

GLOBAL AND LOCAL FORCES SHAPING QUANTUM TECHNOLOGY
DEVELOPMENT: INSIGHTS FROM THE RESEARCHER PERSPECTIVE

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ABSTRACT

GLOBAL AND LOCAL FORCES SHAPING QUANTUM TECHNOLOGY DEVELOPMENT: INSIGHTS FROM THE RESEARCHER PERSPECTIVE

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The second quantum revolution has created an opportunity to produce technologies that promise significant benefits across various sectors. It has opened a transformative chapter in technological development, offering rich opportunities while posing complex challenges. This study explores how local and global dynamics shape the development trajectory of quantum technologies (QT), highlighting their influence on the research ecosystem. By analyzing the experiences of researchers, it examines how these dynamics impact work practices, collaborations, and technological outcomes. Factors such as funding structures, policy strategies, and global competitiveness are assessed, revealing how researchers' working conditions and perspectives both shape and are shaped by these forces. This qualitative study employs online interviews conducted via conference platforms to generate data. Ten experts from various backgrounds and working in different countries, all specializing in quantum technology constitute the sample. The data generated is evaluated and analyzed within the Social Shaping of Technology (SST) framework, which suggests the powerful existence of fluidity and regime

elements in an emerging technology. In the case of quantum technologies, the unpredictability of the technology itself, the dynamic roles and relationships among actors within the QT development ecosystem, and the structural factors tied to both QT-specific and broader stability collectively shape the development trajectory in a complementary manner. Based on the analysis of researchers' experiences and perceptions, this study aims to propose policy models that guide QT development toward maximizing its potential while fostering ideal working conditions and collaborative environments that align with researchers' expectations and needs.

Keywords: Quantum technologies (QT), social shaping of technology, policy development, research ecosystem, global-local dynamics



ÖZ

KUANTUM TEKNOLOJİSİNİN GELİŞİMİNİ ŞEKİLLENDİREN KÜRESEL VE YEREL DİNAMİKLER: ARAŞTIRMACI PERSPEKTİFİNDEN GÖRÜŞLER

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İkinci kuantum devrimi, çeşitli sektörlerde kritik faydalar sağlayabilecek teknolojilerin üretilmesine olanak tanır. Bu devrim teknolojik gelişimde yenilikçi bir dönem açarak zengin fırsatlar sunmakla birlikte teknolojik gelişim ve var olan sisteme entegrasyonu konusunda belli zorluklar da getirmiştir. Bu çalışma, kuantum teknolojilerinin (QT) gelişim sürecini yerel ve küresel dinamiklerin nasıl şekillendirdiğini incelemekte ve bu dinamiklerin araştırma ekosistemi üzerindeki etkilerini ele almaktadır. Nitel bir çalışma olan bu araştırmada, veriler çevrimiçi platformlar üzerinden yapılan görüşmeler ile üretilmiştir. Kuantum teknolojileri konusunda farklı ülkelerde çalışan on araştırmacıdan oluşan bir örneklemden üretilen veriler Sosyal Teknoloji Şekillendirme (SST) çerçevesi içerisinde analiz edilmiştir. SST çerçevesinin çizdiği modelin Kuantum teknolojilerine uygulandığı durumda, teknolojinin kendisindeki belirsizlik/değişkenlik, buna bağlı olarak QT ekosistemindeki aktörlerin dinamik rolleri ve QT'ye özgü ve özgü olmayan yapısal faktörler birlikte, tamamlayıcı bir şekilde gelişim sürecini şekillendirmektedir. Bu bağlamda fon yapıları, politika stratejileri ve küresel rekabet gibi faktörler incelenmiş

ve arařtırmacıların alıřma kořullarının bu glerle nasıl řekillendięi ve bu glere nasıl katkıda bulunduęu ortaya ıkarılmıřtır. Arařtırmacıların deneyim ve algılarının analizine dayanan bu alıřma, QT'nin potansiyelini en iyi řekilde kullanmasını saęlayacak ve arařtırmacılar iin ideal alıřma kořulları ile iř birlięi ortamlarını destekleyecek politika modelleri nermeyi amalamaktadır.

Anahtar Kelimeler: Kuantum teknolojileri, teknolojinin sosyal řekillendirilmesi, politika geliřtirme, arařtırma ekosistemi, kresel-yerel dinamikler





To My Beautiful Family

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LIST OF ABBREVIATIONS

AEOI	Atomic Energy Organization of Iran
ATRC	Advanced Technology Research Council
CETQAP	Centre of Excellence for Technology, Quantum, and Artificial Intelligence Pakistan
CNRS	Centre National de la Recherche Scientifique
EDI	Equality, Diversity and Inclusion
GTQTSB	Global QT Standardization Body
IQTEC	Iranian Quantum Technologies Research Center
NMR	Nuclear Magnetic Resonance
NTI	National Technology Institute
NQCC	National Quantum Computing Centre
NQI	National Quantum Initiative
NQL	National Quantum Lab
NQS	National Quantum Strategy of Canada
NQTP	National Quantum Technologies Programme
NUST	National University of Science and Technology
QED	Quantum Electrodynamics
QEP	Quantum Engineering Programme
QIS	Quantum Information Science
QKD	Quantum Key Distribution
QRC	Quantum Research Center
QT	Quantum Technologies
R&D	Research and Development
RQC	Russian Quantum Center
SA QuTI	South African Quantum Technologies Initiative
SCOT	Social Construction of Technology
SMEs	Small and Medium-sized Enterprises

SQUIDS	Superconducting Quantum Interference Devices
SST	Social Shaping of Technology
TII	Technology Innovation Institute
UEAM	METU Applied Ethics Research Center
WESP	World Economic Situation and Prospects



CHAPTER 1

INTRODUCTION

"Quantum mechanics forced physicists to reshape their ideas of reality, to rethink the nature of things at the deepest level, and to revise their concepts of position and speed, as well as their notions of cause and effect".

Kleppner, D. (2000). "One Hundred Years of Quantum Physics." In, Science, 289(5481), p.893.

To evaluate the effects of such a development that is transitory in mechanical, societal, and philosophical aspects of our lives would be a very intricate act. However, it is equally necessary to observe the new power dynamics caused by this development in everyday life and to reassess positions with the mentality of a "better/progressed life". Theories are developed in order to answer our basic questions on how the world works. The next step is to find out how the answer could be used to make things "better". The technologies, inventions, and innovations emerge with the primary aim of progress. However, in the background, there occurs more questioning about "what is better? whose better is this? and progress to where?". Saving these questions to the rest of this work, it should be explained what quantum mechanics is and why it is chosen for this study to direct my research questions with the filter questions of the above.

Philosophically, the power of quantum theory to radically change the way we perceive our surroundings can be understood from the fundamental difference between quantum and classical theory. To explain briefly, classical mechanics, which was formulated in the 17th century by Newton and Galileo, studies the motion of objects on macroscopic scales. It relies on deterministic principles, where the future state of a system can be precisely predicted if the initial conditions are known

(Chow, 2013). On the other hand, quantum mechanics examines the particles on microscopic scales, such as atoms and subatomic particles, with the main task of figuring out the spectrum of light given off by hot objects, which is known as blackbody radiation. Vermaas (2017) explains that, in classical physics, physical systems are categorized as either particles or waves. However, quantum theory introduces a fascinating twist by allowing these systems to exhibit particle-like and wave-like behavior. It challenges classical physics, in which particles have well-defined positions and velocities, by introducing uncertainty into the positions and velocities of particles and upping the ante by superposition, where physical states can exist in combinations. Therefore, "...quantum mechanics replaces the deterministic worldview of classical physics in which the behavior of systems is with certainty fixed through time, with a worldview by which systems behave in a fundamentally stochastic way" (Vermaas, 2017, p. 243). For example, the double-slit experiment illustrates this principle. It is observed that when electrons are shot at a barrier with two slits in it, they make an interference pattern as only waves do. This means they go through both slits simultaneously, indicating a stochastic behavior rather than a deterministic one. In addition, Heisenberg's uncertainty principle, which suggests that one cannot know arbitrarily precisely simultaneously position and momentum, is another indicator that things are going from deterministic to probabilistic understanding in the physical systems. "Such indefiniteness or indeterminacy is core to what is supposed to be distinctive about quantum phenomena..." (Calosi & Wilson, 2021, p.3292).

This research examines the multidimensional landscape of quantum technology development under the impacts of global and local dynamics. It aims to offer comprehensive insights into the dynamics shaping QT on both national and international scales through the eyes of the researchers. By analyzing the current trajectory, the study seeks to identify critical areas of focus for maximizing the potential of these technologies, by ensuring an optimal development path for the researchers.

In short, this study questions the mutual relationship between how the national and international dynamics and QT shape each other. The starting point should be

understanding why quantum technologies hold the potential to be highly influential and how they remain open to being shaped by various social, political, and economic factors in both local and global levels. By examining these underlying reasons, it becomes possible to grasp their trajectory and potential impact in a better way.

1.1. Historical Background

Just like any other theoretical development, the history of quantum mechanics is marked by a complex and unpredictable path. “The creation of quantum mechanics by a handful of theoretical physicists in the years of 1924-1926 was perhaps the most wonderful burst of creativity in the history of mankind”, says Binney & Skinner (2014, p.5). The foundations of quantum mechanics were laid out through the work of multiple physicists in the early 20th century. As they explain, quantum mechanics emerged as a mathematical framework through a series of inspired conjectures and reinterpretations aimed at reproducing experimental data. Among the earliest influential works stands Albert Einstein's 1905 paper on the photoelectric effect, a pivotal contribution to the emergence of quantum theory. Following Louis de Broglie's groundbreaking advancements, the years spanning from 1925 to 1928 witnessed the establishment of quantum mechanics' foundational principles: the exclusion principle, matrix mechanics, wave mechanics, the uncertainty principle, and Paul Dirac's relativistic wave equation. In 1948, Richard Feynman introduced a third formulation of quantum mechanics, complementing Werner Heisenberg, Max Born, and Pascual Jordan's matrix mechanics and Erwin Schrödinger's wave mechanics, known as the path integral formulation (Nature Reviews Physics, 2023; Kleppner, 2020). While these milestones are noteworthy, it's crucial to recognize that the development of quantum mechanics resulted from a collective pursuit of answers during a challenging period.

As a result of these efforts, advancements of and out of quantum theory are generally categorized into two parts, the first and the second quantum revolutions. Quantum technologies, often classified as primary and secondary revolutions, reflect this transformative transition. The first quantum revolution, which began in the early 20th century, had a profound impact on technology and daily life. Visionaries such as

Erwin Schrödinger and Werner Heisenberg gave a start to this era by introducing quantum mechanics, which revealed wave functions, the uncertainty principle, and the unpredictable nature of quantum events. This sparked a scientific revolution that yielded advances such as lasers and computers, which is named as the first quantum revolution (Shankar, 1994; Schleich et al., 2016). Technologies associated with the first revolution, ranging from nuclear magnetic resonance (NMR) to superconducting quantum interference devices (SQUIDS), laid the foundations. However, the phrase “quantum technologies” predominantly refers to the advances of the next generation (Dowling & Milburn, 2003).

In the second half of the 1940s, a new dimension in the quantum field emerged: Quantum Electrodynamics (QED), the discovery of Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga (Kleppner, 2000). However, it was only in the 1980s that secondary quantum metamorphosis gained momentum, promising profound effects predicted to last until mid-century (Dowling & Milburn, 2003). Dowling and Milburn (2003) argue that the primary distinction between the first and second quantum revolutions lies in the transition from passive understanding of how things work to active manipulation of our surroundings through strategic utilization of quantum principles. The claim is that the "second quantum revolution brought the realization that human beings do not have to be passive explainers of the surroundings anymore; they can create and shape as well" (Dowling & Milburn, 2003, p.1656). Although through this claim, the authors' suggestion of human beings being mere passive observers is exaggerated and debatable, the technologies belonging to the second revolution could indeed have a higher degree of manipulation and shaping. Therefore, the first quantum revolution, fuelled by theoretical efforts to explain experiments on black-body radiation, presented fundamental quantum concepts and pioneering technologies. The second quantum metamorphosis, led by the “active manipulation”, represents a paradigmatic shift that pushes us to explore new opportunities and expand our understanding of the physical universe.

Quantum technologies (QT) stand on the threshold of revolutionizing numerous industries, promising advancements in computing, communication, sensing, and

beyond. The first quantum revolution, which yielded foundational technologies such as microwaves, lasers, and magnetic resonance imaging (Akçomak, S & Seskir, Z., 2021), laid the groundwork for the emergence of game-changing quantum technologies. “Quantum information science” means the storage, transmission, manipulation, or measurement of information that is encoded in systems that can only be described by the laws of quantum physics (NQIA, 2018, H.R. 6227). In a broader sense, quantum technologies encompass three main branches, Quantum Computing/Simulating (Quantum Bits, Quantum Algorithms), Quantum Communication Systems (Quantum Cryptography, Quantum Key Distribution), and Quantum Sensors, Imaging & Measuring (Quantum Radar, Quantum Simulation, Quantum Microscopy, Quantum Metrology) (EC, 2016; HLSC, 2017; Seskir et al., 2023). The subfields of QT are explained in the section 2.2. Subfields of Quantum Technologies in detail.

1.2. Research Questions

This study explores the role of national & international dynamics in shaping the development and adoption of QT across various nations in the period of the second quantum revolution. This involves analyzing how geopolitical contexts and interactions affect national strategies and priorities regarding the development process of QT. It seeks to uncover the ways in which factors that contribute to these variations, including economic, social, and political influences impact the design and access to these technologies, as well as the distribution of assets resulting from their development.

- How do researchers consider the local, and global factors that shape the development of quantum technologies?
- How is the research ecosystem impacted by these factors?

The study employs the Social Shaping of Technology (SST) theory as its theoretical framework to explore the occurrences and implications of quantum technologies. The Social Shaping of Technology (SST) framework provides a theoretical basis for this study’s focus on how national and international dynamics influence the development

and adoption of QT. According to Howcroft & Taylor (2023), SST theory allows for the analysis of how technology's development and application are influenced by broader socioeconomic factors and political contexts. While its theorists do not accept the straightforward causality proposed by technological determinism, which suggests the uni-directional effect of technology over social aspects of life, they also recognize that the technical side of technology plays a significant role. In addition, it cares for the effect of formerly constructed infrastructures, organizational practices, and technology applications, as well as the effect of stakeholders' choices reflecting their interest within the power dynamic on technology development. By applying SST, this research examines the complex interactions between various stakeholders, including researchers, policymakers, and industry actors, as well as the geopolitical influences that shape national strategies regarding QT. The research question, "How do researchers consider the local, and global factors that shape the development of quantum technologies?", is derived directly from SST's premise that technological development is inherently influenced by the social contexts within which it operates. SST's emphasis on how these forces shape not only the creation but also the adoption of new technologies provides a critical framework to investigate the disparities and commonalities across nations in their approach to QT, reflecting the varying priorities and constraints faced by different countries.

Within the framework of the research questions, I found it appropriate to apply the qualitative method in this study to examine how social, economic, and political factors influence researchers from different countries in shaping the development process of QT with all its intricacy. Because, the qualitative method provides in-depth insights into the analysis by uncovering the experiences in detail, and gives detailed narratives about the experiences of the researchers, as the most important data source of this study. With these detailed narratives, the complexity of the relationships of current dynamics is expected to show itself the best. The qualitative data collection method even provides information through the usage of the language, their word choices, the changes in the energy of the interview among questions, pauses, and tones of the interviewees. All of these elements are further inputs for the study that indicate, comfort/discomfort, hesitation/confidence, struggle, fluidity, etc., therefore resulting in data that is richer in quality. This kind of data expands

knowledge by providing a grounded understanding of how the theoretical framework, Social Shaping of Technology (SST), operates in practice, showing the way technologies evolve in response to social, economic, and political factors impacting the development process.

Data is generated through online interviews with 10 purposefully selected participants based on their affiliation with academia or the sector and their geographical location, ensuring a balanced representation from various continents. The interviews were conducted via an online conference app, and the results were coded and analyzed using a qualitative data analysis software, MAXQDA.

The data generated is thematically coded within the framework of SST. The first theme reflects the current snapshot of the 'QT Researcher Environment' through global and local Dynamics which are the subthemes of this section. The second theme is the 'Fluidity' aspect of QT development that is explained by fluidity in technological/scientific capacity building, in meaning creation, and in adoption for strategy of QT development. The last theme is 'Structure and Stability' aspect of QT development which is separated as QT-specific and Non-QT-specific structural elements. In the upcoming sections, details and subfields of QT, and their sectoral and social implications are reviewed in Chapter II: Literature Review. Chapter III: Methodology includes the theoretical framework and its operation in shaping the structure of this thesis, data generation process, and limitations. The strategies, efforts, and national initiatives of the selected countries are provided in Chapter IV: Background for Selected Countries to be the base in analyzing the data. Chapter V: Findings & Analysis data generated is explained and gained meaning by the analysis within the theoretical framework. Finally, this analysis opens up the possibility of suggesting a policy in Chapter VI: Analysis & Discussion.

CHAPTER 2

LITERATURE REVIEW

QT is significant and is found worth to invest since breakthroughs are expected in a wide number of areas such as computation, communication, healthcare, and security (Arute et al., 2019). Acín et al. (2018) suggest that investing in these technologies is considered foundational for maintaining technological, economic, and strategic advantage by governments and companies around the world; thus, it drives serious investment in research, development, and implementation. One of the motivating factors for my study regarding the existence of interest and investment was to explore how investment choices and strategies could affect the development of technology and its capacity to reach full benefit. In order to understand the field better, this section includes details about the subfields of QT and their sectoral and social implications.

The emergence of QT subfields result in the creation of various dynamics. Through the course of this study, I find it appropriate to search for and apply the most inclusive and generalizable dynamics and the patterns. For this, I tried to represent the changes through technologies with my question set and participant selection.

2.1. Subfields of Quantum Technologies

During the second quantum revolution, significant progress has been made in the field of **quantum computing**.

Researchers and companies have made progress in creating practical quantum computers with the ability to solve complex problems much faster than classical computers. Quantum computation and simulation are anticipated to integrate into

critical industries such as finance, pharmaceuticals, transportation, and energy (CIR, 2018). The increasing amount of data also results in the possibility of an application as "quantum humanities", which Barzen and Leymann (2019) address as a tool to "find a common language to communicate between these disciplines" (p.3). It is basically the research in the humanities with methods and techniques from quantum computing.

In the area of **cryptography**, the principles of quantum entanglement enable encoding and decoding of the data in an extended range by generating encryption keys, "securing" data transfer/ communication, and "protecting against" cyber threats through the Quantum key distribution (QKD) method (Cava et al., 2021).

Quantum mechanics are used to enhance **sensors**, which provides high precision that cannot be seen in the classical counterparts. Applications of these technologies are in the areas of GPS systems, navigation, monitoring, security and defence. In addition, quantum mechanics are applied to enhance the imagining techniques, quality control and further sensing technologies like medical imaging, healthcare, biotechnology, and remote sensing (Roberts, 2019). Furthermore, its measurement accuracy is used in the area of metrology and earth measurements in general. Quantum simulators contribute to research on drug development and materials science by modelling processes (Brown, 2021).

2.2. Sectoral and Social Implications of QT

Marrone and Hazelton (2019) claim that technologies are not inherently disruptive but rather transformative. In the case of QT as well, although the revolution phrase suggests a "revolution" that makes every other previous technology formed by classical physics meaningless and useless, Quantum technologies are unlikely to replace their predecessors. Instead, they may require significant resources from classical counterparts to function effectively. Therefore, QT have also been referred as transformative technologies by many (Guy, 2018; Preskill, 2018; Seskir et al., 2023) due to their potential to significantly affect various sectors such as healthcare, defence, finance, and energy. In the healthcare domain, QT can advance diagnostic

and treatment tools, leading to more precise diagnoses and improved treatment outcomes (Flöther & Griffin, 2023). Within the defence sector, QT can enhance communication systems, sensors, and navigation devices, bolstering the safety of military personnel (van Amerongen, 2021). In finance, QT can refine risk management and portfolio optimization algorithms, fostering better investment decisions (Gschwendtner et al., 2023). Moreover, Hidary & Sarkar (2023) emphasize the potential of QTs generating job opportunities in their World Economic Situation and Prospects (WESP) article. Therefore, beyond sectoral implications, QT may provoke social and ethical shifts, altering employment dynamics and cultural norms, and thus reshaping societal ethical agreements. While forecasting these changes may seem bold, technology profoundly influences society, impacting political, social, and cultural realms. Technology is inherently value-loaded, reflecting the values and aspirations of the society that develops and employs it.

