaching and training students, researchers, and professionals in the field of QT. Their role is essential in building a skilled workforce that understands the ethical, social, and environmental implications of QT development and use.	They are vital stakeholders because they shape the knowledge, skills, and values of future QT professionals. Their expertise aids in designing effective educational programs and resources, ensuring preparedness to address complex challenges. In the context of VSD, their influence on ethical considerations makes their inclusion in decision-making processes crucial.
End-users and adopters	Individuals or organizations utilizing QT in various fields; their experiences, values, and needs must be considered for useful and responsible technology development.	They are affected by the design and functionality of QT, and their experiences, values, and needs must be taken into account to ensure the technology is useful and responsible.
Regulators and policymakers	Governmental entities creating laws, regulations, and policies governing QT development and use; responsible for protecting public welfare and promoting responsible innovation.	They have the responsibility to ensure that QT is developed and used in a way that aligns with society's values and interests, protecting public welfare and promoting responsible innovation.
Investors and funders	Public and private funding sources for QT research, development, and commercialization; influence the direction and focus of QT development and ensure alignment with societal values.	Their financial support influences the direction and focus of QT development, and they have an interest in ensuring that the technology is developed responsibly and provides a return on investment that aligns with societal values.
Industry partners and suppliers	Companies and organizations providing resources, infrastructure, or expertise to support QT development; their involvement can influence the design, availability, and adoption of the technology.	Their involvement in the QT ecosystem can influence the design, availability, and adoption of the technology, and their values and interests should be considered in the development process.
Ethics and societal experts	Individuals and groups focusing on ethical, social, and legal aspects of QT; help identify, analyze, and address potential implications of QT to ensure alignment with societal values.	They help identify, analyze, and address potential ethical, social, and legal implications of QT, ensuring that the technology is developed and used in a manner consistent with societal values.
General public and affected communities	Wider society and specific communities impacted by QT development and applications; their values, concerns, and potential should be considered for responsible and inclusive technology development.	They have a stake in how QT is developed and used, as it may impact their lives, environment, or social structures. Their values, concerns, and potential benefits should be considered throughout the design process to ensure responsible and inclusive technology development.

Media and journalists	Professionals communicating news, updates, and critical analysis of QT to the public; facilitating dialogue and raising awareness of QT's implications and potential impact on society.	They play a crucial role in shaping public opinion, raising concerns, and generating constructive discussions that can guide the development and use of QT in a way that aligns with societal values. By accurately and responsibly reporting on QT, they help ensure that the wider public stays informed and engaged with the technology's progress and ethical considerations.

While the list provided offers a comprehensive overview of the main stakeholders in the QT domain from a VSD perspective, it is essential to acknowledge that the landscape of stakeholders can evolve over time, and the identification of stakeholders highly depends on the context. New stakeholders may emerge, and the roles and interests of existing stakeholders may change as QT develops and becomes more integrated into society. Moreover, it is challenging to create an exhaustive list of stakeholders that captures every individual or group with a potential interest in or who may be impacted by QT. Therefore, it is important to continually reassess and update the list of stakeholders as the field advances and new insights emerge.[4] For this reason, conceptual investigations like this remain iterative, reformulating as novel and potentially conflicting empirical data is considered.

As an example of the way the list can be constructed differently, one can argue that educators and training providers could be considered as part of (a) Researchers and developers, as they are often involved in academic institutions, and research organizations responsible for the creation and advancement of QT. Although they play a crucial role in educating and training the next generation of professionals in the field, they are traditionally considered a subgroup under academics as academics and industry R&D teams handle most emerging technologies-related education and training. However, it is possible to emphasize their role separately by including them as an additional stakeholder category, as in the QT community, there are many global education and training programs that cannot be classified as a subgroup of researchers and developers.

4.3. Stakeholder Sampling

There is limited literature specifically addressing stakeholder sampling in the context of VSD. However, stakeholder sampling can be informed by general principles and strategies found in many other resources which aligns with VSD's commitment to adopting best practices of extant methodologies. For the purpose of this work, we introduce three widely utilized and adopted sampling strategies (Bryman, 2016) which are snowball, maximum variation, and purposive sampling. A summary of the strategies and their respective shortcomings for VSD purposes can be found in Table 3.

