

## ROLES OF QUANTUM ECOSYSTEM ACTORS OPENING INNOVATION PATHS FROM TECHNOLOGY TO IMPACTS

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This paper studies the co-evolution of quantum technology ecosystems across three European regions: the Basque Country, Finland, and The Netherlands. By examining the roles of ecosystem actors during the innovation path from research to commercialisation, the study aims to understand how these roles facilitate the emergence and development of quantum technologies. Using a comparative multi-case study approach, the study identifies key characteristics, collaborative dynamics, and challenges within these ecosystems. The findings highlight the importance of different ecosystem types, the significance of individual and organisational roles, and the need for dynamic interaction between technology innovation and industrial adoption. Practical implications are provided for academics, managers, and policymakers to enhance ecosystem development and competitiveness in the field of quantum technologies.

*Keywords:* Quantum ecosystems; innovation paths; quantum technologies; ecosystem actors; actor roles; collaborative dynamics; multi-case study.

## Introduction

Quantum technologies encompass various domains, including quantum computing, communication, and sensing. These quantum technologies are forecasted to have game-changing practical impacts on science, business, and society in ways we cannot yet foresee. Understanding the future potential of emerging and disruptive technologies, such as quantum technologies, requires bridging together a variety of competencies from quantum physics to engineering, innovation management and foresight. Since the disruptive impact of emerging technologies continually evolves, actors, their roles and responsibilities, and ecosystem embeddings must adapt over time (see also [Geurts and Cepa, 2023](#)). Unknown future business opportunities and a lack of transparency of technology disruptions may lead to a significant gap between the developed technical solutions and end users' needs.

Interconnected technologies for quantum systems offer a fertile ground for collaborative initiatives among researchers, academic institutions, and industry players to emerge ([Coccia and Roshani, 2024](#)). In such settings, multiple actors from different domains, their different interests, agendas and competencies, and technological solutions compete along the innovation path. In an emerging technology field characterised by numerous uncertainties and risks, public funding agencies and governments are among the key actors influencing technological development and convergence.

However, an ecosystem approach helps open the innovation path from research to development and, finally, commercialisation through shared meaning-making. Furthermore, understanding the roles and resources of ecosystem actors not only provides the basis for enabling the required knowledge flows between the actors but also contributes to the development of the emerging ecosystem ([Pisa et al., 2024](#)). Although previous research has widely investigated different ecosystem

typologies and categorisations, it offers a limited understanding of dynamic co-evolution within ecosystems (Hou and Shi, 2021; Valkokari *et al.*, 2024).

The remainder of this paper is organised as follows. A literature review establishes the conceptual foundation of our study, followed by a description of the research process. Next, the empirical findings are provided, together with the conceptual framework. The concluding section presents the discussion, implications for scholars and managers, and reflections on the study's limitations.

## **Theoretical Background**

Discussion related to open innovation (OI) highlights the importance of exploring how innovation is conducted, i.e., processes and phases that organisations go through to become more open or closed over time (Bogers *et al.*, 2017). Similarly, previous research on ecosystems has widely investigated ecosystem types and introduced a variety of approaches to ecosystems and other collaborative arrangements for innovation. Consequently, the need to solve wicked problems is where closer links can be forged between OI and ecosystems (Dahlander *et al.*, 2021). The lack of established capabilities for organizing ecosystems for innovation is a pivotal challenge in the current business environment (Linde *et al.*, 2021; Pisa *et al.*, 2024) and especially when innovation work is linked to the future impacts of innovation and related business opportunities (Valkokari *et al.*, 2024).

### **Ecosystems in quantum**

Despite numerous papers on different ecosystem types, it remains unclear what constitutes an ecosystem. An ecosystem can be described by its activities, 'business or innovation ecosystem' by its actors, 'entrepreneurial ecosystems', or by its boundaries, 'regional or national ecosystems'. Likewise, there are several views on 'quantum technology ecosystems'. These include various national quantum ecosystems, industry ecosystems, as well as quantum start-up ecosystems dedicated to specific quantum technologies, among others. However, up to date, limited studies focus on the co-evolution of quantum ecosystem structures (actors, their roles and collaborations between them) (Jiménez Farías *et al.*, 2024; Jiang and Chen, 2021).

Aligned with a co-evolution approach to ecosystems (Hou and Shi, 2021), our preliminary research framework explores how ecosystem characteristics and actors' roles emerge and change in the process of collaborative innovation process, including research, development and innovation phases (Fig. 1).