What is important for this study is coming from the meaning/value creation of the artifacts (inventions, innovations, technologies...). Since the emergence of meaning comes from a common ground in understanding, different kinds of meanings may be attached to the same technology and the value formation plays a pivotal role in the imagination, designing and usage of this technology. The attached meaning is generally built upon the usage of the technology which creates more various grounds to be formed. It is significant because the same technology can create a utopian or a dystopian world in different imaginations and construction scenarios. “Each application of quantum technologies has dual-use characteristics, contemplating both socially beneficial and nefarious uses grounded in the same technological platform...” says Forge (2010, p.7). That is why, the nature of this study necessitates the explanation of QT, their possible usage, and imaginations in order to evaluate the creation process of policies in a more holistic way.

2.3. Review of Existing Literature

In this thesis, I aim to contribute to the existing literature on QT by focusing on the influence of local and global dynamics on QT development and adoption, with particular attention to the experiences and perspectives of researchers. The existing

literature predominantly focuses on the technical aspects of QT, with some exploration of its social, economic, and political dimensions. For example, Wolbring (2022) examines social engagement in QT research through the lens of Equality, Diversity, and Inclusion (EDI). This study uncovers the extent to which QT-focused academic literature incorporates EDI principles and how marginalized groups are represented in these discussions. It provides a critical foundation for understanding the social dimensions of QT. Similarly, Vermaas (2017) and Grinbaum (2017) discuss the societal impact of QT and the narratives employed to make quantum theory more accessible. Their works emphasize responsible communication and engagement. There are also studies that examine structural and policy-related aspects of QT. Suter et al. (2024) analyse narratives in government, business, and media, offering insights into how these sectors shape public perception and policy. Seskir et al. (2023) investigates democratization in QT, exploring access, grassroots movements, and corporate narratives. These works provide valuable perspectives on governance and accessibility but do not specifically address the interplay between researchers' work environments and the broader trajectory of QT development. In addition to these efforts, my research aims to fill this gap by focusing on the effect of both local and global factors—such as funding structures, policy frameworks, and international collaboration—on the research environment and the trajectory of QT development. Examining researchers' experiences will offer a unique perspective on how the interactions between these factors shape technological advancements and their application.

In addition, understanding the subfields of QT, such as quantum computing, quantum communication, and quantum sensing, and their sectoral implications helped in the imagination process of this work, and guided my research questions. It was important to see the foundational knowledge about QT in order to detect the point to focus on. In this case, it turned out to be the researchers' experiences and perspectives because the literature review indicated that the current stage of QT development allows two main players: the administrative/funder level (government and industry) and the researcher level. Quantum technologies that are going into certain channels, and the formation of research centers in addition to administrators' efforts signify a possible conflict between these parties. By considering both the technical and social

implications and synthesizing diverse perspectives, I will be able to identify the underlying forces shaping QT development from multiple angles, providing a more comprehensive understanding of the factors influencing the field. This will also allow me to propose a policy model that addresses both the technological potential of QT and the ideal working conditions necessary for researchers to advance the technology.



CHAPTER 3

METHODOLOGY

This study employs a qualitative approach to investigate the dynamics of QT development through the lens of the Social Shaping of Technology (SST) theory. The SST theory contributes to my study from several aspects, particularly by clarifying the interrelations between the factors that are inherent to QT and external to them within the research environment. Through its focus on socio-technical dynamics, SST provides a framework to analyze how these interconnected elements shape both the research setting and the advancement of technology. It does not only frame the relationality, it also signifies the roles of the actors, especially the researchers, and spaces. It takes the “relevant actors, their positions, and their interactions” into account for a proper analysis which makes it” sensitive to political processes through which actor-positions are identified, negotiated, and redefined, in conjunction with the way technology becomes manifest” (Jørgensen et al., 2009, p.82). The qualitative method allows for an in-depth exploration of the perspectives and experiences of individuals involved in the development and regulation of quantum technologies. The chosen method is used to conduct online interviews with purposefully selected experts from academia and the quantum technology sector across diverse countries. Countries were selected according to the criteria determined to be compatible with the purpose of the study. In what follows, I detail theoretical framework and illustrate the details about the interview and qualitative data process.

3.1. Theoretical Framework

The theory of Social Shaping of Technology (SST) theory is chosen as a theoretical framework because of its specific perspective on questioning and explaining the developments of technologies within the context of its relationality.

The SST emerged in the 1980s with the influence of MacKenzie & Wajcman. It came out in response to the Technological Deterministic approach. While technological determinism suggests that the development of technology stems from its own logic, follows a linear model of innovation and, therefore, drives social change, SST suggests otherwise. In this way, technological determinism is seen as an oversimplification that “contains a partial truth” (MacKenzie & Wajcman, 1985, p.2). Therefore, SST theorists opposed the simple cause-and-effect theory of historical change, which does not take political, economic, and cultural factors into account. From this perspective, adopting a technology, as well as creating one, includes forming a new - or transformed- economic, political, and even cultural structure.

Langdon Winner as one of the SST theorists argues that technology is inherently political (MacKenzie & Wajcman, 1985). Schraube (2021) explains Winner's three major dimensions of technological politics, intentional politics, unintended consequences, and democratic shaping. The second dimension is crucial as one of the bases for this framework. "Technological artifacts embody a political function because their doings are more than what was intended. The reciprocations exceed the projection. Artifacts represent a site of magnification and embody a surplus of meaning which can bring human imagination to its limits. Both, the intentional and unintentional doings of things are political. The unintentional doings are even more politically significant, because they unfold a power whose meaning for human life has not been adequately imagined, intensifying thereby the discrepancy between humans and technology" (Schraube, 2021, p.115). Furthermore, Howcroft & Taylor state the comparison of technological innovations with regulation or political institutions of Winner, “as they also influence how people work, communicate and consume over time: to choose a particular kind of technology is to choose a particular form of political life" (2023, p.354).

SST suggests that technology is not neutral but is created within the power dynamics. According to this theory, technology is both negotiable by particular groups and forces with various motivations and irreversible because it is fed by earlier technological choices (Williams & Edge, 1996). The negotiability aspect means that

decisions about the design, implementation, and use of technology are influenced by the interests and values of different stakeholders, such as governments, corporations, researchers, and users. The SST approach focuses on the negotiation processes going on among these actors and how these processes shape the final form and function of technology, in most cases for the benefit of the interests of dominant groups, potentially leading to the marginalization of other groups.

MacKenzie and Wajcman argue that the SST theory suggests five main mechanisms that are responsible for technology development. These are the science of technology, economics, social relations, the state, and gender (Howcroft et al., 2004). In this study, I prefer to focus on the mechanisms of state and social relations on the local and global scale. The Social Shaping of Technology (SST) approach is specifically valuable for analysing and addressing the dynamics of technology development. SST identifies "spaces and situations" where socio-technical change takes place, highlighting occurrences of "mobilization, displacement, and reconfiguration" of actors and institutions (Jørgensen et al., 2009, p.82). It suggests that research and development are not isolated scientific endeavours. They are inherently shaped by the interactions and roles of people, technology, and systems within actor-networks, consciously, or unconsciously (Jørgensen et al., 2009). This perspective highlights that the experiences and practices of researchers contribute directly to how technologies evolve, emphasizing the significance of their involvement in the transformation process. Hence, in this study, researchers' experiences are utilized to observe the influence of both spatial (local/global) and situational (political/socio-economic) factors on the development of QT.

3.2. Data Generation

Through interviews, the qualitative method aims to reveal how researchers working in academies, industry, and governmental/policy-making departments perceive the economic, and social forces shaping the development and adoption of QT at global and local levels. The data for this study is generated through online interviews with 10 participants selected through purposeful sampling.

Purposeful sampling is an effective technique for selecting participants or cases based on specific criteria, ensuring that the data collected is both relevant and insightful for addressing the research question. This method is particularly valuable in qualitative research, as it allows researchers to focus on individuals or cases that provide the most informative perspectives aligned with the study's objectives (Patton, 2002).

Selection criteria for participants are based on their affiliation with academia and/or the sector, as well as their geographical location. Geographic location is significant because regional factors often shape the perspectives, experiences, and resources available to individuals working within both academic and industrial settings. This approach supports a complementary understanding of how local and global dynamics interplay in QT development and provides insights into how factors like regional policy and investment trends impact researchers differently based on location. Furthermore, the secondary data analysis method is obtained in order to establish a solid foundation for the utilization and interpretation of the first-hand data generated in this study.

3.2.1. Country Sampling

The first step of the sampling process was the country selection. The selection of countries was guided by consideration of four aspects:

- Countries' investment level in quantum technologies,
- Countries' geographical locations and the political structure created by these locations on a historical level (their geopolitical position in the globe in short),
- The presence of national initiatives/strategy, and
- Countries' position in the categorization of the economic development levels.

Considering these aspects, the amount of investment of the countries was the first step to determine the efforts and importance given by the countries to the QT. Table 1: Investment Amounts of the Countries to the QT indicates the countries'

investment levels in the last two years in order. Countries highlighted in blue are included in this study.

Table 1: Investment Amounts of the Countries to the QT

Countries (Ranked by the investment level)	Investment in 2023	Investment in 2024
1. China	15 B	15 B
2. US	4.3 B	4.9 B
3. UK	3.7 B	4.3 B
4. Germany	3.3 B	3.3 B
5. South Korea	2.3 B	2.35 B
6. France	2.2 B	2.2 B
7. Russia	1.4 B	1.1 B
8. Canada	1.1 B	1.1 B
9. EU Flagship	1.1 B	1.1 B
10. Netherlands	904 M	1 B
11. India	735 M	735 M
12. Japan	700 M	700 M
13. Denmark	406 M	406 M
14. Israel	390 M	390 M
15. Taiwan	282 M	318 M
16. Sweeden	160 M	170 M
17. Australia	155 M	582 M
18. Singapore	138 M	138 M
19. Austria	127 M	127 M
20. Spain	67 M	67 M
21. New Zealand	36.7 M	36.75 M
22. Finland	27 M	40 M
23. Philippines	17.2 M	15.3 M
24. Brazil	12 M	12 M
25. Switzerland	11 M	91 M
26. Hungary	11 M	11 M
27. Qatar	10 M	10 M
28. Thailand	6 M	6 M
29. South Africa	3 M	3 M

Source: QURECA Ltd. 2024, <https://www.quireca.com/quantum-initiatives-worldwide-2024/>

The investment levels of the countries are a direct indicator of how much importance they place on this emerging technology. The importance can be constructed over several potential aspects, for instance, **National Prioritization**, aiming for various areas, such as technological and economic development, increasing national welfare, research and development capacity, etc.; **Strategic Power of Economic and Technological Leadership**, which can lead to competitive advantages in various sectors; and **Educational and Workforce Development** that is crucial for long-term sustainability and growth. Investment levels can also signal a country's **readiness to collaborate internationally or compete** in the global market.

The second step of the country selection process is determining the existence of a national strategy or initiative. The data for the existing initiatives/strategies and activities of the countries (summarized in Table 2: List of countries categorized by the existence of national strategy/initiative) are taken from the CIFAR report (2021) titled "A Quantum Revolution: Report on Global Policies for Quantum Technology" (p.12).

Table 2: List of countries categorized by the existence of national strategy/initiative

Countries with Coordinated National Quantum Strategy		
• Australia • China • France • Germany • Hungary • India • Iran • Israel	• Japan • Netherlands • Russia • Singapore • Slovakia • South Korea • Taiwan • United Kingdom • United States	Quantum Strategy in Development • Canada • South Africa • Thailand
Countries Without National Strategy, but with Significant Government-Led Or -Endorsed Initiatives		
• Australia • Denmark • Finland • Ireland • Italy • New Zealand	• Norway • Portugal • Spain • Sweden • Switzerland • United Arab Emirates	

Table 2. (continued)

Countries Without Significant Initiatives but Are Participants in International Partnerships	
• Belgium • Bulgaria • Croatia • Cyprus • Czech Republic • Estonia • Greece	• Latvia • Lithuania • Malta • Poland • Romania • Slovenia • Turkey

Source: CIFAR, 2021. "A Quantum Revolution: Report on Global Policies for Quantum Technology".

For the course of this study, I prefer to include countries that both have and lack a national strategy/initiative for QT because the presence or absence of such a strategy serves as a significant indicator of the importance a country places on QT and its commitment to translating this importance into actionable frameworks. By examining countries with established national strategies, I can analyse the impact of structured planning and dedicated resources. Conversely, including countries without such strategies allows me to explore alternative models of QT development and the potential challenges and opportunities they face in the absence of a national framework/strategy/initiative.

As the third and fourth steps of choosing the country sample, the aim is to capture diverse perspectives and potential differences between countries of (almost) each continent because having countries from different continents ensures a balanced representation of global efforts in QT. In addition to that, Table 3: Economic Development Levels of Countries According to the WESP categorizes countries according to their "development" levels of economies. Although it would be Eurocentric to segregate countries according merely to the "development levels", categorization based on the economic criteria found appropriate to utilize in this study. In this line of thought, the United Nations categorization of World Economic Situation and Prospect is used in the selection process of countries. Therefore, a wide and diverse geographic sample from different economic development levels helps identify regional strengths and challenges, giving a complete view of the global QT landscape.

Table 3: Economic Development Levels of Countries According to the WESP

Developed Economies				
Northern America	Asia and the Pacific	Europe		Other Europe
Canada United States	Australia Japan New Zealand Republic of Korea	Australia Belgium Bulgaria Croatia Cyprus Czechia Denmark Estonia Finland France Germany Greece Hungary Ireland	Italy Latvia Lithuania Luxembourg Malta Netherlands Poland Portugal Romania Slovakia Slovenia Spain Sweden	Iceland Norway Switzerland United Kingdom
Economies in Transition				
South-Eastern Europe		Commonwealth of Independent States and Georgia		
Albania Bosnia and Herzegovina Montenegro North Macedonia Serbia		Armenia Azerbaijan Belarus Georgia Kazakhstan Kyrgyzstan	Republic of Moldova Russian Federation Tajikistan Turkmenistan Ukraine Uzbekistan	
Developing economies by region				
East Africa	West Africa	North Africa	Central Africa	Southern Africa
Burundi Comoros Democratic Republic of the Congo Djibouti Eritrea Ethiopia Kenya Madagascar Rwanda Somalia South Sudan Uganda United Republic of Tanzania	Benin Burkina Faso Cabo Verde Côte d'Ivoire Gambia Ghana Guinea Guinea-Bissau Liberia Mali Niger Nigeria Senegal Sierra Leone Togo	Algeria Egypt Libya Mauritania Morocco Sudan Tunisia	Cameroon Central African Republic Chad Congo Equatorial Guinea Gabon Sao Tome and Principe	Angola Botswana Eswatini Lesotho Malawi Mauritius Mozambique Namibia South Africa Zambia Zimbabwe

Table 3. (continued)

East Asia		South Asia	Western Asia	
Brunei	Mongolia	Afghanistan	Bahrain	Syrian Arab
Darussalam	Myanmar	Bangladesh	Iraq	Republic
Cambodia	Papua New	Bhutan	Israel	Türkiye
China	Guinea	India	Jordan	United Arab
Democratic	Philippines	Iran	Kuwait	Emirates
People's	Samoa	(Islamic	Lebanon	Yemen
Republic of	Singapore	Republic	Oman	
Korea	Solomon	of)	Qatar	
Fiji	Islands	Maldives	Saudi Arabia	
Hong Kong SAR	Taiwan	Nepal	State of	
Indonesia	Province of	Pakistan	Palestine	
Kiribati	China	Sri Lanka		
Lao People's	Thailand			
Democratic	Timor-Leste			
Republic	Vanuatu			
Malaysia	Vietnam			
Caribbean	Mexico and Central America		South America	
Bahamas	Costa Rica	Honduras	Argentina	Ecuador
Barbados	Cuba	Mexico	Bolivia	Paraguay
Belize	Dominican	Nicaragua	(Plurinational	Peru
Guyana	Republic	Panama	State of)	Uruguay
Jamaica	El Salvador		Brazil	Venezuela
Suriname	Guatemala		Chile	(Bolivarian
Trinidad and	Haiti		Colombia	Republic of)
Tobago				

The UN creates four categories of economies: major developed economies, developed economies, economies in transition, and developing economies. According to all the three tables above, five countries are included in the category of “major developed economies”.

- **The United States of America** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 4.9 billion dollars in the QT in 2024, and
 - ✓ being categorized as a “major developed economy”.
- **The United Kingdom** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 4.3 billion dollars in the QT in 2024, and
 - ✓ being categorized as a “major developed economy”.
- **France** is found suitable for

- ✓ having a national initiative,
- ✓ investing 2.2 billion dollars in the QT in 2024, and
- ✓ being categorized as a “major developed economy”.
- **Canada** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 1.1 billion dollars in the QT in 2024, and
 - ✓ being categorized as a “major developed economy”.
- **Japan** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 700 million dollars in the QT in 2024, and
 - ✓ being categorized as a “major developed economy”.

One country is included in the category of “economies in transition”.

- **Russian Federation** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 1.1 billion dollars in the QT in 2024, and
 - ✓ being categorized as an “economy in transition”.

Seven countries are included in the category of “developing economies”.

- **China** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 15 billion dollars in the QT in 2024, and
 - ✓ being categorized as a “developing economy”.
- **Singapore** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 138 million dollars in the QT in 2024, and
 - ✓ being categorized as a “developing economy”.
- **South Africa** is found suitable for
 - ✓ having a national initiative,
 - ✓ investing 3 million dollars in the QT in 2024, and
 - ✓ being categorized as a “developing economy”.
- **Iran** is found suitable for
 - ✓ having a national initiative,

- ✓ being categorized as a “developing economy”.
- ✗ The total investment was not disclosed in the available sources.
- **Pakistan** is found suitable for
 - ✓ not having a national initiative,
 - ✓ not having any investment, and
 - ✓ being categorized as a “developing economy”.
- **The United Arab Emirates** is found suitable for
 - ✓ not having a national initiative, and
 - ✓ being categorized as a “developing economy”.
- ✗ The total investment was not disclosed in the available sources.
- **Cameroon** is found suitable for
 - ✓ not having a national initiative,
 - ✓ not having any investment, and
 - ✓ being categorized as a “developing economy”.

Table 4: Selected Counties

Major Developed Economies	Economies in Transition	Developing Economies
US (strategy / 4.9 B investment)	Russian Federation (strategy/ 1.1 B investment)	China (strategy / 15 B investment)
UK (strategy /4.3 B investment)		Singapore (strategy / 138 M investment)
France (strategy /2.2 B investment)		South Africa (strategy / 3M investment)
Canada (strategy /1.1 B investment)		Iran (strategy / investment not known)
Japan (strategy /700 M investment)		Pakistan (no strategy / no investment)
		United Arab Emirates (no strategy/ investment not known)
		Cameroon (no strategy / no investment)

3.2.2. Participant Recruitment

Among these countries, a total of 10 online interviews were conducted. Shortly after I started the interviews, I realized that participants are experiencing a radical career

change either in their work location (geographical change), or in their sectors (sectoral change). 7 out of 10 interviewees studied in more than one country; therefore, they were able to represent each country in which they worked. That is why, 13 countries are represented by 10 participants. This exploration added an unexpected dimension to the study. However, as this study does not incorporate this additional dimension into its design, it is suggested as a valuable area for future research.