Table 3: Sampling strategies and their shortcomings

Sampling strategy	**Description**	**Shortcoming**
Snowball	Initial stakeholders are asked to recommend	May result in a biased sample, as stakeholders

[4] A foundational precept of the VSD is exactly the point of the dynamic nature of society and technology, and, as a result, any design project should be open to continual reevaluation (Friedman and Hendry, 2019).

	additional stakeholders to involve in the process. This approach can help to identify stakeholders who may not have been initially recognized but have valuable insights and perspectives to offer.	who are already connected or share similar perspectives are more likely to be included, potentially overlooking less connected or minority viewpoints.
Maximum variation	Aims to include stakeholders representing the widest possible range of perspectives and experiences. It helps to capture diverse viewpoints and identify common patterns across different stakeholder groups.	May limit the depth of understanding in VSD research, as it focuses on including diverse stakeholder perspectives, but might not fully explore each stakeholder's nuanced opinions, values, or experiences in detail.
Purposive	Involves selecting stakeholders based on specific criteria relevant to the VSD process, such as expertise, demographics, or roles within an organization. This approach can help to ensure that stakeholders with the necessary knowledge and experience are included in the VSD process.	May be subject to researcher bias, as the selection of stakeholders is based on the researcher's judgment, which can inadvertently exclude important perspectives or fail to represent the full range of stakeholder values and concerns.

These shortcomings can be overcome by using a combination of sampling strategies, tailored to the specific context and goals of the specific VSD research at hand. By employing a mixed-methods approach, VSD practitioners can leverage the strengths of each strategy while minimizing their limitations. One such path could be to start with purposive sampling to ensure that a wide range of stakeholder perspectives and expertise are included. This will help address potential bias by selecting individuals or groups that the researcher believes will bring valuable insight into the study. The following step can be the use of maximum variation sampling to further diversify the sample and ensure that both majority and minority viewpoints are represented. This will help to reduce the risk of overlooking less common or less connected perspectives (Patton, 2002, pp. 234-235). Finally, employing snowball sampling as a third step can expand the sample and uncover additional stakeholders who might have been missed in the initial selection process. This will help to ensure that the study includes a broader network of stakeholders and captures a more comprehensive range of opinions, experiences, and values. By combining these sampling strategies in a systematic way, practitioners can create a more robust and representative sample of stakeholders, ultimately enhancing the validity and relevance of the VSD research for their respective fields of QT.

One caveat here might be also to emphasize when a stakeholder belongs to multiple groups. It is essential to recognize and address the multifaceted roles and interests of such stakeholders. One approach is to create a distinct category that captures their unique combination of roles and explains how this combination influences their perspective on the technology. Alternatively, one could mention their multiple affiliations within the stakeholder descriptions, clarifying their diverse connections and contributions to the technology's development and application. Acknowledging these overlapping roles will help ensure that they are not reduced to a single role.

4.4. A Stakeholder Search

For researchers and practitioners aiming to work on VSD for QT, we have generated two lists of potential stakeholders and access points for them to utilize in their projects. Please note, as mentioned above, it is essential to acknowledge that the landscape of stakeholders can evolve over time, and the identification of stakeholders highly depends on the context. New stakeholders may emerge, and the roles and interests of existing stakeholders may change. That being said, our list of stakeholders provides a good starting point for those aiming to follow the three-step sampling process of purposive, maximum variation, and snowball strategies.

In line with typical VSD conceptual analyses concerning stakeholder identification, the first dataset we present consists of results obtained by analyzing the 76,724 publications selected from the Web of Science Core Collection utilizing a search query (see Appendix) previously utilized in the literature (Seskir & Aydinoglu, 2021) on the 6th of April, 2023. Anyone with access to the WoS interface can re-run our query and obtain an updated version of our dataset. But for those that do not want to take that route, our dataset can be accessed via Seskir, Umbrello & Vermaas, 2023b. The details on the content of our dataset are listed in Table 3.

Table 3: Information on the contents of our dataset obtained from the WoS Core Collection

Type of data	**Number of entries**
Affiliations	772
Funding agencies	256
Conference titles	120
Grant numbers	184
Publication titles	179
Publishers	54

For all the data types, except conference titles, we selected the cut-off point as 50, meaning that only affiliations, funding agencies, grant numbers, publication titles, and publisher with at least 50 publications out of the 76,724 publications selected from the Web of Science Core Collection via the query. For conference titles, the cut-off point was selected as 15, due to the low number of entries per conference title in the dataset. These cut-off points are rather arbitrary but beneficial in cutting the numbers down into manageable and meaningful sizes for their potential uses in stakeholder sampling strategies. As mentioned above, any researcher or practitioner interested in the full set can re-run the search query on the WoS interface and obtain the full lists.

In the following step, we embarked on a more manual process to create what we called a "Preliminary QT Stakeholders" list (Seskir, Umbrello & Vermaas, 2023a). Initially, we aimed to follow previously formulated lists and categories in the literature, such as those found in WEF (2022) and Perrier (2022), or as shown in Table 2. However, we encountered difficulty in assigning many of the stakeholders to just one category or even to any category at all. As a result, we opted to provide the raw list with our preliminary categorization, leaving the more detailed categorization (i.e., adapting this list to the specific context of a research question or project) to our audience and VSD designers engaging in empirical investigations. Our dataset also builds upon those found in the literature, such as Dargan (2022) for venture capital and Seskir et al. (2022) for start-ups. Table 4 presents some details on the content of our second dataset.