The preliminary framework outlines how ecosystem structures and focus areas evolve from basic research on quantum-related technologies to commercialising innovation in various sectoral business ecosystems.

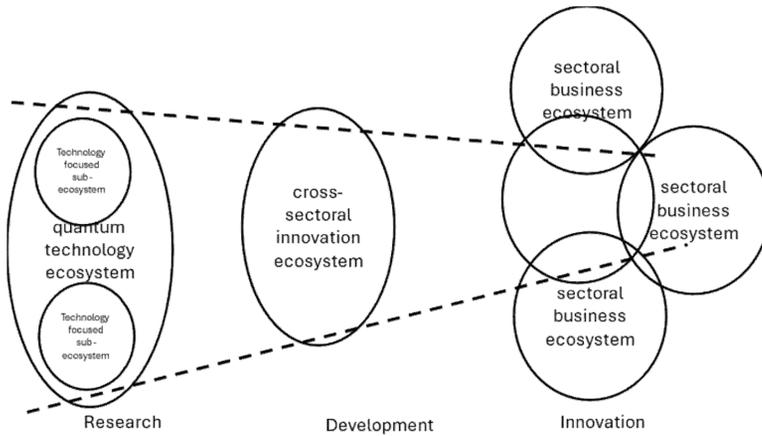


Fig. 1. Co-evolution of ecosystem structures in quantum technologies.

### Roles in quantum ecosystems

Consequently, there is limited research on actor roles in the different ecosystems — particularly within quantum ecosystems. Therefore, we have explored the roles of ecosystem actors in collaborative innovation and ecosystems literature. These roles range from direct value creation to supporting and encouraging innovation, as well as leading and orchestrating the ecosystem (Dedehayir et al., 2018). However, the discussion is quite scattered and presents different views highlighting, for instance, ecosystem orchestration (Ritala et al., 2022), innovator roles (Nyström et al., 2014), or considering the perspectives of a single actor, such as the role of universities (Medina et al., 2022).

From the governance or structural perspectives of the ecosystem, the actors' roles could be simply categorised as an orchestrator and a specialist role, whereas the functional roles in the business ecosystem include value creation, delivery and monetisation (Brea, 2023). In this study, we utilise the four categories of actor roles (Leadership roles, Direct value creation roles, Value creation support roles and Entrepreneurial ecosystem roles) presented by Dedehayir et al. (2018).

These categories of actor roles are mapped to three main phases of ecosystems' co-evolution (Fig. 1), as follows:

- in the focal quantum technology ecosystem, including both direct knowledge creation roles (knowledge producers, technology providers, complementors, or users) and supporting roles (facilitators, intermediators),
- in the cross-sectoral innovation ecosystem consisting of core roles in innovation and supporting roles for future value creation and market shaping (ecosystem promoters, builders and orchestrators, sponsors, funders and regulators),

- in the sectoral business ecosystem involving direct business value creation roles (manufacturers, service/technology providers, complementors, or users) and supporting roles (knowledge producers, knowledge-intensive business services (KIBS)).

It is assumed that during co-evolution, an ecosystem actor may fulfil multiple roles (Valkokari *et al.*, 2024). For example, universities occupy a core position in the quantum technology research ecosystem while they serve in a supportive knowledge producer role within the sectoral business ecosystem or a facilitator role in the development of cross- sectoral innovation ecosystems.

## Methodology

We focused on complex social issues to determine what is happening in ecosystem collaboration during the co-evolution of emerging technology. To assess this phenomenon ‘in a new light’ (Robson, 2002), an explorative multi-case study fits our purposes. This paper aims to advance understanding of the different roles that quantum ecosystem actors have and, in particular, explore how these roles enhance the opening of the innovation path from technology to future business opportunities. Accordingly, we formulated the following three research questions:

- “What are the key characteristics of quantum ecosystems?”,
- “How do the roles of the involved actors take shape within quantum ecosystems?”, and
- “How do these roles enhance opening the innovation path from research to future business?”

## Research design and case descriptions

The study is based on a qualitative research approach. The comparative cases were selected based on similar aims related to emerging technologies but with partially different ecosystem models. These similarities provide comparability, while specific differences reflect the diverse realities found in ecosystems and are expected to create enough variety in co-evolution within ecosystems. Table 1 gives an overview of three case ecosystems (their structure and actors engaged).