The countries in this case are highlighted in light green in Table 4: Selected Counties. This realization made the condition of experiencing a leap among different sectors or countries an important indicator of the analysis of this study. This approach allows for the exploration of changes in regulatory practices and geopolitical dynamics across different contexts. Furthermore, Table 5: List of Interviewees in the Data Collection provides details on the participants’;

- professional background (academia, sector, or policy-making),
- their positions, the countries they have worked in, and
- their years of experience in the field of QT.

There is one participant from industry, four from academia and research, three at the intersection of academia and industry, one policy-maker, and one at the intersection of academia and policy-making. Within each group, participants are listed in regard to their years of experience in QT.

The highlight colours used in Table 5: List of Interviewees in the Data Collection are not indicators. They are merely used for a better differentiation of the categories.

Table 5: List of Interviewees in the Data Collection

Group of Participants	Interviewee	Country	Position	Expertise in working in the QT
Sector (S) ¹	S1	Russia* UAE	-Lead Researcher	18 years

¹ Sector (S): People who are working in various industries and private companies involved in the development and application of quantum technologies as engineers, technicians, entrepreneurs, start-up founders, consultants, etc.

Table 5. (continued)

Academy and Sector	AS1	US	-Professor -Consultant (Government and Private Sector) -Start-up founder	44 years
	AS2	Canada Germany Russia* UK US	-Professor -Industry Professional	21 years
	AS3	UAE UK Singapore	-Industry Professional	21 years
Academics and Researchers (A) ²	A1	China Pakistan*	-Assistance Professor	15 years
	A2	Iran* South Africa	-PhD student	12 years
	A3	Japan UK*	-Lecturer -Post-doctoral Research Fellow	10 years
	A4	Cameroon*	-PhD student	6 years
Policy Makers (P) ³	P1	Canada*	-Director of National Quantum Strategy Secretariat	-
Academy and Policy Maker	AP1	France US (Greece)*	-Research Director -Regulatory authority	16 years

(*) Indicates the participants' place of origin.

3.2.3. Question Set

The interviews follow a semi-structured format with open-ended questions aimed at delving into the various dimensions of quantum technology geopolitics. These questions cover topics such as:

² Academics and Researchers (A): Individuals working in educational and research institutions who are focused on advancing quantum technologies, such as university professors, graduate students (Master's and PhD), postdoctoral researchers, etc.

³ Policy Makers (P): Individuals involved in the creation and implementation of policies related to quantum technology at various levels of government and international organizations, such as Ministers, secretaries, other government representatives, regulatory authorities (standard setters), international organization representatives, etc.

- Researchers' both good and bad experiences such as facilitators or obstacles to the development of quantum technologies in different countries.
- The impact of national initiatives on participants' work and the policies and regulations they believe should be implemented.
- Perspectives on the global competition and the concept of the "quantum race".
- The influence of geopolitical factors on the development of quantum technologies.
- Views on the QT perception.
- Views on the possible inequalities in the ecosystem and their implications.
- Understanding of protectionism in quantum technology studies.
- Opinions on international cooperation and consensus-building in the development of quantum technologies.
- Evaluation of the effectiveness of international regulations and standards.
- Experiences with soft and hard regulations in previous technology developments and their impact.

In short, my aim is to investigate how local and global dynamics, including regulatory practices and strategic policies, shape the work environment experiences of researchers involved in quantum technologies, and the outcomes they produce.

The interview guide is given the Appendix A: Interview Guide.

3.2.4. Interview Process

To serve my purpose mentioned above:

- I reached out to individuals through the Internet (personnel websites, institution websites, university websites, LinkedIn, etc.)
 - who have made significant contributions to this field,
 - who have an influential position,
 - who are commonly recognized in this field,

- who work(ed) in the selected countries and want to advance in the field,
- specifically, those who have indicated openness to collaboration by sharing a means of contact.
- After the details of the study were delivered to potential participants via e-mail.
- The interview dates were scheduled according to the availability of those who agreed to participate in the study under the specified conditions.
- All interviews were conducted through an online conference application (Zoom) due to geographical constraints.
- The interviews were planned to last no more than one hour, and they took between 30 minutes to one hour.
- The audio recording was taken in each interview under the consent of the participant and notes were taken as a back-up. The recordings were stored on my personal account to ensure confidentiality.
- To maintain ethical standards determined by the METU Applied Ethics Research Center (UEAM, 0295-ODTUIAEK-2023), all participants were briefed about the study and the conditions of the interview. The preliminary information below was given to each participant before the interview:

“Participation in this study is entirely voluntary. Under your consent, interviews will be audio recorded. You may decline to participate or withdraw at any time without any consequences. You can also choose not to answer specific questions during the interviews. All collected data will be kept confidential, ensuring no association between data and participant identities.”

- Participants were also informed about the possibility of changing their answers through follow-up e-mails, in the case of any necessary clarifications, or simply changing their minds.

Despite some scheduling conflicts and occasional technical issues, the meetings were successfully conducted. Adaptations, such as re-scheduling, or using alternative communication platforms, such as Google Meet or Microsoft Teams were made to address these challenges effectively.

The results of the interviews were coded and analysed using a qualitative data analysis software, MAXQDA.

3.2.5. Limitations

During the process of carrying out this study and generating data, I encountered six limitations.

- 1) No eligible candidate that I would like to include in my study who is both a citizen and a resident of the countries of Russia, Japan, and China accepted my invitation. The rate of getting a response regarding my invitation from these countries, even a negative one, was very low compared to the other countries.
 - a. I overcame this limitation by contacting participants who were Russian citizens but not currently working there, and who were not Chinese or Japanese citizens but had experience working there.
- 2) I either did not get a response to my invitations or did get a response that stated their lack of knowledge over the subject from the countries that are categorized under Caribbean, Mexico and Central America, and South America by WESP.
 - a. I overcame this limitation by reaching people from both Africa and Asia continent in the ‘developing economies’ category.
- 3) Only three people out of 10 who I would like to include in my study as representatives of governments agreed to participate in the study. This rate was lower than the response rate of the participants in any other sector.
- 4) Inability to make appropriate time scheduling due to time differences between countries/continents.
 - a. I overcame this limitation by adapting to the hours available to the interviewees.
- 5) Interruption of meetings due to technical problems such as internet connection loss or microphone problems in the online conference application.
 - a. I overcame this limitation by scheduling two meetings on two separate online conference platforms for the scheduled meeting time,

and by continuing the meeting via the other connection without wasting time when there was a problem.

- 6) Lastly, the evolving nature of QT was a theoretical limitation of this study, since it causes no scenario to go beyond an assumption, and the "bets" placed on these scenarios by the actors cause my study work to gain meaning only within these contexts.
 - a. There is no overcoming of this limitation. It is a valuable part of this study.

3.3. Data Generation

In this study, the analysis process was guided by a theoretical thematic analysis using a deductive approach. Theoretical thematic analysis is a method that applies a predetermined theoretical framework to guide the coding and analysis process. This approach contrasts with inductive methods by prioritizing theory-driven insights rather than emerging patterns from the data alone (Braun & Clarke, 2006). The Social Shaping of Technology (SST) framework provided the foundation, with its categories of fluidity and stability serving as the core themes for the examination. These themes were employed to explore the factors influencing quantum technology (QT) development at both local and global levels, focusing on how dynamic, unpredictable elements interact with structured, stable components to shape researchers' work and innovation practices.

The data analysis process began with face-to-face interviews, which were transcribed word-to-word to capture the participants' responses with precision. After each interview, reflective notes were written to document observations and initial impressions, helping to contextualize the data. Using the theoretical framework as a starting point, key themes and subthemes were identified, providing a structure for organizing and analysing the data. A thematic map was developed to align the theoretical framework with the expected patterns in the data.

The transcribed interviews were imported into MAXQDA for systematic examination. Line-by-line coding was conducted to ensure a detailed and thorough

engagement with the data. The theoretical categories of “Fluidity” and “Stability”, alongside their related subthemes, guided the coding process. This deductive approach allowed the analysis to remain focused on the theoretical lens. The analysis identified three main themes: “QT Research Ecosystem”, “Fluidity”, and “Structure & Stability”. These themes were further divided into seven subthemes, supported by 16 codes and 22 subcodes, derived from a total of 41 quotation clusters. Further details about the codes and their relationships are provided in the study’s codebook (Appendix B). This deductive approach, rooted in the SST framework, ensured that the analysis remained consistent with the study’s theoretical objectives while providing a detailed exploration of the factors shaping QT development.



CHAPTER 4

BACKGROUND FOR SELECTED COUNTRIES

4.1. National Initiatives

National initiatives of the countries are important for comparing and analyzing the data generated in this study. This helps determine how the global strategic positions of researchers, sector employees, policymakers, economies, societies, and nations are affected.

As stated in the methodology section, the countries selected to be represented in the study are (according to the alphabetic order) Canada, China, Central Africa, France, Iran, Japan, Pakistan, Russia, Singapore, South Africa, UAE, the UK, and the USA. Therefore, it is necessary to examine the initiatives, strategies, and actions of these countries. In this section, the national initiatives- if existed-, strategies, and actions have been analysed based on the topics outlined in the questionnaire. The general trends in the plans have been identified through discourse analysis, highlighting the primary themes and explaining the underlying mindsets.

4.1.1. Countries with National Initiatives/Strategies

4.1.1.1. The National Quantum Strategy of Canada

The National Quantum Strategy of Canada (NQS) was launched in 2022. The NQS aims to amplify Canada's significant strength in quantum research; grow Canadian quantum-ready technologies, companies and talent; and solidify global leadership in quantum science and its commercialization.

Three Key Missions of NQS:

- Make Canada a world leader in QT
- Ensure the privacy and cyber-security of Canadians in a quantum-enabled world
- Enable the Government of Canada and key industries to be developers and early adopters of new quantum sensing technologies.

Three core pillars of NQS to reach the three key missions are *research* (supporting basic and applied research), *talent* (developing, attracting, and retaining critical talent), and *commercialization*.

Technological Focus: Quantum computers, Quantum software, Quantum communications, Quantum sensors, Quantum materials are mentioned as 5 principal QT in the strategy.

Motivations for Development: The aspect of *leadership and pioneering* is dense in the strategy. It is mentioned almost in every section several times. Canada is seen as an ‘Early Leader’. “Canada has taken a leadership position through investments in quantum science over many decades...” (NQS, 2022, p.5).

“Canada’s investments in quantum technologies and research over many decades have made the country a global leader in the field...As the rest of the world expands its own quantum programs, Canada must continue to invest and innovate if it is to stay ahead” (NQS, 2022, p.2).

Securing the Canadian economy and digital sovereignty and building confidence in Canadian providers of quantum-safe communications solutions among their trusted international partners is one of the motivations of the strategy.

"The Government of Canada will work toward ensuring existing and future data systems are *protected* before they are threatened" (NQS, 2022, p.14). This includes promoting the use of post-quantum cryptography and developing a national quantum communications network to secure highly sensitive information in the future.

Main Tools to Reach the Development: There is a high emphasis on *domestic and international collaboration* and “like-mindedness” criteria in international collaboration activities (NQS, 2022, p.3).

According to the strategy, *standards* are crucial for the commercial success of quantum technologies as they facilitate access to global markets. The Standards Council of Canada and other organizations will engage in activities that support standardization, such as creating policies and regulations for integrating quantum applications to benefit Canadian businesses and society. Furthermore, participation in international discussions to ensure that global standards align with Canadian principles and serve the interests of Canadian industries is signified.

4.1.1.2. The National Quantum Strategy of China

It is highly evident that China outlines long-term plans for the country's development process with any kind of technological turn. The "Made in China 2025" strategy, a roadmap released by the State Council in 2015 to guide the country's advanced industrial manufacturing, has seen steady progress in industrial capability, smart manufacturing, innovation, as well as product quality and branding (Xinhua, 2017).

“By 2049, China aims to emerge as a global leader in three strategic technologies, identified by President Xi Jinping as critical for China’s national rejuvenation: space, AI, and quantum communications and computing” (Goswami, 2023).

As the national plan for QT is included in the “Made in China 2025” strategy, the focus of examination is counted as this strategy. China's national strategy focuses on achieving technological independence and leadership in AI, quantum technology, advanced semiconductors, and other high-tech areas.

The country allocates over 50% of global public funding to quantum research and development. This significant state investment has established China as a global leader in developing a comprehensive quantum communications network and building the world's largest quantum research facility (Jacob, 2023).

The aim of the strategy is:

- to boost China's economic competitiveness by advancing China's position in the global manufacturing value chain,
- leapfrogging into emerging technologies, and
- reducing reliance on foreign firms.

Quantum Computing is one of the 10 industries that Made in China 2025 targets (The China Project, 2018). The end goal for QT is to achieve a leading position in quantum science and technology globally by 2030 (Chen, 2020), in general, by 2049, lead global manufacturing and innovation with a competitive position in advanced technology and industrial systems.

Technological Focus: Quantum computing, Quantum cryptography and Quantum communication.

Motivations for Development: The primary motivations are to reduce dependency on foreign technology, boost domestic innovation, and enhance national security. However, from my research, it is clear that China's main motivation is to lead the competition (specifically with the US). By leading in quantum technology, China seeks to secure its technological sovereignty and economic strength, positioning itself as a pioneer in next-generation technologies. The aspect of emerging technologies' usefulness to society does not exist in their prior efforts.

“MIC 2025 has been a major U.S. policy focus because of the tactics it has intensified, including technology transfer, licensing and joint venture requirements, state-directed IP theft, and government-funded acquisitions of companies in strategic sectors” (Sutter, 2020).

Main Tools to Reach the Development: Funding: The Chinese government provides significant financial support through state funding, low-interest loans, tax incentives, and subsidies. Infrastructure Investment: Investments in research infrastructure, such as quantum research laboratories and technology parks, facilitate innovation and development.

Policy Support: Policies that encourage collaboration between universities, research institutions, and industry players are in place to foster a conducive environment for quantum technology development.

Talent Development: Initiatives to attract and retain top scientific talent, both domestically and internationally, ensure a skilled workforce to drive quantum research and applications.

4.1.1.3. The National Quantum Strategy/Plan of French

The new Quantum Plan announced by President Emmanuel Macron on January 21, 2021, is designed to create a structured framework that aligns France's industrial and research capabilities, aiming to establish the country as a significant/leading player in quantum technology (Science/Business, 2021).

QT is seen as one of the ‘enabling technologies’. Therefore, it is obvious that a high amount of care is given in this area by France.

“The plan encompasses numerous strategic aspects, such as encrypted communications and enhanced computing capacity, and brings together the French Ministries for the Armed Forces, of the Economy, Finance and Recovery, and of Higher Education, Research and Innovation” (Felix, 2021).

It is explained that, as QT is still in the stage of basic research, The French government has collaborated with its three main research organizations to shape its strategy. The strategy is defined as “ambitious” for including 37 measures (Science/Business, 2021).

Key Missions and Aims of the Plan:

There are three main aims of the Plan, which are:

- To maintain and strengthen national sovereignty, particularly against major players like the United States and China.

- To stimulate economic growth and industrial development through fostering industrial partnerships.
- To sustain and expand France's scientific leadership in quantum research.

Furthermore, the strategy is structured around six strategic objectives:

- Advance quantum computing technologies and their applications
- Gain expertise in quantum sensor technologies
- Develop and spread post-quantum cryptography
- Progress quantum communication technologies
- Master enabling quantum technologies (Swayne, 2024).

Technological Focus: The National Plan focuses on four technological areas mainly, which are quantum computing, quantum communication, quantum simulation, and quantum sensing.

Motivations for Development: *International Competition:* Responding to significant investments by other countries and tech giants in quantum technologies. According to Quantum Technologies officer at the Centre National de la Recherche Scientifique (CNRS) and a member of the government's task force, "the combination of national acceleration strategies, such as the finalisation of an agreement between France and Germany, would foster competitive innovation" (Felix, 2021).

Economic and Strategic Benefits: Recognizing the potential economic benefits and strategic advantages of leading in quantum technologies.

National Security: Ensuring the protection and advancement of national security interests through quantum innovations.

Main Tools to Reach the Development: *Funding and Support:* Allocating substantial national resources and encouraging industrial investments in quantum research and infrastructure.

Academic-Industry Collaboration: Strengthening collaborations between academia and industry to foster innovation and application of quantum technologies.

Interdisciplinary Research: Promoting interdisciplinary research and education to build a robust quantum workforce.

Education: Quantum training for technical diploma, undergraduate and master's students (CIFAR, 2019).

4.1.1.4. The Quantum Technology Innovation Strategy of Japan

Institutional efforts of Japan:

- 5+ quantum innovation centres
- 10+ venture companies supported via government investments, procurement, etc.
- Quantum Leap Flagship Program (3 flagship projects and supporting basic research) (CIFAR, 2019).

QT is counted as an innovative technology in Japan's society, economy, industry, and security. There are two national initiatives, one can argue, Quantum Technology and Innovation Strategy, established in January 2020, and Vision of Quantum Future Society, established in April 2022. While the strategy focuses on Research and Development (R&D), the Vision focuses on the socio-economic transition.

Aims of the Vision:

- Create opportunities for industry to grow and solve social challenges by
 - incorporating QT into the overall socio-economic system and
 - integrating QT with conventional (classical) technology systems (hybrids)
- Promotion of the use of QT by development of testbeds, etc.
- Creation and revitalization of industries and startups using QT.

The values created by quantum technology in the future society and the Hybridization of quantum and classical technologies are some of the headings of the

Vision. From this point of view, it seems like an adequate amount of importance is given to every aspect of QT.

Motivations for development:

- Global Competition in the Quantum Industry (Exertion of hegemony by being in the competition)
- Progress in Basic Technologies for Quantum Computer
- Rapid Development of DX under the COVID-19 Outbreak
- Value on Carbon-Neutral Society
- Growing Importance of QT for Economic Security

Technological Focus: Quantum computer, quantum security networks and quantum measurement and sensing/quantum materials are the three technologies that are the initiative's focus.

Tools: Promote a wide range of initiatives ranging from basic and basic R&D to implementation in society, international cooperation, strategic intellectual property management, international standardization, and development of excellent human resources. (Government of Japan, 2021, p.86).

Three perspectives for making QT practical and industrialization:

- *Collaboration*: Under the collaboration aspect of the three perspectives on the practical use and industrialization of QT, the creation of new value under participation, strengthening global cooperation and market development indicates Japan's wider focus on development. In other words, Japan also puts global development and value creation of the QT upfront.
- *Accessibility* (Realization of an environment for the use of QT open to industry)
- *Incubation* (Aggressive support of startup/venture and new business creation)

4.1.1.5. The National Roadmap of Russian Federation

Institutional efforts of the Russian Federation:

In 2010, a private research institution for conducting fundamental and applied research in modern quantum physics and technologies, the Russian Quantum Center (RQC), was founded (Fedorov et al., 2019). The Quantum Communications Competence Center of the National Technology Institute (NTI) is a unique scientific and educational organization in Russia, created on the basis of the consortium of the RQC, as well as a number of innovative and industrial enterprises, developing such high-tech areas as quantum communications and quantum cryptography. The strategic goal covers the aspects of carrying basic research to applied research and then to the commercialization of the technological products that are useful for society (MISIS, n.d.).

In 2016, the National University of Science and Technology (NUST) "MISIS" and the Russian Quantum Center created the NUST MISIS Quantum Center. This center involves top scientists from Russia and around the world working together with leading research centers on various quantum technology research programs (MISIS, n.d.).

Technological Focus: The initiative focuses on Quantum computing and simulation, quantum communications, quantum metrology and sensing. “The main goal of the Russian Quantum Technologies Roadmap is building a full stack of quantum computing technologies” (Fedorov et al., 2019, p.2).

Motivations for Development: *Leadership* is seen as a significant motivating factor in the improvement of the QT.

“Today, quantum computing and quantum computer are the field of competition for the world scientific schools and technological giants. There are normal games for the leadership in this area. I am sure that the National Quantum Laboratory will contribute a lot to high positions of our country in this area,” the General Director of ROSATOM (Swayne, 2022).