Table 4: Information on the contents of our Preliminary QT Stakeholders dataset

Type of data	Number of entries
NGOs/Communities	42
QT Start-ups and SMEs	460
Public Organisations	5
Venture Capital	127
Professional/Trade Association	5
Partnership/Consortia	14
Manifestos/reports	8
Major Companies involved in QT	19
ELSA Researchers	34
ELSA Groups	20
Media and journalists	5

Combining the information found in both datasets, summarized in Tables 3 and 4, researchers and practitioners of VSD can gain access to a comprehensive range of QT stakeholders. These datasets can also be used in conjunction with existing resources that focus on specific groups or subfields of QT. A list of such resources can be found in Table A.1 in the Appendix section. This integration offers interested parties a solid foundation and multiple options for implementing a mixed-methods approach to sampling strategies in their VSD applications.

4.5 Discussion on Methodological Approach

While our study provides an extensive list of stakeholders actively engaged in the QT realm, we acknowledge the methodological limitation of our work. By using the Web of Science Core Collection, we have predominantly captured stakeholders who are deeply and actively contributing to the QT literature. This method inherently leans towards stakeholders who are potentially very positive towards QT. It's crucial to note that while these active contributors play a significant role in shaping the QT landscape, they represent only one facet of the vast array of stakeholders affected by the rise of QT. Many stakeholders, especially those who might experience the broader societal, economic, or ethical impacts of QT, may not necessarily be publishing extensively on the topic but still hold significant stakes in its development and implications.

For a more comprehensive view, future research may consider integrating methods like surveys, interviews, or focus groups targeting sectors not represented in our dataset. Engaging in public discourse or hosting public forums could also shed light on concerns, values, and interests of individuals and groups who are indirectly affected by QT. A good example of this approach is the Quantum Technologies Public Dialogue Report (NQIT, 2017). By combining insights from both active contributors and broader society, we can work towards a more holistic understanding of the QT stakeholder landscape, ensuring that its development is both inclusive and ethically responsible.

5. Limitations and Future Research

In this study, several limitations need to be acknowledged. First, the stakeholder lists provided, while comprehensive, may not be exhaustive. The rapidly evolving landscape of QT may result in the emergence of new stakeholders or changes in the roles of existing ones. Additionally, the categorization of stakeholders is based on our analysis and understanding, which may not perfectly align with every research context or project. Therefore, researchers and practitioners should be aware of these limitations and adapt the lists according to their specific needs and requirements. This is often the case in VSD applications where further empirical investigations are conducted to determine if conceptual investigations like the one conducted in this study are legitimate, and revisions often take place.

Second, our study focuses primarily on the identification of stakeholders, rather than delving into the complexities of their interactions and relationships. While this provides a valuable starting point, it leaves room for further exploration in understanding how stakeholders engage with each other and collaborate in the development of QT. Furthermore, as the study is conceptual in nature, it does not provide detailed guidance on how to operationalize the stakeholder lists for specific VSD applications. However, it does detail a sampling strategy as a tool for such an operationalization of this (or any) stakeholder list. Future research could address these limitations by refining categorizations, conducting empirical studies on stakeholder interactions and their implications, and developing methodologies to integrate the stakeholder lists into the context of VSD more effectively. There are a host of tools that form part of the VSD repertoire that is geared exactly toward these kinds of empirical investigations in order to better determine such interactions and their relevance to any given system design (Friedman and Hendry, 2019).

6. Conclusions

In the rapidly evolving domain of QT, it is paramount to understand its intricacies and implications. While seemingly fundamental with its listing of stakeholders, our research delves deep into the unique nuances of QT's intersection with various societal elements. Stakeholder analysis might appear common across different technologies, but the depth and structure we bring in the context of QT emphasize the unique challenges and ethical dilemmas intrinsic to this field. The importance of our comprehensive list for VSD researchers and practitioners cannot be understated. This list serves as a touchstone to facilitate continuous alignment with societal values. With a spectrum of stakeholders identified, early and ongoing engagement becomes feasible, ensuring QT's alignment with societal values and bringing forth the ethical and moral considerations often overlooked in the race of technological advancements. Additionally, our structured stakeholder list enhances stakeholder literacy and aids in social impact mapping. By delineating these entities, we foster an environment conducive to managing expectations, comprehensively mapping QT applications, identifying potential social risks, and elevating the general literacy surrounding its societal implications. Moreover, our stakeholder list promotes cross-sectoral cooperation and ethical diligence. By highlighting the critical role of governments and other entities, we underscore the necessity of cross-sectoral cooperation, a collective pursuit to grasp QT's holistic impact and navigate the moral conundrums it might pose. In the realm of QT, where the terrain is as mysterious as it is exciting, our research does more than list—it informs, guides, and cautions. The stakeholder landscape we have mapped out is not just a directory; it is a compass for QT professionals navigating this brave new world. This paper, therefore, is n'=ot just an explanation of a dataset—it is a critical guidebook ensuring that as we move forward with QT, we do so ethically, inclusively, and with a profound understanding of its societal repercussions.