In the Basque Country, there are over 20 members in the ecosystems, presenting research, industry actors (both technology providers and end users) and public authorities. The strategy focuses on three areas: (i) developing fundamental knowledge through local–global collaboration, (ii) generating quantum research talent and professionals, and (iii) establishing an innovation district to promote

Table 1. Focus, actors and activities of case ecosystems.

Case	Focus areas	Key actors	Activities
Basque Country	Industrial applications and hybrid solutions (business ecosystems in smart industry, clean energy, personalised health)	Basque Government, provincial councils, universities and basic research centres, RTOs, start-ups, providers, end users and IBM	Several (over 30) small pilot projects with end users, some medium-sized research projects
Finland	National and international research infrastructures and ecosystem focusing on building and testing quantum computers	Research council of Finland and Business Finland (funding agencies) as enablers, 1 RTO and 5 universities, app 20 company members	Two national projects InstituteQ and FQF linked together, over 10 research projects funded, app. 50 companies involved in projects
The Netherlands	Research-based business growth and known as forerunner (cross-sectoral innovation ecosystems)	Five innovation hubs make up the main QDNL ecosystem: each hub consists of research institutes, universities, companies and start- and scale-ups.	QDNL is the main ecosystem, programmes focusing on research and innovation, ecosystem development (incl. commercialisation), talent building, and ELSA

innovation in Southern Europe and stimulate the economy by launching new businesses and ventures.

The ecosystem members in Finland include two funding agencies as enablers, one Research and Technology Organisation (RTO) and five universities as key players, as well as over 20 company members, both quantum hardware (including enabling technologies) and software start-ups. Three main operations are at the core of the Finnish quantum ecosystem: (i) business and innovations, (ii) research and infrastructures, and (iii) education and training.

In The Netherlands, the national quantum ecosystem consists of five innovation hubs: each hub includes research institutes, universities, companies, start-ups, and scale-ups. The three technology catalyst programs are tied together by four action lines: (i) research and innovation, (ii) ecosystem development, (iii) human capital, and (iv) societal impact.

Table 2. Data sources.

Case	Interviews	Organisations presented
Basque Country	Six	IT company/University, start-up, Quantum technology provider, orchestrator, regional policy maker, research and technology organisation (RTO)
Finland	Ten	Start-up, orchestrator, coordinator, funding agency, university, national policy maker, research and technology organisation (RTO)
The Netherlands	Nine	Start-up, orchestrator, coordinator, consultant, university, ministry (national policy maker), research and technology organisation (RTO)

### Data collection and analysis

We conducted semi-structured interviews ( $n = 25$ ) with actors who participated in the planning and development of the strategic activities of the quantum ecosystems in three European territories (Table 2). Data collection was conducted by compiling publicly available information on quantum technology activities across three ecosystems, sourced from on various documents, web pages, and social media channels (see Table 1 for a summary). The interviewees were selected based on the preliminary analyses of these secondary data sources. In addition, discussion with national experts influenced the selection of interviewees.

The interview guide for the ecosystem actors included the following themes: (a) the structure and evolution of the ecosystem(s) and their collaborative efforts, (b) technologies, their applications, and related industries, and (c) the expected outcomes and impacts. The interviewees included project or programme managers, ecosystem orchestrators, and company representatives who had key roles in ecosystems. The interviews typically lasted between 1 and 1.5 h.

The empirical material was collected and analysed by three researchers who applied interview data transcriptions and data coding. First, we conducted a brief within-case content analysis of the interview data. Then, to improve the theoretical triangulation, our multidisciplinary research team analysed the results through the preliminary research framework of ecosystem roles within three phases of ecosystem co-evolution (Fig. 1).

### Findings

The three case ecosystems (the Basque Country, Finland, and The Netherlands) have different strengths and weaknesses, but their focus and structure were

complementary. This provided us with diverse insights into ecosystem characteristics, the roles of actors, and their joint innovation paths, ranging from technology research to business opportunities.

### Characteristics of ecosystems (RQ1)

Our results confirmed that interviewees described a quantum ecosystem as having characteristics of different ecosystem types. First, during the research phase, a knowledge ecosystem that creates new knowledge was highlighted, especially by universities but also by technology providers (including start-ups). Then, during the development phase, interviewees emphasised either an innovation ecosystem that creates value based on complementary resources or an entrepreneurial ecosystem that enhances entrepreneurial activities and start-up networks. Here, the role of spin-offs was particularly noted. Finally, during the innovation (commercialisation) phase the interviewees were highlighting how different sectoral business ecosystems are renewed by emerging technology. This was highlighted by ecosystem orchestrators, technology providers (including spin-off companies), and representatives of RTOs. It was also noted that industrial end users currently have limited involvement in quantum ecosystems. Furthermore, each case highlighted the importance of regional ecosystems, which have a location-based focus and aim to enhance regional competitiveness.