Fedorov et al. (2019) stated that Quantum technologies in Russia are on the list of strategically important cross-cutting directions in the framework of the National Technology Initiative programs and the Digital Economy National Program. Furthermore, "Quantum research in Russia is supported by both governmental and industrial entities in a variety of formats" (p.1). It is seen that competitive grants and private investments are also evident in the development process of Russia. It is stated that Russia has created a long tradition of quantum science and technology, and this is a collaborative effort. "Intense global interest, broadband domestic expertise, and substantial financial support from the government and industry position quantum science and technology in the Russian Federation for dramatic growth over the next five years" (Fedorov et al., 2019, p.8)

Domestic and Self-sufficient technological development: There is a special emphasis on the domestication and sustainable self-sufficiency of strategic technologies, such as cryptographic, "Russian laws require any cryptographic system to be domestically certified if it is used by the government or by commercial entities working on public contracts that require cryptographic information security" (p.6). They see standardization as one of the main phases of the domestic quantum key distribution development. Moreover, "building a sustainable ecosystem" and carrying it into the international sphere is mentioned to be one of the main goals of National Quantum Lab (NQL) by the Director of Digitalization at State Atomic Energy Corporation Rosatom (ROSATOM). "NQL will become an active participant of the international quantum dialogue when it matches large world projects of other leader-countries" (Swayne, 2022).

Main Tools to Reach the Development: National Programs & Collaboration: Head Project Office for Quantum Technologies at ROSATOM declared, "Experience of world leaders in quantum computations has shown that you may achieve prominent results only by creating national programs supported on the highest governmental level...Exchange of competences, developments and information, mutual assistance and acting as single brand significantly support the national standing on the global arena". On the one hand, the assertion suggests that strong national initiatives are crucial for achieving prominent results. This national focus is underlined by the need

for internal coherence and significant investment within the country's borders. However, the same statement also stresses the importance of global collaboration. This indicates that despite the emphasis on national programs, international cooperation remains essential for maintaining and enhancing national standing on the global stage. This dual focus on national efforts and global collaboration carries an inherent tension, which will be discussed in Section 7.2. Balancing the Dualities.

Education: Quantum education programs are considered important and further supported. Priority to the development of educational programs in quantum technologies areas is given by the Research Centers (MISIS, n.d.).

4.1.1.6. The Quantum Engineering Program of Singapore

Singapore's Quantum Engineering Programme (QEP), launched in 2018, aims to

- gain the benefits of quantum technologies for societal use,
- foster ecosystem growth through collaborations,
- deal with industrial challenges.

The Quantum Engineering Programme (QEP) in Singapore is coordinated on a national level across various research organizations. It is supported by the National Research Foundation, Singapore, and the Agency for Science, Technology and Research, Singapore, and is hosted by the National University of Singapore (International Research Foundation, n.d.)

The QEP in Singapore has established three national platforms to enhance the country's quantum capabilities:

National Quantum Computing Hub, National Quantum Fabless Foundry, National Quantum-Safe Network.

Technological Focus: Quantum Communication & Security, Quantum Computing & Processors and Quantum Sensors.

Motivation for development: Societal and global benefit, competition.

Education: The National University of Singapore (NUS) is the leading university in Singapore, emphasizing a global perspective in education, research, and entrepreneurship, with a particular focus on Asian viewpoints and expertise.

Building up technological capacity in domestic companies by The National Research Foundation (NRF) (International Research Foundation, n.d., p.6).

Collaboration: The hub will also build international collaborations and train new talent to address a skills shortage in this emerging industry. (International Research Foundation, n.d., p.2).

4.1.1.7. The Quantum Technology Initiative of South Africa (Sa Quti)

In March 2021, the South African Department of Science and Innovation launched the South African Quantum Technologies Initiative (SA QuTI) after three years of effort and started to fund it afterward. As it is revealed on the official website of the initiative,

“The South African Quantum Technology Initiative (SA QuTI) will create the conditions for a globally competitive research environment in quantum technology and grow a local quantum technology industry in South Africa.”⁴

SA QuTI is made up of five nodes of quantum centers, which are all universities. (University of the Witwatersrand, Stellenbosch University, University of KwaZulu-Natal, Cape Peninsula University of Technology, University of Zululand)

“Wits University has led a national consortium that secured R54 million funding from the Department of Science and Innovation (DSI) to co-ordinate a national quantum technologies initiative” (Wits to kick-start a national quantum technologies initiative with R54 million funding, 2022).

⁴ South African Quantum Technology Initiative, <https://saquti.org/>

It is stated that strong leadership, i.e., “establishing emerging research chairs that will drive innovation, foster collaboration, and develop expertise in this cutting-edge field” is crucial for pioneering advancements. To achieve this, SA has one emerging leader. According to this approach, it is clear that South Africa wants to be in a pioneering position in the development of QT, both domestically and internationally in its own way. “Building a vibrant quantum community and a viable quantum industry” is among the main motivations of the initiative. By attaching importance to bringing up the skilled workforce, SA QuTI gives a scholarship opportunity to Postgraduate students with a Quantum research focus from “All South African Universities”. It also has collaborative efforts such as the partnership of Wits University with IBM Research by becoming the first African partner on the IBM Q Network and has access to its 50-qubit quantum computer.

The leading professor of SA QuTI from the Wits School of Physics mentions the top-to-bottom shaping of the development of QT in South Africa by saying, “We managed to convince the government that quantum research is too important to leave to a small research group, and that they should invest in a national programme”. The national initiative is co-drafted by the professor and then adopted by the government.

“The aim is to eventually have a well-established critical mass in the national quantum community and to work with government to draft new legislation, where it comes to quantum technologies” (Wits to kick-start a national quantum technologies initiative with R54 million funding, 2022).

Therefore, the need to convince the governmental stakeholders is an undeniable part of the development of QT, as in all emerging technologies.

Three driving quantum technologies are determined to be the flagship programmes of SA that focusing on;

- quantum computing (explores how quantum computing can be used most effectively in order to solve problems relevant to the South African socio-economic context)

- quantum communications (emphasizes holistic technology development and deployment, bringing together disparate activities in single photon sources, detectors, random number generation, teleportation, as well as classical communication protocols and security), and
- quantum metrology, sensing, and imaging (will bring together the collective expertise of South African researchers working in the sector to fast-track the development and deployment of a range of products for medicine, aerospace, military, and telecommunications).

4.1.1.8. The National Initiative of The UK

The National Quantum Strategy of the UK (2023) states that “The UK has a world-leading position and quantum is one of the top priorities for the government” (p.7). This strategy sets a 10-year plan “to realize the incredible potential of these technologies for the UK” (p.7). The ‘ten-year vision of the strategy’ is to be a leading quantum-enabled economy by 2033, with a world-leading sector by planning to commit 2.5 billion dollars. It is claimed that the support from this strategy covers the broad spectrum of quantum computing, sensing, timing, imagining, and communications, and works over the strengths of the UK (p.9).

The UK holds the aspects of the significance of quantum technologies, the aspiration for leadership in this field, and maintaining global development of the technologies in similar levels by referring to all more or less in the same amount. The strategy explains the future capabilities and benefits of QT to society and the economy, how to use it, and what it facilitates in daily life. It is also explained that the countries that will develop QT first will have a worldwide advantage in economic growth, health, sustainability, economic/national security, resilience, and defence issues, and therefore "quantum is a priority technology for the government" for the UK (2023, p.8). Accordingly, there is an emphasis on global development and “bringing quantum into widespread use”, while using the funding to capitalise on a leading position in the next ten years (p.9). Alongside that mindset, national self-sufficiency is strategically necessary for the UK in the case of what they determine as ‘critical

technologies.’ For this reason, the strategy puts national development in front of international collaboration by stating that “Although international collaboration is an essential part of our approach, it is not in the UK’s interests to rely purely on others for access to these critical technologies. We will also invest in and strengthen the key ecosystem enablers, such as skills, infrastructure, regulation and standards” (p.9).

Aspect of global development and race:

In the strategy, it is stated that

“We are in a global race to develop and commercialise these capabilities. The UK was an early mover, but other countries are accelerating their own efforts. Investing in quantum now, building on the strengths that we have already established, will ensure that we deliver on quantum technologies for the UK” (2023, p.8).

It announces that the UK National Quantum Technologies Programme (NQTP), planned in 2014 with a 10-year projection involving a \$1 billion investment as a step to make the UK a world leader in QT, has made significant progress. Over nine years, this national program has achieved a "unique and diverse pool of talent, capabilities, and know-how within our quantum sector" (p.9). Therefore, the strategy recognizes the existence of a global race and states that the UK is one of the leaders in this race as an early mover and that the ongoing research for technological development, which they build on their previous strengths, is guaranteed to yield fruitful results.

Objectives: The strategy suggests four goals to actualize the ten-year vision.

Goal 1: World-leading research and skills

For the objective of being a “world leader” in quantum science and engineering, the strategy gives weight to increasing the quality of academic endeavors, such as quantum science and research publications, funding of postgraduate research students, and strategic collaboration activities making bilateral arrangements with “5 further leading quantum nations” (p.11).

Four main activities are pointed out for this objective. Working on R&D, access to the right skills and talent, building a quantum-literate workforce, and international partnerships.

Goal 2: Supporting Business

For the objective of making the UK an “integral part of the global supply chain”, “go-to place for quantum businesses” and “preferred location for investors and global talent”, the strategy suggests increasing the share of global private equity investment into quantum technology companies and the share of the UK in the global QT market (p.11). Eight main activities are pointed out for this objective:

- Collaborating to strengthen the quantum ecosystem internationally. (“The UK quantum ecosystem is comprised primarily of SMEs which operate in specific areas of expertise. This means collaboration is an essential part of the UK ecosystem - within the sector as well as with academia, allied sectors, and user communities - and needs to be a fundamental part of our strategy going forwards” (p.32).)
- Collaborating to strengthen the quantum ecosystem interdisciplinary (between sectors).
- Commercialisation and Accelerators
- Infrastructure (the UK made significant investments in government-owned infrastructure)
- The UK’s business support offer
- Investment to unleash innovation
- Growing global supply chains
- Attracting quantum businesses to the UK

Goal 3: Driving the adoption of Quantum Technologies in the UK

For the objective of benefitting from the usage of QT in the economy, society and the national security of the UK, the strategy plans to make all businesses within key relevant sectors of the UK aware of the potential of quantum technologies, and

making the majority of these sectors to take the steps to prepare for the arrival of quantum computing.

Three main activities are pointed out for this objective:

- Quantum Technologies for Societal Good
- National Quantum Computing Centre (NQCC) test bed for quantum computing applications
- Leading by example through government signalling and procurement

Goal 4: Leading quantum regulation and protecting the sector

For the objective of creating a national and international regulatory framework, the strategy plans to support innovation and the ethical use of quantum technologies and protect UK capabilities and national security. It is stated that, “We will ensure that regulatory frameworks drive responsible innovation and the delivery of benefits for the UK, as well as protecting and growing the economy and the UK’s quantum capabilities” (p.47). The features that must be present for the content of a national and international regulation are listed in the strategy as follows:

- “Stable, coherent and predictable
- Agile enough to move quickly with technological development
- Simple to understand and inexpensive to implement
- Where possible, co-designed with industry
- Focussed on innovation and industry-needs
- Champion the transparent and ethical use of quantum technologies” (p.47).

Furthermore, four main activities are pointed out for this objective:

- Protecting the UK sector to support growth
- Mitigating the risks associated with quantum
- Technical Standards
- Assurance of quantum technologies

Although this goal serves to high virtue, having the aim of making international standards for the ethical use of QT while also focusing on protecting the UK's national security seems hypocritical because of the contradictory nature of prioritizing national security or international efforts. In order for international standardization to be equitable and fair, it must be prepared in accordance with the principles of impartiality and ethics. Therefore, the goal of leading for standardization requires an inherent act of favoritism and creates a self-contradictory target-action relationship.

4.1.1.9. The National Initiative of The Us

As stated in The Federal Source and Gateway to Quantum R&D Across the U.S. Government (n.d.), The National Quantum Initiative Act (NQI Act) was signed into law by President Trump on December 21, 2018 “to accelerate quantum research and development for the economic and national security of the United States.” The initiative aims to ensure “continued leadership” of the US by focusing on more rapid development, expanding the number of researchers/students, increasing the quality of education, increasing multidisciplinary, giving effort in basic research, promoting national departmental collaboration, promoting the development of international standards (both in Quantum Information Science – QIS- and technology security), facilitating innovation and private-sector commercialization (H.R. 6227, 115th Congress, 2018).

The strategy outlines three key objectives aimed at advancing QIS. The first of them is “Getting the science right”. In this section, there is a strong emphasis on scientific precision, focusing on gaining a thorough understanding of the potential applications of QIS and the realistic timelines for their societal impact. This includes identifying and addressing the obstacles that may delay or prevent progress in this field, and this is found to be the only statement that considers the benefit of society within the strategy (H.R. 6227, 115th Congress, 2018).

The second one is “Enhancing competitiveness”. The strategy prioritizes enhancing competitiveness, aiming to accelerate the development of quantum technologies for

both economic and mission-oriented purposes. This involves fostering collaboration with international partners while protecting national security interests. This objective covers both intra- and international competitiveness. The ‘competitive award of grant’ applications are utilized in nearly every field of endeavor. According to the initiative, adopting a collaborative approach to enhance competitiveness does not mean competing against each other, but rather competing side by side (H.R. 6227, 115th Congress, 2018).

Additionally, the strategy underscores the importance of fostering cooperation guided specifically by ‘shared principles’ of the ‘like-minded’ countries including "freedom of inquiry, openness, transparency, honesty, equity, fair competition, objectivity, and democratic values" (National Quantum Coordination Office, 2022). However, the statement lacks clarity regarding the relativity of these “shared principles”. It raises several critical questions: Freedom of inquiry for whom? Whose standards of openness, transparency, and honesty are being referenced? What criteria define fairness, democracy, and equality, and who benefits from them? Moreover, what constitutes objectivity, and who determines its standards? These questions highlight the need for a more nuanced understanding and explicit definitions to ensure that these principles are universally and equitably applied, avoiding potential biases or misinterpretations that could arise from differing cultural or national perspectives. Therefore, these questions will be discussed in Chapter VI: Analysis & Discussion in comparison to the analyzed data.

In the strategy, there are statements stressing the priority given to the national context. The strategy emphasizes the need to empower individuals by establishing pathways and creating opportunities for "all Americans".

Main Themes of the National Quantum Initiative Act of the US: *Priority on Leadership*: There are many statements that emphasize "ensuring," "providing continued," and "maintaining and expanding" US leadership. These statements suggest that the US views itself as a leader in quantum technology development and seeks to maintain or strengthen this position.

National Security Concerns: References to the economic and national security of the US indicate that the development of quantum technology is not only seen as important for economic prosperity but also for ensuring national security interests. This suggests that quantum technology is perceived as having strategic implications beyond its economic value and is stated to be a "critical technology".

Coordination and Collaboration: Calls for coordinated federal programs and the recognition of the importance of collective efforts imply that the US recognizes the need for collaboration and strategic coordination among various stakeholders, including government, industry, and academia, to maintain its leadership position in quantum technology.

Focus on Economic Security and Quality of Life: The mention of enhancing economic security and improving the quality of life indicates that quantum technology is seen as a tool for driving economic growth and improving societal well-being, aligning with broader national objectives beyond just technological advancement.

4.1.2. Efforts of the Countries with No National Initiatives

4.1.2.1. Cameroon's Quantum Technology Efforts

Cameroon does not have a documented national quantum strategy or significant investment in quantum technologies. The country's focus has primarily been on more "immediate" technological and infrastructure needs, and there is no publicly available information indicating a coordinated national effort and investment in QT development.

4.1.2.2. Iran's Quantum Technology Efforts

Iran's national efforts on quantum technology are led by the Atomic Energy Organization of Iran (AEOI) and focus on becoming a leading player in the field within West Asia. AEOI started studies in the field of quantum technology in 2016

(Iran Press, 2021). The head of the Atomic Energy Organization of Iran stated that Iran is a forerunner in quantum technology in West Asia, and their efforts to prepare a roadmap for QT were started in 2017 (Iran Press, 2021).

The country has established the National Center for Quantum Technologies to drive research and development in this area. Iranian Quantum Technologies Research Center (IQTEC) "works in the field of developing, presenting and improving the level of knowledge and application of quantum technologies" (IQTEC, n.d.). The center believes that reducing the costs associated with acquiring this knowledge will lead to faster growth and sustainable development. Additionally, this approach allows businesses and professionals to connect with each other more affordably. IQTEC also provides educational content.

4.1.2.3. Pakistan's Quantum Technology Efforts

Pakistan does not currently have a national strategy or dedicated initiative for QT. Despite this, there are efforts to raise awareness and celebrate advancements in the field. The most active organization is the Centre of Excellence for Technology, Quantum, and Artificial Intelligence Pakistan (CETQAP), which launched the first hybrid R&D center for QT, the Pakistan Quantum Research Center (CETQAP, 2024), and organized 'World Quantum Day in Pakistan'. These events aim to put forward the significance of quantum science and increase interest in the field among the public, particularly the youth. The country's focus appears to be more on promoting education and awareness through outreach programs rather than substantial financial investment or developing a national strategy for quantum technology at this time. On the organization's website, it is stated that

"As Pakistan embraces the transformative potential of quantum technologies, World Quantum Day reaffirms the nation's commitment to advancing scientific knowledge, driving technological progress, and contributing to the global quest for understanding the fundamental principles of the universe" (World Quantum Day, 2024).

Therefore, it is seen that national and global technological progress is prior to the competition. Furthermore, QPakistan is one of the "QCousins" of the QWorld

formation. It enables "an active local community of quantum computation and information practitioners" (QWorld).

4.1.2.4. Uae's Quantum Technology Efforts

The Quantum Research Center (QRC) leads the region in quantum technology research and development. QRC operates under the Technology Innovation Institute (TII), a prominent scientific research center that attracts top scientists and researchers worldwide and focuses on several cutting-edge technological areas. TII is part of the Advanced Technology Research Council (ATRC) of the Abu Dhabi Government, which oversees the emirate's technology research (TII, n.d.).

Abu Dhabi has started work to build its own quantum computer and is recruiting dozens of staff to compete with the likes of Google and IBM in the uber-fast processing technology. the QRC is boosting its staff to between 60 and 80 people and collaborating with international entities such as Barcelona-based Qilimanjaro Quantum Tech. This collaboration includes building the necessary laboratory infrastructure and preparing the first qubits. Abu Dhabi's Technology Innovation Institute is aiming to build the UAE's first quantum computer with this collaboration (Flanagan, 2022)

CHAPTER 5

FINDINGS & ANALYSIS

The development of QT through the SST framework is what is referred to as "technology foresight" in the theory. This concept involves analysing both structural stability and fluidity within technological and research developments (Jørgensen et al., 2009). In other words, according to SST, future technological change, particularly in socio-technical fields like QT, is shaped by both the unpredictable nature of socio-technical interactions and by structured frameworks, or 'regimes' which include established norms, rules, and strategies that guide innovation and minimize uncertainty. The dual focus allows for a comprehensive understanding of QT, recognizing that its development is influenced by elements that guide stability and predictability in the structure while acknowledging the inherent uncertainty and fluidity that characterize emerging technologies.

In the data generation process and analysis of the findings, I made a theoretical thematic analysis through the deductive approach by applying the predefined categories of the SST theory -fluidity and stability- as the main themes of the study. The factors guiding QT development are categorized on both local and global scales, addressing how fluidity and structural elements shape researchers' work and innovation within national and international settings.

Therefore, with the necessary snapshot of the current QT research ecosystem I present and analyze my findings on three main grounds - QT research ecosystem, Fluidity (unpredictable elements), and Structure & Stability (regime elements) as the themes of the analysis. Seven subthemes (two from the QT research ecosystem, three from Fluidity, and two from Structure), 16 codes, and 22 subcodes arose from 41 quotation clusters. The details are provided in the Appendix B: Codebook.

5.1. QT Research Ecosystem

By Agarwal & Searle (2020), the concept of research ecosystem is referred as the complex network of actors, institutions, policies, and resources that support the development and dissemination of scientific knowledge and technology. It includes various stakeholders such as universities, research institutions, governmental bodies, private industries, and funding agencies, all of which contribute resources, expertise, and influence over research directions. Therefore, any data defining and explaining this ecosystem working in QT development is sub-thematized and coded under this section.