Data Availability Statement

The datasets generated by the survey research during and/or analyzed during the current study are available in the Zenodo repository, https://doi.org/10.5281/zenodo.7848870 and https://doi.org/10.5281/zenodo.7848884

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Appendix

TS = ("quantum simulation" OR "quantum imaging" OR "quantum sensing" OR "quantum sensor" OR "quantum computation" OR "quantum computing" OR "quantum computer" OR "quantum coding" OR "quantum programming" OR "quantum error correction" OR "quantum error correcting" OR "quantum circuits" OR "quantum algorithm" OR "quantum algorithms" OR "quantum network" OR "quantum networks" OR "quantum channel" OR "quantum channels" OR "quantum cryptology" OR "quantum cryptography" OR "quantum key" OR "quantum teleportation" OR "quantum information" OR "QT" OR "QT" OR “quantum gates" OR “quantum register" OR “quantum contextuality" OR “quantum decoherence" OR “quantum communication" OR “quantum memory" OR “quantum memories" OR “quantum repeaters" OR “quantum state transfer" OR “quantum zeno dynamics" OR “qubit" OR “qutrit" OR “qudit" OR “quantum correlations" OR “quantum entanglement" OR “quantum discord" OR “quantum noise engineering" OR “quantum state engineering" OR “quantum protocols" OR “quantum annealing” OR “quantum logic gate” OR “quantum internet” OR “quantum repeater” OR “quantum memory” OR “quantum photonics” OR “quantum photonic” OR “quantum biology” OR “quantum machine learning”)

OR

TI=("quantum simulation" OR "quantum imaging" OR "quantum sensing" OR "quantum sensor" OR "quantum computation" OR "quantum computing" OR "quantum computer" OR "quantum coding" OR "quantum programming" OR "quantum error correction" OR "quantum error correcting" OR "quantum circuits" OR "quantum algorithm" OR "quantum algorithms" OR "quantum network" OR "quantum networks" OR "quantum channel" OR "quantum channels" OR "quantum cryptology" OR "quantum cryptography" OR "quantum key" OR "quantum teleportation" OR "quantum information" OR "QT" OR "QT" OR “quantum gates" OR “quantum register" OR “quantum contextuality" OR “quantum decoherence" OR “quantum communication" OR “quantum memory" OR “quantum memories" OR “quantum repeaters" OR “quantum state transfer" OR “quantum zeno dynamics" OR “qubit" OR “qutrit" OR “qudit" OR “quantum correlations" OR “quantum entanglement" OR “quantum discord" OR “quantum noise engineering" OR “quantum state engineering" OR “quantum protocols" OR “quantum annealing” OR “quantum logic gate” OR “quantum internet” OR “quantum repeater” OR “quantum memory” OR “quantum photonics” OR “quantum photonic” OR “quantum biology” OR “quantum machine learning”)

Table A.1: A list of complementary data resources for QT stakeholders

Provider	Context	Stakeholders	Link
Quantum Computing Report by CGI	Limited to quantum computing	Government/Non-Profits, Private/Startup Companies, Public Companies, Universities, Venture Capital	https://quantumcomputingreport.com/players/
QURECA	Public initiatives in QT	Public Organizations, Funding Agencies	https://qureca.com/quantum-initiatives-worldwide-update-2023/
The Quantum Insider	Commercial dataset (paid access)	Private/Startup Companies, Public Companies, Venture Capital	https://app.thequantuminsider.com/
Inside QT	Commercial dataset (paid access)	Market Reports, Historical Data	https://www.insidequantumtechnology.com/data-services/
National Quantum Initiative	Detailed reports but no curated dataset available	Academic and Industrial Stakeholders	https://www.quantum.gov/publications-and-resources/publication-library/
European Patent Office	Detailed patent analytics report with some available curated datasets	Industrial (patent holding) Stakeholders	https://www.epo.org/searching-for-patents/business/patent-insight-reports.html
Quantum Flagship	A self reported directory of QT stakeholders in Europe	QT Stakeholders in Europe	https://qt.eu/about-quantum-flagship/the-european-community/directories
(Kaur & Venegas-Gomez, 2022)	A focused study on the quantum workforce development	Education Initiatives, Conferences, Courses	https://doi.org/10.1117/1.OE.61.8.081806