The three cases also had different focuses between these ecosystem types, and the roles of involved actors differed. As *an innovation ecosystem*, The Netherlands ecosystem is building on complementary resources of different quantum technologies within a network of research organisations and universities. This network is referred to as the Quantum Delta Netherlands (QDNL). Similarly, industry collaboration is active within Quantum Delta activities. Basque ecosystems focus on enabling the potential end-users easy and cost-efficient access to quantum computers, and hybrid models were highlighted. In other words, the focus was, as *a regional ecosystem*, the competitiveness and attractiveness of the region and industrial actors within it. The Finnish quantum ecosystem, as *a technology knowledge ecosystem*, focuses resources mostly on quantum computing solutions and several enabling technologies. Therefore, it has an excellent knowledge base linked to research and education organisations. In addition, all three ecosystems have characteristics of an entrepreneurial ecosystem, and the active start-up and spin-off scene offers potential for emerging new start-ups. However, the ecosystems share the challenges of limited resources in European venture capital activities.

### **Roles of actors in three main phases (RQ2)**

The above-described characteristics of the three quantum ecosystem cases were interlinked with the variety of roles the interviewed ecosystem actors highlighted (Table 3). The views are linked with three phases of co-evolution: (i) Research in the focal quantum technology ecosystem, (ii) Development in the cross-sectoral innovation ecosystem, and (iii) Innovation in the sectoral business ecosystem. As quantum technologies are still in the emerging stage, the core ecosystems have been built around scientific research on core and complementary (enabling) technologies. However, research related to different quantum technologies has emerged from several different basic research traditions. Consequently, it was noted that collaboration in quantum ecosystems involves actors who are unfamiliar with to each other and have diverse backgrounds in research.

During the research phase, the significance of insightful individuals was highlighted, and personal-level connections were mentioned as strong enablers for collaboration. In contrast, the innovation phase was driven by the interests of organisations, which guided the focus of collaborative efforts within the sectoral business ecosystems. Here, regional industrial clusters were identified as an excellent innovation platform, enhancing the involvement of end-user companies. Thereby, during the development phase, between these two ends, this shift from individual to organisational level caused some confusion related to shared aims, interests, and involvement of actors.

Furthermore, university representatives typically noted challenges with ownership of results when moving from research to innovation. Because quantum technologies serve as enabling technologies across multiple sectoral business ecosystems, it is critical to identify the most relevant problems, opportunities, risks, and beneficiaries to boost end-user engagement and attract private investment. Many funding instruments also require private (company) funding, serves as a motivation factor for universities as knowledge producers to engage with industries broadly. Clearly stating the attractiveness of such emerging technologies is challenging, as their potential impacts and timelines vary across different industries.

### **Roles of actors supporting future business (RQ3)**

Through cross-case analyses, we then summarised the direct value co-creation and supporting roles that the leading actors had in three phases of ecosystem co-evolution (Table 4). This summary demonstrates that exploring the future business potential and impacts is still a rather distributed activity in all three cases. However, it also highlights how the roles of actors change during the co-evolution.

Table 3. Overview of actor roles within the co-evolution of ecosystem.

Case	Research	Development	Innovation
Basque Country	In addition to their core role in researching certain Quantum Technologies (knowledge production), universities highlighted supporting roles such as international networking activities that enhance talent building BasQ ecosystem facilitation activities were also run by person with academic background, and regional governments were active in launching them	The cross-sectoral innovation ecosystems were formed around practical challenges based on specific knowledge of universities in physics and materials The role of big companies was highlighted in building up these innovation ecosystems A global technology provider plays a central role in enabling demonstrations of technology and networking with other technology centres	Regional policymakers place emphases on end- user commitment, and RTO has a key role in supporting industrial pilots and further engaging potential end-users The regional industrial clusters were used as innovation platforms The role of venture capital funds and other financial instruments in supporting the growth of the quantum industries was highlighted, especially from the perspective of start-up companies

Table 3. (Continued)