5.1.1. Global Dynamics

Global dynamics of the QT research ecosystem are fed from strategic positionalities of the countries, international relations, and international competition.

According to data, countries have **strategic positionalities** in the global network with the impact of their geopolitical/historical backgrounds. The data indicate that countries tend to develop technologies in a path that follows their geopolitical/historical backgrounds, leveraging what researchers describe as “their strengths, experiences, and expertise”. With his 21 years of experience knowing different geographical development contexts of UAE, UK, and Singapore, Interviewee AS3 claimed “If you are going to try and join a race, you'd like to join a race where you already have some momentum. You don't want to join a race where you're starting from a complete standstill.”

The cumulative efforts lead to significant variations in QT development across countries, as each country builds on specific capacities shaped by its industrial and technological legacy.

P1, a policy maker working as Director of the National Quantum Strategy Secretariat, in Canada, emphasized these capacities and explained which industries to support by claiming that

We always build on our strengths. We are not planning to create new industries that didn't exist. You already have the researchers, the company with strength, you're capitalizing on your strength and you're building it.

This means that a country with a strong automotive industry is likely to form its QT research environment in ways that integrate existing expertise in the operation and production processes of that industry. The same example is also valid for the operational routines of the countries. This preference leads to the creation of a QT ecosystem suited to local strengths and higher overall outcomes in sector-specific innovations. From the perspective of the SST, MacKenzie & Wajcman (1985) discuss this issue from the past technological infrastructure by saying that the “existing technology is thus an important precondition of new technology. It provides the basis of devices and techniques to be modified, and is a rich set of intellectual resources available for imaginative use in new settings” (p.12).

QT development is said to be not standard but strategically adapted based on existing industrial expertise and national priorities. Consequently, countries ultimately foster an ecosystem that reflects their industrial strengths. This path-dependent approach aligns with theories in the social shaping of technology, where existing capacities and socio-economic structures influence how technology develops within a society (MacKenzie & Wajcman, 1985).

Strategic positionalities also include geopolitical tensions and occurrences. In the case of the QT research ecosystem, the impact of Brexit and the current war in Ukraine was used as an example of this factor.

Interviewee AS2, who is originally from Russia and is now based in the UK, mentioned the corruption of his academic collaboration with Russia in QT development because of the Ukrainian War and said that

Russia has a quantum road map, but it is almost off the map now, unfortunately, because of the war...Through the university, the UK government instructed me to stop my collaboration. If they didn't, I wouldn't want to travel to Moscow because I disagree with the regime and the war in Ukraine, but I would want to continue to work with my group in Russia.

The other UK-based QT Researcher, AS3 accused Brexit, *a terrible blow to the entire community*, as the reason for interruptions in his research activities. AS3 said that academics in the UK are said to be heavily reliant on partners in Europe, and after Brexit is completed, the UK Researchers are trying to get back into EU Programmes of which they were already a part originally.

It is apparently seen that the significance that countries place on QT for strategic positioning on the global stage shapes how researchers view their working environment and research practices. Researchers' perceptions reflect this importance, as they adapt their methods and objectives within a research ecosystem influenced by each country's strategic priorities and operations. This environment influences researchers' approaches to QT development, guiding them to align their work with national goals and available expertise.

Another defining factor tied to a country's strategic position is the structural embeddedness of inequality in the global dynamics. According to data, researchers operate in an unequal ecosystem which they perceive as 'normal'. The reason behind that is the direct relationship between the investment and benefit. As explicitly stated by AS3, *"the countries that paid for the development of technology have probably a reasonable expectation that they'll be the first to benefit from it."* At every level of the research ecosystem (from individual to the governmental level), investment is made with the expectation of a benefit. In that logic, it is argued that the larger the investment, the greater the benefit, earlier access, and bigger profit. As underlined by A3 who is a post-doctoral research fellow with 10 years of QT research experience in the UK and Japan, *"The big and very expensive things are always going to unfortunately be focused on countries that have the investment capital available."* Consequently, the larger the benefit, there are more things to protect. For that reason, coming from his research experiences in both China and Pakistan, A1 claimed that every country that invests in QT development has protectionist policies, and hence there is no developmental equality at the global, local, or institutional level.

Structural inequalities in the global research ecosystem suggest that the disparities are reinforced, and the concept of inequality is thus normalized, as researchers accept

the investment-benefit relationship as a primary driver. This mirrors frameworks in political economy and social studies of science that view technological advancements as closely tied to resource allocation, with a nation's strategic position significantly influencing its innovation capabilities (Jasanoff, 2004).

International relations is another global dynamic forming the QT research ecosystem. The global recognition of competitive advantage in QT has created an ecosystem that emphasizes the protection of intellectual assets and national interests. According to data, researchers work within this environment, where international secrecy plays a central role, and funding administration is often shaped by this secrecy. P1 argued that *national policies are designed to protect against research security theft of intellectual property*. In some cases like AS1 pointed out, who is a researcher with 44 years of experience from the US, the protectionist approach results in restrictive conditions that isolate researchers from the broader global scientific community:

When the US government found out that I am working with Taiwan, they were not happy with that. Having to do with international relations, the US worried about losing some info to China through that...Also, in the United States, as they fund research, only if it's secret.

This competitive, protective stance can limit collaboration, affecting the pace and direction of QT research on an international scale, and also can cause various standpoints to form among researchers. For instance, while A3 is overwhelmed by the *protectionist context of the West versus China that limits the creativity of research*, P1 suggested that the major goal is *advancing the national interests*, rather than advancing the technology itself, yet being aware of the development of QT would be faster without protective behaviour. Moreover, a policymaker/researcher in France, AP1 expressed that the French government prioritizes *safeguarding its strategic assets and ensuring that technologies developed within France remain within its borders*. This approach ties these fields closely to notions of sovereignty and autonomy, often leading to a protectionist stance. However, this protectionism can become *excessive, extending to the point of rejecting products or collaborations even with like-minded countries that share similar values, which is too far*.

As investment generates benefits and these benefits create assets that require protection, global relations revolve around guarding national interests while having the necessary relations to have those benefits in the first place because full autonomy is not possible. This reflects that interdependence shapes strategies where protective measures are balanced with collaborations. This type of interaction creates what I refer to as a "globally common-local behavior," where protective measures in one region trigger similar responses elsewhere, reinforcing each other's actions in a cycle. The international relations with protectionist actions at different scales create a layered system that reflects both global interdependence and individual national interests. Therefore, it establishes a restrictive yet interconnected environment for QT research. However, the suggestion is that, in places where the protectionist approach is lacking, more progressive ideas can emerge through unity.

Although the protectionist approach limits collaboration, it is not the only reason for the closeness in international relations. There occurred the dimension of unintentional isolation in international relations. This dimension shows itself in the case of Japan in QT development, expressed by A3,

The professor I'm working directly with is German. It's interesting to see, even though he's been here for 18-19 years, how isolated even he is from the quantum ecosystem. It seemed like there wasn't much understanding on the part of the university of what creating a postdoctoral fellowship like this would entail. For a long while, the postdocs didn't exist in Japan... I think it's been noticed that the rest of the world now has postdocs and working on quantum, Japan wants to be like the rest of the world... There is this lack of international engagement, a lack of understanding of why the rest of the world is doing the things it's doing.

Japan's experience in QT development shows a certain degree of unintentional isolation shaped by the country's uniqueness, described as the 'Galapagos effect/syndrome'. The name comes from the extreme isolation of the Galapagos islands, and the main idea is that "due to language, culture, comparatively small interchange between Japan's markets and foreign markets, some technologies and some products evolved in Japan differently than in other markets" (Fasol, 2013). In QT, this dynamic manifests as Japan's practices sometimes diverge from international relations due to a focus on distinct local frameworks. While Japan has

achieved significant advancements domestically, these practices have occasionally made global integration more challenging.

Moreover, the lack of international regulations and standards is another aspect of international relations that impacts the QT research ecosystem. International regulations/standards are seen as a unifying force in the research ecosystem and the development of QT, since they form a common understanding of the design and usage of the technology. AP1 claimed that *international standards are another version of collaboration, to do a memorandum of understanding for fundamental research, or to do export control for a product, so regulating the global market would be reciprocal*. However, at this current stage of QT development, the efforts have been found ‘*inadequate, late and disappointing*’ by the researchers (AS1, AP1, AS3) mainly because *it's hard to make a standard for a device that doesn't yet exist*, as P1 presented.

From these subsections, ‘lack of international regulations’ might seem to stem from international closeness, yet this is not the case. Instead, the lack of international standards/regulations is more closely linked to the current pace of development in the field. Researchers especially highlighted this point by exemplifying the willingness of the countries considered rivals in QT development -the US and China- to create a common ground in the standardization of QT.

International competition occurs as the final global dynamic with three types of competition; political/strategic, material, and talent-based. The political/strategic competition is what is referred as ‘QRace’ in the research ecosystem. It is an analogy that suggests the importance of positionalities of countries in the QRace. The main contributors are claimed to be *the US, China, and European countries* by A1 and AP1. It is argued that the QRace is a media-guided narrative. Some researchers shared the ranking goals of their countries, such as the statement of President Macron about France's aim to rank third in quantum technologies, likely after the US and China, highlighting the country's strong position (A1). Possessing power and achieving technological dominance/supremacy is seen as one of the biggest gains of the race.

Data indicates that researchers perceive the QRace as both motivating and restricting. A1 noted that *“the governments of these countries are forcing and facilitating the researchers to work hard so that their country will be in this race, and due to this race, QT is developing very fast.”* This competitive environment is also seen as a driver for *unlocking funding* opportunities (AS3) and accelerating QT progress by *challenging the researchers*, as highlighted by A4, a PhD student from Cameroon with six years of experience in the field. According to the researchers, winning the race, or even being in the race, gives the opportunity to have the power to be advantageous in the market and set the standards. Hence, it leads actors to work harder and invest more, increasing funding for R&D while supporting the recognition of technology.

Conversely, it is argued that the QRace can hinder development by prioritizing quantity over quality, cutting off collaboration and communication between actors, and creating a divide that restricts access to the benefits that QT could provide. A3 experiences the communication and collaboration shut down as *a paranoid attempt to try and seal each country's works and just have everyone looking over their shoulders to make sure no one's copying them.*

The main problem in the eyes of the researchers was the transformation of the ecosystem is undergoing to a quantity-based success. Through the administrators' approach, QRace can make researchers focus more on increasing measurable metrics like the number of qubits, rather than on 'meaningful' advancements and qualified research that help the technology to work better at its full capacity. A3 declared the unhelpfulness of following success through the headlines of “being ahead” since it makes researchers *being judged on that basis which might lead them to steer their research in the direction of "go on, stick an extra like double the number of keywords, even if they can't control them, just double the number of qubits.*

This issue has two key aspects of reason, the inherent risk in pursuing high-quality research and the pressure from funding agencies to produce a high volume of work. By AP1, this case is exemplified through the US for being extremely competitive, thus putting high pressure on researchers, and restricting the research, contrary to

France. Meanwhile, an important contribution of this discussion is the diverging objectives between researchers and investors/governments. Contrary to the investors, or administrators the researchers are primarily driven by the aim of innovation and discovery, with financial gain or national recognition often being a secondary/ less significant goal. A3 emphasized this point by stating that science is, and ought to be, a shared resource accessible to all. It represents a collective wealth meant for everyone's benefit. The majority of scientists pursue their work not out of nationalism or financial gain but out of a genuine desire to discover new knowledge or create innovative technologies.

According to the researchers, the focus should be on developing high-quality qubits that work effectively, rather than simply increasing their number. In addition to that, pursuing quality in quantum research is found risky by the researchers. The riskiness of pursuing high-quality research and the pressure from funding bodies to produce a high quantity of work lead researchers to focus on less ambitious projects because researchers put their reputations and careers on the line. Furthermore, this push from funders for a high quantity of research outputs can trap researchers into focusing on less qualified projects that are more likely to succeed in return for rewards like money or promotion. This focus can lead to a neglect of basic research, which is crucial for long-term advancements in QT. AS1 explicitly complained about this tendency by arguing that

Most people talking about how many qubits you have. And if you have a lot of qubits, but they have a lot of errors to it, that's a useless machine. But it's hard to solve the hard problem, because if you fail, you may lose your funding. So, it's a natural tendency to solve the easier problems...It's a worldwide problem: if you want to advance in your scientific career, you have to publish a lot of papers...It is so much easier to get promoted by doing incremental things that are useful. But if you want to do something really new, still you don't want to be too disruptive.

As a result, this situation results in a cycle where incremental advancements are prioritized over groundbreaking research.

QRace encompasses both national-level and company/individual-level competition. At the national level, the primary players are suggested as the US and China, with

European Quantum Flagship countries participating for subsequent positions. Some countries out of the US, China, or EU, like Russia, also view themselves in the lead positions. The literature review showed that countries with national initiatives or strategies, implemented through government-academia-industry collaboration, are more confident about their place in the race. Among the countries that are selected to investigate for this study, Canada, China, France, Japan, Russia, the UK, and the US aim for leadership in at least one area, while Singapore and South Africa majorly focus on development rather than leadership.

Based on participants' statements, two main categories of countries emerge in relation to their roles in the QRace: Aligned and Unaligned. Aligned countries aim to lead in QT development, while unaligned parties support these leaders, contributing as suppliers by aiming for the prize of accessing and applying the advancements of aligned nations.

The data reveals distinct roles for different participants in the QRace, each influencing their respective research ecosystems. The driving narratives behind QRace motivations differ between these categories. The research ecosystem of aligned countries operates with the narrative of "losing the race", emphasizing the competitive edge needed to maintain leadership, just as AS1 shared his concerns about *China beating the US*. He suggests that China might claim to lead globally, though this may not be entirely accurate. However, publishing a single influential paper could create that perception and potentially prompt the US to revise its policies, much like the reaction to Sputnik.

In contrast, the research ecosystem of unaligned countries operates over the "fear of being left behind" narrative, reflecting an urgency to keep up and benefit from existing advancements. AP1 suggested the *fear that some countries that are less developed will fall behind, and will not be able to follow up with this technological development*. This narrative bonds the countries with a necessary strategic collaboration. According to A2, *"If you are a country like South Africa, you don't have any sanctions, you need to collaborate. You should have started by now because it's a fast-paced technology. every fast-paced technology and you don't want*

to be left behind.”. These countries see their position as not aiming to compete directly with the US or China, which allows them to remain open to the global scientific community, and benefit from that openness as stated by S1, the researcher who is from Russia and moved to UAE as a result of the lack of collaborative opportunities.

This framework highlights a global QT development landscape that is asymmetrically structured. A3 explained his experience with the significant disparity in research infrastructure between developed and developing nations. Even between two developed countries like the UK and Japan, he found the gap evident, and suggested that *“it comes down to having the relevant researchers to build up the ecosystem and having the investment to be able to then make it into something”*. Hence, this outcome indicates that globally restrictive research approaches are prevalent among competitive, aligned nations, while unaligned parties tend to support a more open exchange of information. In other words, aligned nations continue to push the boundaries of QT through competitive innovation, and unaligned countries situate themselves within collaborative frameworks, promoting the developmental power of shared knowledge. Ultimately, the interplay of strategic motivations across these categories has created an uneven but interdependent research ecosystem.

Small countries that can help serve the rest of the world that aren't already part of the EU, North America, and China. There is some narrative around that contributing by being an unaligned third-party/country...I wanted to ensure that when someone built a large-scale Quantum Computer, Singapore would have had access to that technology, and they have it. Here in Abu Dhabi, it's premature.”

The countries that are invested in the QRace are aware that the focus is more on the idea of force and strength created by media and narratives rather than on the genuinely beneficial outcomes of the QRace. P1 argued that being the first one who does that work means having the ability to set the standards. It is so much more than the ‘power of having something’. What is chased by the countries in the race occurs to be mostly ‘power of having power’. AP1 claimed that power is what steers the QRace since it affects all transactions and applications. This kind of approach

inherently affects how QT is preferred to be designed to maximize this advertisement, instead of maximizing the social benefit, etc. On the other hand, arguing that it is all hypothetical would be a deception. The position in the race determines the degree of access and the speed of obtaining the benefits. For instance, a country with domestic production capabilities and higher ranked due to fewer impacts from export restrictions or policies can access technology and its benefits faster and to a greater extent. Therefore, ‘power dominance’ is another narrative of the driving force of QRace.

Furthermore, material competition has a heavy influence on the research ecosystem since the geographical and logistical challenges of obtaining the necessary scientific components, equipment/materials related to QT are evident. Data indicates that the limited number of suppliers and export constraints in the field of QT lead to long delivery times and difficulties in obtaining necessary equipment, particularly for niche or high-end technologies to be acquired by the countries that do not have the capacity to produce their own products and, therefore, can only access the product through export. AS3 shared the challenges of reaching the materials produced by three-four countries by stating that *“For an experiment, I needed to buy some components of new specific microelectronic mirrors, and the cheapest we could find was from in Japan. But it took about 3 months to have to deal with various different agreements and signing to say we weren't going to use it for X, Y, and Z purposes. We weren't going to take it apart and look what was inside it then we weren't going to sell it to anyone.”* S1 further explained that in countries like the US, scientific components are delivered quickly, often the next day, whereas in the Middle East, the smaller market for QT equipment leads to longer delivery times. In addition to material competition, the effect of competition on the QR-related talent market is discussed around the arguments that everywhere, the main limiting resource, regardless of country, is access to talent. The larger societies have a larger capability to serve and find talented people which results in a brain drain with a winning side and a losing side, as stated by S1 and AS2. This kind of brain drain is driven by competitive global job markets that offer better resources and opportunities for career advancement, therefore adding a pull effect to the comparison process of the researchers, rather than merely depending on the push effect of the home country.

Moreover, there is also the challenge of keeping people in academia. *“You'd like the people with PhD and skills that you trained to become postdocs. But then, start-up companies are trying to hire these guys into senior positions, offering equity and high salaries that it's hard for the universities to match.”*, said AP1. It is stated that the conditions of QT start-ups draw talent away from academia, impacting the continuity and depth of research in university settings in the same country as well. AS3 further evaluated the issue as suggesting that

People are protective of talent. Manpower is one of the issues we have. You must ensure that you attract talent and then retain it. You want to keep the people in your company that have skills and not have them being approached by other people. I see that within the Abu Dhabi ecosystem...In Singapore, the academic institutes that have created all these trained people are then at risk of losing these people in the spinouts that they have created. The talent competition probably hits us (UAE) a bit harder than it does people in the more established economies.

These issues vary across nations due to differing development dynamics. Countries with less-developed economies often lack the financial resources and infrastructure of developed nations, forcing them to adopt rather than develop new technologies from scratch. In that sense, the challenge arising from the inadequate infrastructure affects developing regions' ability to compete globally.

In addition to that, the competition for skilled professionals is intense. The countries that can offer better living/ working conditions and potentiality in the field lead to brain drain from the countries with fewer opportunities. This drain results in a concentration of talent in regions that already have significant advantages in QT, further widening the gap between developed and developing areas. Universities in less developed regions struggle to attract and retain talent, which affects the efficiency and output of their research. Furthermore, the competition between academia and the sector for talent and resources creates additional obstacles. Better conditions in the private sector attract top talent away from academic institutions, leading to inefficient research environments within universities. This situation is compounded by the fact that the private sector often has more resources and better infrastructure, making it an attractive option for researchers. According to the SST

theory, as soon as technological systems get in touch with the market, operate as economic entities, and participate in market competition, they are driven to experience technical change. This process becomes unavoidable, with its characteristics and direction heavily influenced by market forces. In a global market where national economies are interconnected, technological advancements in one country can create significant pressure for similar changes in others (MacKenzie & Wajcman, 1985). Therefore, the principle of "Economic Shaping is Social Shaping," as emphasized by SST theory, directly applies to the competition for talent and materials within the QT research ecosystem, illustrating how economic dynamics inherently influence the research environment in this context.

5.1.2. Local Dynamics

The data indicates that local dynamics shaping the research ecosystem vary based on the level and nature of involvement from both government or other funder entities and researchers themselves. Researchers argue that **government and company involvement** drives the direction and scope of QT research, influencing how freely knowledge and resources are shared, how funding is allocated, and how regulations shape the global and local competitive landscape. A1 explained that China allocates substantial funding to QT development and has a large number of researchers working in the field. They additionally highlighted that the *Chinese government's strong commitment to advancing QT provides great opportunities for researchers*, which is why China is progressing so quickly in this area. The preference (or necessity) for government-level involvement is an opportunity for some researchers and an obstacle for others in the research ecosystem depending on the governmental and operational mindset. According to A4, the primary limitation of their work is the lack of government support and recognition. They noted that while they have the necessary expertise, there is no infrastructure to fully *dive into* their research. As a result, their focus tends to be more theoretical than practical. This means that awareness level is crucial in determining the well-being of the research ecosystem. As a contrary example, AP1, stating they are very satisfied with France's national initiative, suggested that *"apart from the funding, the government having a plan is a demonstration that the country is dedicated, and committed to advancing this field."*

In cases, such as Singapore exemplified by AS3, it is argued that early and steady investment results in a better working environment and global recognition of the country.

In Singapore, there's been a sustained 15 to 18-year investment in this field, and it's really paid off from there. Now they are recognized as a kind of global hub for this technology... They have more experience with QT, and the funding is quite competitive. But in Abu Dhabi, they're new at all of this. There's less understanding of QT. We don't have the same funding environments.

In the cases where there is **researcher involvement** and high awareness of the top managers/industry/academy about the nature and possible implications of QT development, the top-down shaping nourishes the ecosystem and QT development. How researchers perceive their inclusion or exclusion plays a significant role in how they define their research environment and the level of support they feel within the ecosystem. AS2 provided the example of the Russian Quantum Center to indicate the positive impact of researcher involvement, claiming that this center provided significant opportunities for domestic scientists to remain in the country while also attracting foreign talent. Such efforts are described as pivotal for the survival and advancement of national scientific ecosystems, while a strict top-down approach can lead to researchers being excluded from having roles in technology development, reducing them merely to 'tools' rather than active contributors in the innovation process. The US is given as an example for this case. Despite having significant QT awareness, its approach has often involved a structured, top-down management style that consciously directs the research ecosystem with clear objectives. AS1 observed that the US government imposes strict rules without room for negotiation, leaving researchers to simply comply. They added that if funding authorities had a better understanding of the challenges involved in building a quantum computer, the situation might be different, and further stated that:

It's very hard for me to do something here. I think if I were in China, I would have made that much easier time. I'm a little bit afraid that China is very committed to doing whatever it can to be the world leader. Whereas in the West, there's a lot of other politics going on. And when I was at Google, there were politics. The ultimate goal was not to build the quantum computer, the ultimate goal was to make sure everyone was happy.

Additionally, in cases where awareness of QT is lower among administrators, top-down guidance becomes restrictive, influencing every stage of the research process, including collaborative efforts. One obstacle identified by researchers in the international network is the copying of trends without understanding their purpose. The lack of an established infrastructure might be an indicator of the implementation of innovations and new operational systems without a clear understanding of their purpose or the necessary steps in the processes. This creates a gap in the operational structure, leading to bureaucratic complications and confusion for researchers, as A3 clearly stated that,

It seemed like there wasn't much understanding on the part of the University what creating a postdoctoral fellowship like this would entail. For a long while, the postdocs didn't really exist in Japan, or when they did exist, they only existed for foreigners... I think it's been noticed that the rest of the world now has postdocs, and Japan wants to be like the rest of the world... There is this lack of international engagement, the lack of understanding why the rest of the world is doing the things it's doing.

Moreover, regardless of the awareness level of the administrators and companies, the possibility of exclusion of the researchers from the decision-making process is prominent. Regarding this issue, AS3 reflected on the tension between the need for market exposure and the caution of stakeholders. They emphasized the importance of receiving societal feedback to ensure that the technologies being developed address real-world problems. However, they noted that their stakeholders are hesitant, believing the technologies are not yet ready for such a step. While the interviewee disagreed with this cautious approach and advocated for faster deployment, they acknowledged that the decision ultimately lies with those controlling the funding. Therefore, the gap in the understanding of the governmental mindset indicates a problem for researchers since they rely on a mindset and understanding that is aware of the reasons and results of the work done. Otherwise, a system that does not allow bottom-up shaping, but also fails to facilitate a conducive atmosphere for research through top-down guidance.

The data points out a locally diverse practice of designing grant proposals based on QT. According to this experience, writing grant proposals in a strict box of guidance

results in a standardized QT production. It occurred that this national behavior is determined by the goals and motivations of the funders. The underlying thought of this approach is that competitive funding leads to unequal distribution of resources and one-sided technological development. AS2 highlighted issues with funding distribution, explaining that in some cases, only a single team benefits from a hub, leaving the broader community without support. For such cases, data results in the existence of an obstacle specific to the Western mindset. It is the requirement to apply for grants, competitively in most cases. For the researchers, this requirement limits their creativity and freedom of innovation, as they must constantly seek funding for their research projects, and these funds are given in strict areas. S1 pointed out that *“If you just have a wild idea that you want to try, usually there is not much possibility for it. What could be named as an obstacle in researchers’ life in the West is this requirement to need to apply for grants all the time”*. Moreover, AS2 presented their experiences of the “Western mindset” by stating that:

Something that made my work in Russia, for example, very comfortable, and I don't find anywhere else: the need to apply for grants. So the work of a scientist consists of many aspects so actual research and teaching. Then, studying other people's literature, attending conferences, writing their own papers and writing Grant reports. So writing grant proposals takes significant part of time, and then there is never a significant sense of security. So when you write a grant. Then you never know if you actually receive it or not, and hence long term planning is not possible. And also it's not possible to develop. If you have great ideas right, you have to always correlate it with what the community thinks right. So if you just have a wild idea that you want to try, Usually there is not much possibility for it. Because you have to apply for a grant. The grant has to be approved, and so on. what could be named as an obstacle in, researchers’ life in the West is this requirement to need to apply for grants all the time.

Consequently, a reluctance towards the requirement to apply for grants all the time is observed because it limits the creativity and freedom of the scientist. The obstacle of the necessity to apply for competitive funding that provides a framed research topic is seen to be a controversial issue. Understandably, the necessity to apply for grants reflects a developed and advanced research environment where the distribution of funds must be carefully managed to support the most promising projects. This system ensures that investments are made strategically, which can lead to significant

advancements in specific areas of research without 'wasting' any time (because, in this case, doing an experimental study, which is unlikely to give concrete results, may tend to be seen as a waste of time and resources). However, it also means that scientists must spend a substantial portion of their time and energy on securing funding rather than focusing solely on their research. This process can also restrict innovative ideas that do not align with current funding priorities or the mainstream views of the scientific community. Hence, long-term planning becomes challenging, and researchers may be discouraged from pursuing groundbreaking or unconventional ideas.

Furthermore, as a result of this distribution practice, the development occurs only in the chosen areas. The choices of the path development of administrators/funders on which QT is supported and with what means varies across countries depending on the capacity and the historical background of the decision-maker. A1 shared their observation on distinct priorities and progress levels in QT development across regions. According to them, the US leads in quantum computing, China excels in quantum communication, and many European countries are advancing rapidly in quantum Internet. They further highlighted a disparity in focus between developed and developing nations, noting that while developed countries like the US and China prioritize practical applications, researchers in developing countries tend to concentrate more on theoretical knowledge. AS1 also added insights into this discussion by suggesting that “*China is the only country that really pushed towards that goal, but in Europe, people want to publish papers.*” In other words, technological interests arise from a combination of a nation's capabilities and strategic preferences. In selecting areas for QT development, protecting the limits of an already-established ecosystem -often referred to as "*building on strengths*"- is a key factor.

As a result, the researchers' involvement level highly influences the working ecosystems in funding and strategic decision-making. When researchers are active participants, it allows them to decide on resources and the path of innovation, giving them an opportunity to be creative in this path. If this bottom-up shaping is allowed by the top as well and made a collective understanding/strategy in the field, it would

be the optimal research ecosystem. However, limited understanding or lack of support from top-level managers restricts both funding opportunities and the potential for bottom-up contributions. The gap between what researchers can provide and what higher-level leaders prioritize can create challenges for innovation. This often leads to focusing on meeting specific goals instead of finding the maximum potential of QT. To address this issue, there is a need for collaborative structures that value both strategic ideas and practical insights.

5.2. Fluidity

In this study's approach to QT development, I take fluidity as one of the core elements shaping the evolving research ecosystem. Fluidity here refers to the adaptability and dynamic nature of QT's progress coming from QT's unpredictability - a mix of evolving scientific advancements, national priorities, and international partnerships. This adaptability shapes how researchers approach each step, from securing funding to managing collaborations, making them active in both innovation and shifting global strategies. Here, fluidity is not just a characteristic; it is a driving force that requires researchers and policymakers to constantly reposition themselves. In the analysis of the data, three categories occurred out of this aspect. These are fluidity in technological and scientific capacity building, fluidity in meaning creation, and fluidity in adapting QT development strategies.

5.2.1. Fluidity in Technological and Scientific Capacity Building

The data indicate that the **scientific and technological progress** of QT is still in its early stages, more a beginning than an end. For AP1, *there are lots of things to do*, for P1, *all these talks about the technology are actually about the prototypes*, and AS2 and S1 saw the main obstacle as the *intellectual one*. This period is marked by exploration, experimentation, and incremental improvements rather than hard outcomes, reflecting the unpredictable and fluid nature of QT. Since there are so many unknowns, both in terms of the technology itself and its future applications, researchers acknowledge that they are currently laying a potential foundation rather than realizing immediate results. The researchers stated that many QT research

efforts are currently fundamental, yet are inadequate. AP1 highlighted the necessity of making incremental technological improvements alongside new, innovative ideas to match everything in the field. AS1 adds that despite the field's long history—approximately 20-30 years—people continue to generate new, original ideas, highlighting the field's ongoing evolution and adaptability. The primary reason for this inadequacy in fundamental research is argued to be the limited collaboration between institutions and countries. This lack of openness restricts information-sharing and the creation of a collaborative environment that could greatly benefit the field's development.

Moreover, the need for repositioning the actors comes from the unpredictability of QT at this stage of development. The lack of knowledge of the outcomes results in varying funding structures and the degree of protection of the national efforts. AS1 explained that in quantum computing, existing 30-year-old machines are being used in novel ways, making it *unclear how to protect such advancements*. They also highlighted that the US government is deeply concerned about China's progress in QT, as they feared that *if China gains a lead, it might achieve capabilities the US cannot match due to the transformative and unpredictable nature of the technology*. Therefore, it is logical that in an emerging technology, the inability to provide answers to scientific questions and/or mechanisms that do not have sufficient capacity limits development.

The fact that QRace pushes actors to bet on multiple technologies simultaneously due to uncertain outcomes would be a clear outcome of this issue, as P1 stated,

Will they all work technologically? probably not. Which one of those will win? I don't know but they're not all going to win. So, as a country, you want to have ideally one competitor in each of those. So whichever one wins, you have that architecture to try and sell it export.

When this fluidity came across with its inherently flexible nature -offering a range of potential technologies and diverse applications- it introduces an added layer of caution to its development journey. Hence, there are both scientific and technical problems leading to a feeling of insecurity for the researchers. The content of their efforts is as vague as the ground they plan to insert those efforts.

The lack of practical utility and the gap between the theoretical potential of QT and their current practical capabilities stresses the need for continued R&D. The data points out the expectations of the researchers for the future projections of QT and the outcomes of its adoption by society.

Furthermore, the hardship of developing hardware is specifically mentioned by A2, AS3 and A1, stating that it *is quite niche and the standardization is difficult at this moment*. The challenge of developing hardware shows itself in the literature review as well. The South African Quantum Technology initiative is prepared according to the mindset where the emphasis is on “quantum technology”, rather than “quantum science”. The idea behind SA QuTI's operation is for South Africa to prioritize software development and app creation for quantum computers rather than focusing on hardware construction, aiming to occupy a strategic position in the global quantum community. Given that hardware development requires more practical work and funding, while software development is more theoretical and less costly, South Africa appears to be shaping its national strategy based on a careful assessment of its strengths and limitations. “South Africa cannot compete with the billions of Euros invested in quantum technology development in other countries. That is why we have to be strategic by bringing together our quantum community – research, academia, government, and industry – to save decades in time and money,” explains Forbes, the leading professor of the initiative. This approach is called as “side-stepping the competition”. SA QuTI aims to avoid direct competition by focusing on a niche within the quantum field. To understand the philosophy of the 'side-step the competition' further, “...take the smartphone industry: you don’t have to be a smartphone manufacturer to be part of the smartphone revolution – the economy of smartphone apps is huge, perhaps even bigger than the phone industry itself (Wits University to Coordinate South Africa’s National Quantum Initiative, 2021). Following the mindset of how the smartphone app industry thrives alongside smartphone manufacturing, they plan to impact quantum computing by developing software and applications for quantum computers, rather than building the hardware. This strategy leverages South Africa's strengths in software development, offering a more efficient and cost-effective path to influence the global quantum community.

Data indicates a further issue over the lack of trained researchers/workers in the field as a QT development capacity problem. This shortage reveals that there is both limited access to skilled talent and a lack of individuals with practical experience in this field. As the technology and its applications continue to develop, the demand for specialized expertise changes as well. AS3 argued that while there is a shortage of people interested in the field, *it is harder to find candidates with the necessary qualifications and hands-on experimental experience*. P1 also stated that although Canada trains a lot of people in QT, the availability of a trained workforce is still a challenge for the national goal of QT development. Therefore, the fluid nature of QT research means that discoveries regularly alter the skill requirements, presenting ongoing challenges in building a workforce capable of meeting these demands. A3 additionally linked this issue with the capability of the nations by arguing that,

To work on communications and quantum computing, you do cutting-edge research, and the main limiting resource, regardless of country, is access to talent. In a larger society, you would have a larger capability to serve and find talented people.

The scarcity of skilled professionals who are experienced in experimental areas is a common challenge across different countries and industries while the size of the society is also seen as a factor in the talent source, necessarily depending on the capability of that size.

On the other hand, the data shows that there is a **technological relativity** issue regarding QT, meaning that there could be two usages of one QT or there could be two positionalities of one QT. This relativity captures how one QT innovation can serve two different purposes or positions depending on how it is designed, reflecting flexibility that can shift based on strategic or practical needs. This duality in QT perception underscores how the technology's potential can adapt according to its positioning, allowing for multi-purpose uses. The first one comes from the nature of QT, which provides dual applications, one named risk, and one named benefit in this case. The second one is a result that emerged by reading between the lines of the generated data. It was determined that what is beneficial to one actor (nation, company, society, etc.) is a risk to the other actor. I referred this as two

positionalities of one technology. AS2 shared a direct indicator of this relativity through these words, *“The most well-known offensive side is that the quantum computer can decrypt public key cryptography and make many commercial technologies useless... That will be a significant disruption. But it is also a technology that protects us against that...and has already been commercialized. It's already successful. So, the shield is ahead of the sword.”* With the shield-sword analogy, it is seen that the same quantum technology can be used both as an instrument for protection/defence or attack depending on where you are looking at that tool. The decision of this usage is explained by AS3 as,

Who's evaluating risk versus benefit usually happens at the funding level. The individual researchers have their own prerogatives. The funder guys make those decisions, and the private companies will be the ones who ultimately decide who has access to, for example, large-scale corner computers, and they'll probably give it to the highest bidders. So, from that sense, it won't be equitable at all.

AP1 saw this issue as problematic by claiming that, *“The various applications can potentially help even the malevened parties. So, communicating with absolute security without being intercepted can also help people who don't want to be intercepted.”* This perception, therefore, is one of the justifiers of the protectionist approach.

5.2.2. Fluidity in Meaning Creation

The fluid meaning of QT is one major aspect depending on the **lack of value proposition** of QT. I can state that, the value creation, or proposition, may be one of the most important and intricate processes for emerging technologies to gain. The Social Construction of Technology (SCOT), which is a more centralized subfield of SST theory (MacKenzie & Wajcman, 1985; Howcroft et al., 2004), conceptualizes the fluidity aspect in meaning creation as “interpretative flexibility”. It mainly works in making sense of the imagination process of the technology. For this fluidity, there occurred two opposite approaches that could settle as a ground for the prospective value of QT. One of these approaches is coming from the unfamiliarity and anxiety toward QT among potential users outside of the field of quantum. There is an

undeniable anxiety from both people in-quantum and out-quantum which stems from not having enough knowledge and not being able to foresee the future. At this point, filling in a concept causes great pressure and is overwhelming due to the multitude of possibilities. The other approach is that the concept is emptied of its content and loses its importance in a way because it is seen only as a tool that will make things go more easily, which is the very purpose of technology. According to the information obtained from the data produced, these two opposing scenarios exist simultaneously in the QT development phase. Therefore, just as the same technology can have different areas of use, in this case, the perception of the QT can consist of both;

- o Overwhelmingly many possibilities - the uncertainty that arises from this and the hesitation that arises regarding the future – and,
- o A point where all possibilities can be ignored and it does not matter what its features are, only in practice, because it makes life easier.

Regarding the uncertainty aspect, it is noted that people outside the quantum field tend to view these studies with scepticism and even fear. A4 stated, *“The main obstacle is our mindset. Because quantum studies are looking in a magical way, like a story of witchcraft. There are a lot of things to stigmatize this topic in our wish.”* P1 also pointed out that a key challenge for QT lies in the unfamiliarity of those outside the quantum industry by arguing that *“they're a little bit scary for those who are not familiar with them. Because people don't understand, they don't know, and they're not comfortable with it. There is a general malaise.”*

On the other hand, the unpredictability of the results and processes leads to the lack of value proposition of the technology. While this confusion and discomfort stem from a lack of understanding, which may block the development or adoption of QT, the real value of quantum technologies may get lost in the practice. According to the P1, the potential buyers are not interested in the quantum nature of a product, but in its tangible benefits, *i.e. they just want something better*. In this way, being that ‘something better’ becomes the only definer of QT in this case. Furthermore, AS3 indicated that,

There's plenty of quantum technology already, like semiconductor fabrication, mobile phones, GPS, and stuff. No one calls those quantum technologies. We just they're just technology. So the sign of a successful technology is when it gets absorbed into society, but we should not forget about what was to begin with.

This disconnects the technology's potential and its perceived practical benefits and creates a significant barrier to the technology's value acquisition process. On the other hand, it signifies an indicator of successful adoption of the technology. The problem with this, according to the researchers, is the restriction of the potential of QT.

The current **hype of QT** is another fluid element of this meaning creation. Basically, the concept of hype refers to "over mediatization and inflated, excessive or misleading claims that are applicable to particular products, products categories, technology trends, scientific domains, personalities like artists or politicians, and even speculative financial bubbles and scams" (Ezratty, 2022, p.2). According to the data, the QT hype is shaped by the manipulation of media and creates a public perception that drives innovations. S1 stated that they *expect that the current level of media attention is not sustainable, and drop off over time*. A3 also considered that *when things do not immediately match the hype, quantum winter starts, which inevitably is going to happen with any technology because "things never match the hype"*.

The hype surrounding QT is significantly influencing perceptions of its potential—whether as a powerful advancement, a risk, or something to admire or fear. Often described as "revolutionary", AS3 reflected on societal concerns surrounding the disruptive potential of QT, particularly regarding new materials or optimizations emerging from quantum computing. They noted, *"These advancements will clearly be disruptive, and with disruption comes the risk of negative consequences"*, and emphasize the importance of societal preparedness to address these challenges, pointing out that while the risks associated with quantum technologies are well understood, the uncertainty lies in their timing. By asking *"When will the so-called quantum apocalypse—or whatever buzzword we're using—actually happen?"*, they

highlighted the unpredictability of when these risks will become relevant. QT gains both increased funding and competition, as countries start to see research developments as assets that require protection. However, the unpredictability/fluidity of QT adds complexity to these perspectives. This openness means that QT's value and significance can be interpreted in many ways, making it easy for stakeholders to project both optimism and caution. Consequently, while the hype generates crucial support and attention, it also adds a strategic and sometimes cautious tone to international and national QT initiatives.