Case	Research	Development	Innovation
Finland	<p>The activities of one university professor, an RTO representative, and some start-up actors were the starting point for the ministry's investment decision</p> <p>The focus was on technology investment (developing a superconducting quantum computer), while RTO and the university were core actors</p>	<p>RTO and two universities had their own focus areas in which they planned to explore quantum technology as a disruptive technology</p> <p>Ecosystem orchestration is led by a core group consisting of the representatives from three research organisations</p>	<p>The existence of technology provider companies was mentioned as a strength of the ecosystem.</p> <p>However, the ecosystem's resources to support start-up companies were mentioned to be quite limited</p> <p>A long-term commitment is required from the public side, as private investments require direct value addition and linkages to the strategic agendas of cross-sectoral business ecosystems</p>

Table 3. (Continued)

Case	Research	Development	Innovation
The Netherlands	The university, RTO, and the local government played a central role in launching the activities and provided the initial funding	A hub between start-ups and universities has been an important instrument for collaboration providing access to knowledge	Involving direct business value creation roles (industry actors as end-users) was still in its very early phases There is a wide variety of different quantum technologies which have utilisation potential in many industrial sectors

Source: Analysis of interview data.

*Roles of Quantum Ecosystem Actors Opening Innovation Paths from Technology to Impacts*

Table 4. Summary of actor roles supporting ecosystem.

Roles	Research: Quantum technology ecosystems	Development: Cross-sectoral innovation ecosystems	Innovation: Sectoral business ecosystem
Direct value co-creation roles	<p>Knowledge producers (universities, RTOs) have limited interests in business impacts</p> <p>Technology providers (large companies) are providing infrastructure services (access) and consulting</p> <p>Complementors (start-ups, spin-offs) are looking for collaboration opportunities both for research and business</p>	<p>Knowledge, and technology providers have similar roles in research</p> <p>Spin-offs from knowledge producers looking for business potential</p> <p>End users are exploring future opportunities without clear development agendas</p>	<p>Actors of sectoral business ecosystems (manufacturers, service/technology providers, complementors, or end users) focus on exploring potential, and some pilots are launched</p> <p>Regional industrial clusters were used as innovation platforms to identify business potential; RTOs have an active role in the coordination of such activities</p>
Supporting roles	<p>Universities and RTOs have roles as facilitators and intermediators, including activities related to international (research) networks</p>	<p>Universities and RTOs have roles as ecosystem promoters, builders and orchestrators; separate organisations were launched for this purpose</p>	<p>Technology provider companies have roles as knowledge producers offering business services for exploring business impacts</p>
Other stakeholders	<p>Public funding organisations were identified as important actors, in addition to financial support, they had roles in agenda-setting and international network-building</p> <p>Governmental decision-makers (both national and regional) have similar activities than funding agencies</p>	<p>Public funding organisations, and governmental decision-makers have roles as promoters, sponsors and funders</p>	<p>The role of venture capital funds and other financial instruments is crucial in supporting the future growth of the quantum industries</p>

Direct value co-creation roles naturally had different emphases over ecosystem phases from research to innovation. In addition to their core role in knowledge production, universities and RTOs act as ecosystem facilitators, intermediators, promoters, builders, and orchestrators. Technology providers offer supporting business services to explore impacts and develop their own technology capabilities through research. These activities have also had an indirect influence on building awareness of business opportunities. Public funding organisations were identified as crucial players, providing financial support, setting agendas, and building international networks. Governmental decision-makers, both national and regional, share similar roles with funding agencies, promoting, sponsoring, and funding initiatives. Also, regional industrial clusters serve as platforms for innovation, helping identify business potential. Venture capital funds and other financial instruments are necessary to support the future growth of quantum industries, as well as technology implementation and renewal in different industrial sectors.

Our findings indicated that within emerging technology, the knowledge producer plays a fundamental role in the collaborative process from research to innovation. Anyhow, the actors within this role changed during the ecosystem evolution. As noted above, during the research phase, individuals who could bridge and mediate between different ecosystem actors were especially important. Although universities and research organisations typically had the role of knowledge producers, these individuals had different backgrounds, rather than purely academic backgrounds in the specific research area. Thus, the technology providers were mainly research organisations and large corporations or spin-offs from RTOs or universities. Therefore, their resources and capabilities were partially unbalanced, which influenced to activities and willingness to take different roles. The lack of early adopters among end-user companies was mentioned as a barrier to the utilisation of technology. Similarly, it was indicated that there are challenges in explaining the future opportunities of technology to end-users.

The three core ecosystems organised supporting roles — such as facilitators and intermediaries — in distinct ways, and their funding models varied widely. These funding differences affected both the resources available and how each ecosystem structured its activities. Despite differences, all interviewees emphasised a common goal and activities to enhance ecosystem development and attractiveness. One reason for this was that talent acquisition was identified as a challenging process. On the other hand, in all ecosystems, there was also an actor(s) specialised in supporting future value creation and exploring business impacts. These actors also substantially impact the opening of innovation towards business opportunities. Although public funding is necessary in the early stages of highly complex technology, it cannot be relied upon in the longer term, as agendas typically change with each new government.

Furthermore, the ultimate markets for innovation outcomes are outside of quantum technology ecosystems. If ecosystems concentrate solely on technology development, they risk stunting business growth. The end users from different sectors need to be involved early in identifying the high-value business opportunities and understanding the potential disruptions. In doing so, all ecosystem participants align around the goal of translating emerging quantum technologies into real-world impacts. However, it should be noted that although the ecosystem actors agree on shared goals, conflicting interests and expectations exist. Therefore, further studies exploring the impacts of ecosystem collaboration in terms of outcomes and different impact dimensions are required.

## Discussion and Conclusions

In this multi-case study, we explored how the different roles that quantum ecosystem actors have to enhance the opening of the innovation path from technology to future business opportunities. Thereby, our study fills gaps in research on the co-evolution of quantum ecosystem structures, including actors, roles, and collaborations (Jiménez Farías *et al.*, 2024; Jiang and Chen, 2021).

The quantum technology innovation process, from early knowledge exploration to commercial exploitation, unfolds over timelines that extend far beyond the scope of current ecosystems' operations. Therefore, our findings suggest that dynamics within ecosystems' innovation activities require going beyond the linear process model. Our study demonstrates how we can identify potential development paths by mapping ecosystem actors and their activities. This adds to our current discussion on ecosystems, which still focuses on structures and typologies rather than co-evolution (Hou and Shi, 2021). Furthermore, regarding the direct value creation role, our preliminary research framework noted a knowledge producer as an additional role, compared to the roles identified by Dedehayir *et al.* (2018), and our empirical data emphasised the importance of this complementary role.

However, we highlight the need to reflect the connections between the actors and make their different roles more transparent. Here, our results align with those in the previous literature, which emphasise that understanding the roles and resources of ecosystem actors contributes to the development of the emerging ecosystem (Pisa *et al.*, 2024). Our study completes the discussion by clearly indicating that the same actor can have different roles in three different phases of emerging technology evolution. As noted, the research discussion on the roles of ecosystems is still quite scattered (Ritala *et al.*, 2022; Medina *et al.*, 2022), and a longitudinal study over the ecosystems' co-evolution would be an interesting

avenue for future research. Based on our preliminary research framework, it would be beneficial to study this development further from the perspectives of all involved actors and analyse critical events that influence the co-evolution of an ecosystem.

### **Practical implications**

The practical implications of our study are threefold. First, managers and innovation professionals — particularly those working with quantum technologies — can use these insights to navigate the junction where deep technical expertise meets real-world end-user needs. Positioning innovation at this intersection is key to building cross-sectoral impact. Second, companies active in these ecosystems can leverage our role framework to rethink how they contribute during both technology development and ecosystem design, ensuring they add maximum value at each stage. Finally, policymakers and regulators can draw on our findings to craft targeted policy instruments that bolster national competitiveness and translate emerging technologies into societal and economic benefits. Together, these recommendations offer a roadmap for turning quantum-technology promise into lasting impact and future competitiveness. The analyses of actors and their roles can be utilised to further tailor the ecosystem structures to different circumstances, understand the impacts at multiple levels (business, government, and society) and define scales (local, national, regional, and international) in order to achieve successful innovation paths from technology to business impacts.

### **Limitations**

There are limitations to how much we can generalise from this qualitative case study. Further research is needed to more systematically test and refine the actors' roles in different emerging technology contexts and within different time frames. Especially the longitudinal studies would shed more light on the dynamics within the co-evolution. Through such analyses, a variety of possible pathways could be identified around emerging technological opportunities, related ecosystem activities, actors, and their roles. However, longitudinal studies may be rather challenging to organise when the influence of technology emergence from research to innovation can vary from months to decades.

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