5.2.3. Fluidity in Adopting QT Development Strategies

Countries/firms and institutions differ in their strategies. As I discussed in Section 5.1.1. Global Dynamics, these strategies can be adopted according to their geopolitical positions and historical backgrounds. However, in addition to the unique conditions of the adopter actors, the conditions of the adopted subject, i.e. QT, matter as well. Since these conditions are unpredictable at this stage, the data reveals that the fluidity in the understanding of the networks QT develops in impacts the strategies of the developers, mainly the administrators. P1 suggested that *“Different countries have different strengths right now. I think some countries are a little bit ahead in one area, and a little bit behind in another. It's hard to say what kinds of technologies will win out.”*

Researchers experience two types of strategies at the governmental level. The first one is the necessary **prioritization of specific QT**. This causes a race between the technologies and a path-dependent innovation model, meaning that current technological developments and choices are heavily influenced by past decisions, leading to a specific trajectory of innovation (David, 1985). S1 highlighted the importance of prioritization in technological development, emphasizing that no single entity can do everything. They provided examples from the semiconductor industry, *“Japanese manufacturers focus on crystals, Taiwan specializes in final manufacturing, and some European countries are dedicated to building equipment.”* On the other hand, AS3 emphasizes the *cautiousness of the UAE in terms of not wanting to waste resources.*

The second type of strategy arises from the concern for **being ready for the fluidity** in the technological variety. For a ground as slippery as this one, industry and governmental decision-makers, who could afford it, choose to make investment and knowledge accumulation on various QT types. They are “betting” on many technologies at once for the possibility of one of them winning, as AS1 suggested,

What QT is capable of is such a novel way to process information that could be really powerful. People want to learn about it so that when the breakthrough comes then the companies and countries won't be flat-footed. So, a lot of it invests in to make sure you understand what they can do.

As I said, this strategy carries the worry of being ready. Being ready to catch the train, as Ahiska explains "the apparent emphasis on movement and speed best exemplified in the metaphor of 'catching the train' before it is too late" (2003, p.352), although she uses in a different context. From the perspective of A1, being ready is *both forward-thinking and protecting itself in the case of a big exciting development that they can take advantage of it right away*. As a result, the participants argue that this pushes countries in the race to advance many QT areas as much as possible. AP1 indicated that *"You don't quite know yet what the applications will be, for some cases, we literally don't know what the applications will be. We just know how important these applications will be because we have good evidence that they can be game-changing. So everybody is trying to advance as much as possible, but some big countries managed to develop quite a few of these technologies, so they do not have to necessarily choose."*

Of course, the motivation behind this act of being ready is for such reasons as protecting or benefitting. Therefore, this act also holds the development path over certain lines of interest, not quite aiming to discover something that no other party would be interested in getting the benefit of.

Otherwise, the act in question would not be 'being ready', but it would be 'pioneering exploration,' aiming to discover paths without needing immediate, tangible benefits that attract competitive interest from other nations. This approach would prioritize curiosity and fundamental advancement rather than practical preparedness for an expected outcome.

5.3. Structure & Stability

In discussing structure and stability within the QT development landscape, my analysis focuses on the frameworks and infrastructures that guide research environments. Structure and stability refer to the institutional, regulatory, and policy-driven elements that offer a foundation and a framework for researchers to operate. These factors are also known as 'regime elements' such as standards and regulations in SST theory. This analysis divides structural elements that are detected to have an impact on the development of QT into components of QT-specific and non-QT-specific.

5.3.1. QT-Specific Regime Elements

The data indicated that government initiatives, educational programs, scholarships, and funding coming out of the regulations/initiatives/standards that are specifically tailored for QT are crucial for the advancement of QT. Interviewees who defend the positive impact of regulations see the regulation as an awareness step at the governmental or institutional level. AP1 highlighted that certified products are essential for driving technological progress and supporting regulations to manage the usage of technologies with their full implications. AS3 stressed the necessity of standards for the implementation and adoption of QT, arguing that *without them, market accessibility would be restricted, slowing adoption and increasing future risks*. Similarly, S1 underscored the transformative potential of international standards, citing the quantum key distribution standard as a positive example that *enables market development and fosters international collaboration*. Finally, AS1 advocated for benchmarking in quantum computing, pointing to *experiments like quantum supremacy as valuable efforts that drive improvements in qubit quality and facilitate the creation of more practical technologies*. Therefore, according to data, the awareness of QT's possible implications and its imagination has the power to increase the pace of development by guiding the researchers in a way that either benefits the QT development and market dynamics or benefits the nation.

As it is seen in the example quotations, standardization in QT is the most suggested regime element for the **benefit of the technology** itself. There is a significant

detection that the standards and the regulation dynamics are market-based and the meaning of standards comes from mutual recognition and validation of the parties.

On the other hand, what is argued to work for **benefitting the nation**, is expectedly national policies. AS3 highlighted Singapore's long-term investment in quantum technologies, noting that sustained funding over 15–18 years has yielded significant outcomes, including the establishment of 4–5 spin-out companies and strong academic engagement. This effort has positioned Singapore as a global hub for quantum technology. AS3 also pointed out the crucial role of legislation in driving technological adoption, particularly in sectors like banking. They observed that quantum-safe techniques are unlikely to be adopted without legal mandates, citing the UAE as an example where government legislation enforces a gradual transition to quantum cryptography. Another example of this issue is given by A1,

China has a lot of funding for this purpose, and many people are working on quantum technologies. I think the Chinese government doesn't compromise on funding for any type of obstacle. There are many more opportunities and the people that are working very hard to make some progress in the field of quantum technology. China recently launched a quantum spaceship, and they made a lot of progress in quantum communication with the help of that spaceship. So, in this way China is progressing faster in this field.

They play a significant role in protecting the value of the work done in QT. According to the researchers, these policies ensure that collaborations, especially in critical areas like quantum communications, are carefully managed to protect "national interests". AP1 emphasized *the importance of maintaining secrecy in "strategically significant areas"*, noting that the classification of such technologies as vital ensures tighter control over their use and dissemination. It is also mentioned that, although regulations are helpful in this sense, they may limit collaborative activities, hence the development of QT.

The participants who see the regulations positively find the implementation of regulatory frameworks as crucial for the widespread adoption of QT and eventually for national development. In that sense, regulations ensure the transition from previous technologies to QT. That decreases the risks resulting from the slow adoption.

In another case where there is a lack of awareness of QT in the structure, the negative impact of it is seen as well for both technological and national development. For instance, A4 shared that they are working with their supervisors to demonstrate the feasibility of advancing quantum technologies within their country. However, they highlighted a significant challenge rooted in what they described as the "*Cameroon mindset*" where progress often faces bureaucratic difficulties and delays. They noted with concern that the government does not prioritize these topics or take them seriously.

Therefore, early and steady investment contributes significantly to the formation of a healthier structure for QT development. The role of government is crucial here, as its standards and regulations shape the field by highlighting its importance and potential. These efforts often include funding and standards that support interdisciplinary collaboration and create common interests within society. Local regulations, meanwhile, serve dual purposes: they not only provide strategic development and protection but can also reflect a form of nationalism, positioning QT as an asset protected for national interests.

Additionally, the structure formed with the awareness of the QT's potential was proven to be helpful by providing a quality working environment both locally and globally. In other words, the data showed that QT-specific regime elements result in the **creation of an international-level common interest**. AP1 highlights that the need for standards in QT is a universal discussion, with active efforts seen in regions like Asia, the US, South Korea, Singapore, Japan, Canada, and even China. They pointed out that *there is a shared understanding across these regions about the importance of pushing for standards to drive progress in the field*. AS1 added that things are shifting positively, with *more international agreements and better funding coming into play*, making collaboration smoother and more effective. Hence, it is emphasized that standards facilitate global market integration, and enhance collaboration and mutual development. In addition to that, its power to control the usage of technology by impacting the choices of the policymakers and/or actors, to provide access to technologies and affect their adoptions are put forward.

At the same time, the data highlights the potential of international standards to guide QT development. In many cases, weaker players in the global market align themselves with the dominant actors, adopting their regulatory practices and technological pathways, as also claimed by P1,

Not all markets are equal. When the Americans are setting the standards, they're choosing them. I could have a different Canadian one that I want to adopt. But I don't know that the Americans are going to change their levels for the Canadian standard. So, there is a market-based play that people have to go along with. We usually work on that rather than creating a parallel universe where we try and foist Canadian standards and regulations onto others that's likely to be less successful.

This dynamic creates a hierarchical development model, where the influence of stronger players shapes the trajectory of innovation in QT, often making collaboration and competition intertwined elements of the field's progress. Therefore, the way powerful players influence the field of QT creates a system where collaboration and competition often go hand in hand. This dynamic makes it clear that while innovation in QT is driven by unpredictability, there needs to be a solid framework to guide its growth. Regime elements step in to offer this structure, helping to steer the rapid developments in a way that balances flexibility with clear direction, allowing for progress despite the uncertainty.

5.3.2. Non-QT-Specific Regime Elements

Non-QT-specific regime elements significantly influence the development of quantum technologies by shaping the broader research and innovation environment. Policies like intellectual property laws dictate how discoveries are shared or protected, impacting collaboration and competition. Immigration regulations, such as age-based employment restrictions, limit the flow of skilled talent, particularly foreign researchers.

Similarly, funding mechanisms prioritize certain areas over others, steering research agendas. Trade policies and national security concerns further restrict the exchange of sensitive technologies, emphasizing protectionism over openness and slowing the progress of global quantum collaboration.

Non-QT-specific elements impact QT development in two ways. The first one is the **technological development and market dynamics**. The data indicates that the regulatory approaches impact both the pace of innovation and the inclusivity of the research ecosystem. Regulatory frameworks can be used as tools for control and 'protect'. This behavior, which might also be beyond QT, potentially limits international collaboration and affects the inclusivity of the research environment. P1 argued that *"The national policies impact who we work with and who we collaborate with."* Another example comes from China. A1 claimed that China is an ideal location for individuals under the age of 35, as numerous policies encourage Chinese universities and industries to hire foreign nationals in this age group. However, after turning 35, it becomes much harder to find employment in China due to the policies. A3 presented personal experience by indicating that,

Regulation could be targeted at, having seen interesting ads from the UK Government, it always feels like nationalism in disguise. I guess it's bringing in paranoia about...it feels a little like it's defeating the purpose of science. When it comes to actual applied technologies that could be leveraged for the military, it may be a bit different. But for basic technology itself, or basic science itself. I wouldn't want regulation or control in that way.

According to the data, nationalistic approaches to regulation, that is also protectionist, impose a risk to the 'purpose' of science. When regulations prioritize control over openness, they influenced the flow of funding and the direction of research. This is suggested to lead to the classification of sensitive research and limit opportunities for global cooperation. S1 gave a logical solution by suggesting that *"The bureaucracy is good when decision-makers are ready to listen to scientists, with these decisions research direction can be changed immediately. It can be very very good for both researchers and the government."*

Creating an environment that supports scientists involves not only establishing a strong infrastructure for their work but also ensuring a high quality of life through comfortable living conditions. *Everything depends on how well the infrastructure works*, said S1. This is highlighted as a key structural factor influencing QT development, even though it is not specific to the field. In other words, **the living and working conditions of researchers**, encompassing not only professional

environments but also broader quality-of-life factors, significantly influence QT development. Daily life aspects such as access to reliable infrastructure, efficient public services, safety, healthcare, and education contribute to researchers' productivity and long-term commitment. Countries offering a high standard of living are better positioned to attract and retain global talent. A3 shared the story of another researcher who completed their Master's and PhD but is now doing her postdoc in the Netherlands. She does not want to return, as it is not just about science or technology, *it is also about the quality of life*. A2 also gave an example regarding their experiences,

Because it's not only about the science, about the technology, about the quality of life. One factor that I applied for another country is Freedom. Sanction. I like, for example, this is my visa card. Like, I haven't had this kind of visa card in my life. Now I have. This is the quality of life.

In order to determine what researchers consider to be the optimal QT development environment and to later use these insights for shaping policy recommendations, I created a section titled "Researcher Expectations". This section goes beyond the scope of my initial data analysis framework for a deeper exploration of the preferences and priorities of researchers that can inform effective policymaking.

5.3.3. Researcher Expectations

Finally, I asked for the interviewees' recommendations on what type of structural elements are essential for creating an ideal environment for the development of QT both locally and globally. As a result, seven major steps are recommended for the optimal development of QT in the eyes of the researchers. AS2 presented the general framework with the following words:

It's a matter of a country, I think any country can have good science. What's needed is a few conditions: Good funding, good management of science, a secure government, and maybe some culture that makes the life of a scientist comfortable. So that's what's needed. And so, the role of the country's government is to create this atmosphere, to satisfy these 4 conditions, and once these conditions are satisfied, then scientific research will grow. It's like fertile soil, and then fruit grows. Also, if you have great ideas right, you have to always correlate them with what the community thinks.

It is suggested that a **secure government** plays a pivotal role in fostering a proper environment for scientific research by ensuring stability, protecting national interests, and having a deterministic mindset. A secure government that provides stability is expected to provide consistent funding support, long-term research initiatives, and an environment suitable for private sectors to be a part of it as well. For AS1, the most important national policy to a scientist is whether *there is going to be funding to develop the quantum computer*. While having control, the data indicates that the **effective management of scientific research** is crucial as it involves understanding the needs/demands of researchers, aligning administrative decisions with the broader goals of the scientific community, and deciding the meeting point of the technologies with society. **Organizing efforts and aiming for future projection** by making plans are stated to be significant for continuous progress. This involves coordinating national efforts, setting clear objectives, and ensuring that all stakeholders are aligned towards common goals. P1 suggested that “*Those things take time, but you can't engage with other countries if you don't know what you're engaging them on.*”, and further exemplifies as follows,

We engaged in about a year's worth of consultations with Canadian researchers and companies for the initiative, as well as the national, federal, and provincial governments. We had round tables and input on the Internet, we took all that input in, we had developed and released it...In our document, we also mentioned how important it is to collaborate and work with other like-minded nations...The UK, for example, has great strength in medical imaging using quantum. That's not something that Canada has. So there's an area that we can work together on. We also looked at what other countries had done and borrowed the best ideas from that.

The vital role of **creating supportive regulations**, including initiatives and strategies that push for developmental factors such as collaboration, spinouts, societal adaption, etc. is emphasized a lot. Although regulations may seem both as a support or as a limitation, this relativism depends on the context (i.e., country, branch, or technology) in which the regulation is to be applied. The importance of collaboration is stressed in almost every part of this study by the participants by stating the effect of lack of collaboration on the inadequate fundamental research. both across countries and interdisciplinary collaboration is included in these mentions. According to A3, “*There should be consultation and engagement with relevant*

scientists, physicists, engineers, mathematicians, and information people.” In addition to collaboration, one of the recommended steps is interaction with abroad and adapting the successful methods and practices of other countries to your own country, when necessary. **Providing an encouraging environment for scientists** by providing both a supportive infrastructure for work and a comfortable environment in living is suggested as another important step. When it comes to topic of QRace, the participants supported a **framework that has balance between openness and protectionism**. AP1 emphasized the need for a balance between protectionism, regulation, and openness, particularly for emerging technologies like quantum, as research and development are still ongoing. They also highlighted the importance of ensuring that the quantum hype does not overshadow the significance of continued research in the field. Therefore, **managing expectations** is crucial to avoid the pitfalls of hype and, therefore, should be taken into account by the actors according to data.

CHAPTER 6

DISCUSSION & POLICY SUGGESTION

6.1. On the QT Research Ecosystem: Main Outputs of the Data Analysis

The development of Quantum Technology (QT) is a dynamic field shaped by global and local forces, fluidity, and structural stability and their impacts on the research ecosystem. To understand how these factors interact, it is necessary to analyse their interdependencies and identify strategies to overcome the possible challenges. This chapter discusses these dynamics while suggesting policy models to address systemic issues.

Global Dynamics in the QT research ecosystem consist of strategic positionalities of the countries, international relations, and international competition. *Strategic positionality* in the global QT network refers to where nations prefer to or have to position themselves. This positioning is based on their capabilities, geopolitical strategies, and historical contexts. Therefore, this aspect is a legacy of a country that results in shaping its research ecosystem accordingly. This aspect can be thought of as being on its own in the global network. Through this ground, the researchers acknowledge, accept, and adapt to specific conditions of the country they work in, such as their necessity to build on strengths, or the impact of political decisions like war. This understanding leads to the acceptance of an unequal working system, which suggests the direct correlation between the investment level and benefit.

From this perspective, although this issue may seem like a local dynamic, the national positionalities are formed ‘within’ the global network. In other words, the global aspect is what creates the foundation for defining these more of a passive stance. From a more active perspective, how countries relate with each other and

how they prefer to bond within this network is explained in the international relations section. I have to explain that by calling this a passive stance, I mean countries' self-standing existence, without being engaged to any other nation. Their status quo. Whereas, by active stance, I refer to the actions and interactions between each other within the global network. Hence the reason behind these relations is important here. Relationships may range from open partnerships to restricted collaborations, often influenced by strategic interests. The dominant reason occurred as positioning defensively, focusing on protective measures. The argument for the rationale behind protectionism is the significant investments made in QT, which are expected to create valuable assets, such as economic development, sovereignty, and autonomy that nations/companies are motivated to guard. Protectionism is also driven by the need to maintain the competitive edge, which is referred as the QRace. In this race, a nation's positionality determines its access to resources, influence in setting standards, and ability to attract talent and investments. The countries that are invested in the QRace and, in fact, care about the positions they hold, are aware that the focus is more on the idea of force and strength created by media and narratives rather than on the genuinely beneficial outcomes of the QRace. This kind of approach inherently affects how QT should be designed to maximize this advertisement, instead of maximizing the social benefit, etc. Hence, the reasons or justifications for the protectionist approach include ensuring returns on investments, obtaining and maintaining competitive advantage, and securing national interests. As a result of this focus, researchers agreed that having a competitive environment is healthy at some point, although after that point it is intoxicating the research ecosystem by pushing the development in a standardized, uncreative, quantity-focused, and privacy-focused path where there is an excessive protectionism. Therefore, there is an inherent trade-off between the openness required for fundamental research and the protection needed for national interest. While openness facilitates the free flow of information and accelerates innovation, the need to protect sensitive technologies and maintain competitive advantages leads to restrictive measures in the case of QT. In this way, the dual pressure of maintaining openness for scientific advancement while ensuring the protection of national interests creates a challenging environment for researchers. Moreover, the lack of a unified international regulatory framework in the global QT landscape strengthens this

tendency. Currently, the differing standards, priorities, and levels of scientific adequacy make it challenging to build a common understanding, which is suggested to be what this ecosystem needs. As a result, creating an inclusive and transparent global framework, and international standards that encourage collaborative problem-solving while respecting national interests could intervene in this dark side of the development path.

The strategic positionality of the countries comes into the picture here once again with the narratives of "falling behind" or "losing the race". It turned out that countries with less-developed economies often lack the financial resources and infrastructure, forcing them to adopt rather than develop new technologies. In that sense, the challenge arising from the inadequate infrastructure affects developing regions' ability to compete globally. This is because countries with established operational practices have infrastructures that support future developments, while the adopter countries necessitate unique modifications. In some cases, which are seen as problematic, the adopter or follower countries apply successful models exactly as they are, without adapting them to their unique contexts. As a result, a rising structural gap shows that the local academic infrastructure may not support such roles, creating challenges for both institutions and researchers. Each system operates differently in various environments, and what succeeds in one country may not necessarily succeed in another. For instance, Japan's approach is deeply rooted in its operational traditions and unique mindset, making it difficult to replicate in other nations without similar foundations. These countries can be termed follower-leaders, as they invest and actively try to implement advanced practices but struggle due to their different foundational structures.

In that sense, balancing the power of the parties in the race would be a dead-end effort, which also would not make sense. This balance can only be succeeded in a win-win situation. A win-win scenario in a competitive market for talent and materials is possible but requires deliberate efforts to balance competition with collaboration. The challenging issue here is to find out the win for the economically developed countries. A potential item of the persuasion process could be resourcing cost-efficiency and stable supply chains. By forming strategic alliances, developed

countries can reduce the risk of supply chain disruptions, which is critical for maintaining industrial and technological leadership. With this scenario, I also would like to examine the case of small players of the race as a survivor/successor of this win-win situation.

In the section on **local dynamics** affecting the research ecosystem, the main discussion turns over the bottom-up versus top-down conflict, namely government involvement and researcher involvement in the QT development. The role of governments and private companies in QT development is pivotal, as they define the pathways through which research and innovation progress. National capacity, including funding levels and operational capabilities, influences the strategic priorities and the interplay between theoretical and practical research. For example, some nations emphasize foundational research to advance scientific knowledge, while others prioritize applied technologies to ensure commercial competitiveness. This divergence also extends to technology selection, where national contexts dictate the areas of focus, such as quantum computing, communication, or sensing. The researchers' involvement level, on the other hand, highly influences the working ecosystems in funding and strategic decision-making. When researchers are active participants, it allows them to decide on resources and the path of innovation, giving them an opportunity to be creative in this path. If this bottom-up shaping is allowed by the top as well and made a collective understanding/strategy in the field, it would be the optimal research ecosystem. However, limited understanding or lack of support from top-level managers restricts both funding opportunities and the potential for bottom-up contributions. The gap between what researchers can provide and what higher-level leaders prioritize can create challenges for innovation. This often leads to focusing on meeting specific goals instead of finding the maximum potential of QT. Therefore, the main issue is the knowledge gap among top-level administrators, where decision-makers, due to limited expertise, may adopt trends without a clear understanding of their strategic purpose.

Minimizing regulation is found generally preferable at this stage of QT development, as excessive bureaucracy can limit the 'agility' of research. When researchers realize that their work is going in the wrong direction and need to pivot, being restricted to a

specific grant can result in significant delays. If research is confined to rigid bureaucratic structures, it may take years to finalize a project before a shift can occur. However, bureaucracy can be beneficial when decision-makers are receptive to scientific input. This openness allows for rapid adjustments in research direction, benefiting both the researchers and the government/company investing in the project. To address this issue, there is a need for collaborative structures that value strategic ideas and practical insights of both administrators/funders and researchers.

Fluidity captures the unpredictable and evolving elements shaping QT development. It covers This phase reflects the challenges inherent in addressing the unknowns of QT, from the basic science to the future applications, and how stakeholders handle these shifting technological, institutional, and market dynamics. The unpredictability of QT, both in terms of technological outcomes and societal applications, complicates strategic planning. National protectionist policies and varied funding structures reflect this uncertainty, with actors often forced to invest in multiple technological avenues without clarity on which will prove fruitful. This dynamic, driven by the competitive pressures of the "quantum race," underscores the challenges of balancing national interests with the global potential of QT.

Furthermore, the evolving nature of QT research means that skill requirements are constantly shifting, making it difficult to cultivate a workforce capable of adapting to these demands. This scarcity is particularly pronounced in countries with smaller populations or less developed research infrastructures, further highlighting the need for international cooperation to address talent shortages and build capacity.

As an emergent field, QT often faces challenges related to the problem of **value proposition**. It appears that the process of creating and establishing value is both crucial and complex for emerging technologies. The SST supports this view by emphasizing the “cultural need’ for a technology” (MacKenzie & Wajcman, 1985, p.18) The lack of a concrete value of the technology, which indicates its immaturity in the stages of giving outcomes and adoption by the society, results in behaviours mentioned in the geopolitical balances and interaction practices.

In my research, I identified two contrasting approaches that influence the perceived value of QT. The first approach, concerns among potential users, stems from the unfamiliarity of QT by actors mainly outside but also inside the quantum field. This experience is detected to be due to insufficient knowledge and uncertainty about QT's future applications. This creates pressure and is overwhelming because of the multitude of possibilities. The second approach views QT as losing its significance when seen merely as a tool to simplify tasks, disregarding its unique features. This perspective reduces QT to its practical applications, while indicating its successful adoption. The research data shows that these two opposing scenarios coexist in the QT development phase. QT's perception involves both overwhelming possibilities and a practical focus that overlooks its specific attributes. This duality creates a disconnect between QT's potential and its perceived practical benefits. These obstacles underline the need for better communication, education, and demonstration of the practical benefits of quantum technologies. Overcoming them is crucial for the broader acceptance and integration of quantum solutions into the market and society.

The uncertainty about which technologies will integrate into society since QT is an emerging field with potential across almost every sphere of life, which results in the aspect of **fluidity in adaptation for strategy**. In practice, countries and firms simultaneously develop mutually exclusive technologies, turning the competition among technologies into kind of a gamble for developers. Adapting to the rapidly evolving QT landscape requires readiness for technological variety, as nations and organizations often bet on multiple technologies to mitigate risks and maximize opportunities. This approach entails accumulating knowledge across various domains, such as quantum computing, cryptography, and sensing, to ensure that unforeseen breakthroughs do not disrupt strategic goals. However, this strategy also presents challenges, as resources are dispersed across many fronts, potentially slowing progress in any single domain. Moreover, the prioritization of specific QT technologies reflects another aspect of fluidity, as stakeholders often must choose between short-term gains and long-term ambitions. Furthermore, the unpredictable nature of quantum technologies often creates technological relativity, where a single technology may have multiple uses or interpretations depending on the context, often leading to protective policies and regulations as nations seek to manage potential

risks tied to the technology's uncertain trajectory. The analysis of the responses suggests a complex relationship between protection and innovation as the drivers of QT. While innovation is viewed as the currency of success, essential for solving existing problems and preparing for future advancements, protection emerges as a significant motivator in specific areas, such as preparing for potential threats. The importance of being prepared for future technological breakthroughs, which can be seen as both forward-thinking and a form of self-protection is emphasized. An underlying theme running across these viewpoints is, therefore, strategic planning for future returns. In addition to the motivations driven by innovation or protection, positioning in front of the future and assurance of being ready appears to be the third part of this system.

The final theme that is examined through QT-specific and non-QT-specific categories, is the **Structure and Stability**, namely the regime elements in SST theory. They encompass institutional, regulatory, and policy-driven factors that provide both direction and foundation for QT development.

In the context of advancing quantum technologies, a supportive regulatory framework plays a crucial role. The analysis of these statements reveals that positive regulatory approaches, including mandated transitions to quantum-safe technologies, protective policies for national interests, and substantial governmental funding, are crucial for the advancement and secure adoption of QT. Efficient regulatory frameworks significantly enhance the development environment, while a lack of support and recognition can limit progress.

On the downside, participants who have a negative approach towards regulations think that the regulations through funding eliminate the opportunity for creativity in research. Furthermore, in this system the efficiency of the distribution of funds is questionable. Competitive environments like the US place high pressure on delivering promised results, which can restrict researchers and lead to a stressful working atmosphere. Conversely, in countries with less bureaucracy, the development and implementation of QT are stated to be more efficient, as lower bureaucratic barriers facilitate smoother progress.

On the one hand, there is the practice of highly competitive research grants that guide the development of QT in a politic path, and for the rest, while the absence of a grant application requirement might appear to offer more freedom, it often coincides with a lack of available funding. This situation reduces competition for resources but also limits the overall potential for R&D. Moreover, it brings the constant need to convince the funders about the imagined potential of the research, which is stated to be a positive aspect. Therefore, the flexibility of having less regulation is appreciated and seen as an opportunity to shape regulatory frameworks since it benefits both researchers and governments by preventing wasted funds on unproductive research paths.

6.2. Policy Suggestion: A Model to Support QT Development

The discussion generated on the background of data analysis led to the necessity of conducting a needs assessment, which subsequently resulted in a gap analysis. Based on this analysis, Table 6: Need Assessment for Policy Suggestion was created as a preliminary step toward policy suggestions. This table serves as a framework to identify areas requiring strategic intervention and inform future policymaking efforts.

Table 6: Need Assessment for Policy Suggestions

THEME	SUBTHEME	CODE	MISSING VALUE / GAP
QT RESEARCH ECOSYSTEM	Global Dynamics	Strategic Positionalities of the countries	<i>Need for a global ground that provides each country -and indirectly its research ecosystem- opportunity and place in the development process of QT</i>
		International Relations	
		International Competition	
	Local Dynamics	Government/ company-level involvement	<i>Need for the collective involvement of the administrators and researchers in the development process of QT</i>
		Researcher involvement	

Table 6. (continued)

FLUIDITY (Unpredictable elements)	Fluidity in Technological and Scientific Capacity Building	<i>Need for a future projection that takes values and conditions of countries without reducing the variety of possibilities</i>
	Fluidity in Meaning Creation	
	Fluidity in Adaptation for Strategy of QT Development	
STRUCTURE & STABILITY (Regime elements: standards/regulations)	QT-specific	<i>Need for localized guidance through administrators</i>
	Non-QT-specific	

Table 6: Need Assessment for Policy Suggestions created as a result of the analysis of the generated data explains the missing values/gaps that should be taken into consideration for the policy recommendation.

6.2.1. Common Ground For Countries

In international relations, while some actions are justified as 'protective measures', they often indicate underlying motivations such as achieving leadership in the field. Regardless of the justification, these actions influence the speed and direction of technological advancement. Moreover, the excessive focus on protection (or its representation in the media) encourages other countries to adopt similar measures, leading to a self-fulfilling prophecy where the perceived need for protection increases the actual risks, creating a vicious cycle.

In establishing interactions between countries, the general perspective is to create a balance. While being autonomous, or independently functioning in the market is seen as a noble endeavor, the reality that it is hardly possible makes the establishment of international relations crucial for survival. Researchers, therefore, expect international standards to serve this purpose. They believe this will help create a

common goal, a shared set of values, and an equitable development through mutual sacrifices. Nevertheless, it is seen that collaboration among countries with already-aligned objectives is prioritized even though each participant agrees with the previous statement.

- ❖ According to the data, market size, and influence play a significant role in setting standards. Since the markets are not identical, there cannot be one standard that works for all.

This case pushes both specific standards to be created for the unique conditions of each country or for the countries that share similar market conditions and common standards to be created for the globe. In addition, in the experiences of the researchers, I realized the perception that smaller markets often have to align with standards set by larger markets to ensure compatibility and avoid creating parallel systems. Hence, in order to avoid the risk of a parallel system of regulations, standards, and applications needs special coordination. As a result, to participate in the development process of QT, countries must develop strategies tailored to their unique historical, cultural, and infrastructural contexts. This underscores the need for localized policies and innovations that consider specific national strengths and weaknesses.

It is important to acknowledge the differences in capacities and mindset of the countries. Without trying to mold them into one model, or eliminate these differences, a common ground for an ideal development process and maximization of QT potential can be achieved in this path. Inclusivity, relative equality, and the creative contributions of each actor, especially within emerging technologies like QT, are crucial. QT, as one of the rare technologies with the potential to be shaped by creativity, can lead to more focused, diverse, and forward-looking breakthroughs. Such inclusivity would yield applications to help ease current crises. Creativity is also helpful when it comes to strategy-making.

In such cases, countries with fewer resources may inadvertently create an environment that fosters niche innovation, which could be an amazing advantage.

With less regulation and fewer funding constraints, researchers might explore more creative or unconventional projects. In other words, countries with limited funding might adopt a bottom-up approach, relying on researchers' creativity and initiative rather than top-down guidance. While this can lead to unique developments, it also carries the risk of wasted resources on projects that may not yield practical results.

Singapore and South Africa are two main examples of small players can take part among the big players as well. Interviewee **AS3** summarized the success of Singapore as saying, *“The Singapore government recognized quite early on quantum technologies were an area where a small country could have an outside impact if they invested early.”*

Moreover, The South African Quantum Technology Initiative (SA QuTI) seeks to avoid direct competition by targeting a specific/niche area within the quantum field, which is a strategic approach. It follows the concept of 'sidestepping the competition.' Just as the involvement in the smartphone revolution does not require manufacturing smartphones (Wits University to Coordinate South Africa's National Quantum Initiative, 2021), SA QuTI adopts a similar approach. It intends to contribute to quantum computing by focusing on developing software and applications for quantum computers, rather than creating the hardware. The approach uses the strength of South Africa in the area of software development to achieve an efficient and cost-effective way to make an impact on the global quantum community. Consequently, in environments with limited regulations, creativity tends to thrive, which often allows countries to specialize in niche areas. However, if a country engages in many projects without adequate funding, the risk of investing resources in unproductive efforts rises, hence resulting in wasting the limited funds.

6.2.2. Researcher and Administrator Involvement

On the other hand, countries with limited resources may find themselves in this situation because they lack alternatives. Without top-down guidance, they may adopt bottom-up approaches, which can be advantageous at the start of a technological race. However, in a field where other countries have significantly advanced, the

potential benefits of such innovations may be less clear. Nevertheless, any effort is better than none. This period of adaptation might help smaller countries in quantum technology to better integrate and quickly implement new technologies, potentially gaining a foothold in the market. Akçomak & Seskir (2022) discuss the shift in technological leadership and suggest that the techno-economic paradigm approach states, “the way to get ahead is to run in a different direction” (p.5) In this model, technological revolutions provide follower countries with a chance to surpass the leading countries.

The success of these efforts may be based on their unique national attributes. If a unique approach does not fit well within a standard system, countries that excel in the traditional system might leverage their differences to achieve greater success and advance technology further. Countries could support each other, with funders maintaining control over commercial aspects and smaller countries benefiting economically, strategically, and in terms of vision.

6.2.3. Motivating the Possible Varieties of Development

- ❖ Value creation that affects and is affected by each phase of societal adoption might be what QT needs the most at this stage of development.

According to the data, it is clear that actors work so hard to achieve progress with different motivations. However, there is so little effort in meeting the technology with the society and even the market. Jasanoff states “Through technology, human societies articulate their hopes, dreams, and desires while also making material instruments for accomplishing them. Collective visions and aspirations, moreover, change and evolve as societies become habituated to new technologies and use them to pursue altered understandings and purposes. Technological choices are, as well, intrinsically political: they order society, distribute benefits and burdens, and channel power” (2016, p. 242). The lack of a value attributed to QT is evident in the shared experiences of the researchers. Incompatibility that may occur by the top-down approach to the shaping of technology and the motivations of actors in ‘top’ being different from actors in ‘down’ becomes more apparent as developments progress.

The importance of shaping a new “social contract” over the development process and usage of an emerging technology, which includes value, trust, and equity, is also suggested by the World Development Report (2021).

Additionally, the inherent uncertainty of QT and the challenge of demonstrating its immediate value might not necessarily slow down its adoption and development. These factors do not have to be barriers to the value proposition. Because the process I call value proposition is actually a meaning creation. That is creation. Therefore, the uncertainty should not restrict it but support it in a way that increases the power of imagination.

6.2.4. Policy Suggestion

Breaking down the main values highlighted in the table, it becomes evident that the current state of QT development is not perceived merely as a technological and knowledge advancement activity. Instead, there exists a normalized yet unequal distribution of investment and benefits. To realize the full potential of QT, ecosystem dynamics should not overshadow research dynamics to such an extent. Additionally, key challenges include the prioritization of security and protectionism, tendencies toward isolation, and excessive sensitivity to geopolitical strategies. Moreover, since QT is not a straightforward technology that will have manageable unintended consequences or harmful outcomes, it requires administrative involvement due to its significant security implications.

To address these issues, there is a clear need for the establishment of an objective global governing body that maintains equal distance from all countries and ensures impartial governance. This need forms the foundation of my policy design efforts. Considering these necessities, I suggest a two-stage policy/initiative model to be applied to reach the optimal development process of QT.

Stage 1: Establishment of a Global QT Standardization Body (GTQTSB)

The aim is creating a centralized yet inclusive international body to provide a universal framework applicable to all QT stakeholders through the development and implementation of QT standards.

The GTQTSB will include representatives from national governments, research institutions, private sector stakeholders, and international organizations. This ensures equitable representation, with advanced QT nations holding leading roles and emerging nations contributing insights from niche areas.

- Specialized committees will focus on areas like global standards development, tailored standards integration, societal adoption, and researcher engagement.
- Standards will be co-developed through multi-stakeholder consultation processes involving governments, researchers, industry leaders, and civil society organizations. Local workshops and focus groups ensure diverse perspectives inform policies, preventing dominance by a few nations.
- Member states integrate GTQTSB standards into their national policies and legal frameworks.
- Contributions will come from member states based on GDP and QT engagement levels, supplemented by private sector funding and grants from international bodies like the World Bank or regional development organizations.

The GTQTSB will guide nations in creating tailored standards reflecting their unique contexts, ensuring alignment with global benchmarks through compatibility protocols and continuous knowledge sharing.

QT has the potential for both civilian and military applications. For this reason, The GTQTSB should adopt dual-use regulations that would control QT development and proliferation processes for harmful purposes and ensure that technologies remain only in peaceful and constructive applications. Since this is a subjective issue, an action, regulation or a policy that is good for one actor could be bad for another, it is a must to include ethical discussions and agreements which is done in a mutual and transparent way. Furthermore, creating reasonable expectations in society and funders i.e. controlling the hype will be one the missions of The GTQTSB.

- The first 1-3 years will be the establishment phase; the 3-5 years will be the adoption phase (it will begin with implementation of global standards,

starting with high-priority areas like quantum encryption and quantum communication), and after 5 years, the GTQTSB will be in full operational phase, providing technical and financial support to nations developing tailored standards, ensuring they complement global frameworks.

Stage 2: Structured Role Division Between Aligned and Unaligned Countries

The GTQTSB will form a framework to define complementary roles for technologically aligned (leader) and unaligned (adapter) countries ensuring equitable collaboration and resource optimization.

According to the role assessment; Aligned countries will focus on both foundational and applied research, infrastructure development, and global standard-setting. They lead in creating cutting-edge QT technologies and global frameworks. They are also expected to provide training programs and leadership guidance to build capacity globally.

On the other hand the unaligned countries will specialize in theoretical and applied studies, local adaptations of global standards to local contexts, and region-specific QT applications. They are also expected to act as testing grounds for scalable QT applications, enabling large nations to refine their technologies.

The role of the GTQTSB in the application of this framework will be coordinating partnerships and facilitating knowledge exchange, ensuring all members commit to complementary contributions, and creating regional QT networks under GTQTSB, which will pair the nations for joint projects and resource sharing, including the design of regulating the talent pool and stopping excessive brain drain. Moreover, providing all stakeholder-level education for a value proposition and awareness of QT.

In the case of the initiative being successful, the GTQTSB will launch collaborative projects, like a quantum agriculture initiative, where aligned nations provide infrastructure and unaligned ones develop applied solutions.

The establishment of a Global QT Standardization Body ensures a structured, transparent, and collaborative approach to QT standards, balancing global coherence with local flexibility. By defining complementary roles for leader and adapter nations within this framework, the initiative fosters an inclusive and efficient ecosystem where all actors benefit and contribute to the transformative potential of QT. Therefore, this model emphasizes sustainable progress while addressing power imbalances, ensuring QT's value is maximized to reach greater well-being



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APPENDICES

A. INTERVIEW GUIDE

- 1) What do you think about the main obstacles to the development of quantum technologies in the world vs. in your country?
- 2) What is your opinion on your country's national initiative (if present) for QT? How does it affect your work? What policies and regulations do you think should be included and why?
- 3) What do you think about the concept of “quantum race”? Where do you think your country stands in this so-called race?
- 4) How do quantum race and national policies affect the development of quantum technologies?
- 5) (If the interviewee mentions the quantum divide in the previous question, proceed to Q6) What do you think about the quantum divide between the countries?
- 6) What does “protectionism” mean to you in terms of QT studies? (What do you think is the limit of protection?)
- 7) In your work or workplace, which one do you prioritize: innovation or precaution? / Which one do you think is the driving force for the development of QT?
- 8) How are the risks and benefits of QTs determined? Whose risks/benefits are they? (Market's, societies', or which nations' specifically?)
- 9) What is your opinion on the bargaining process among nations to ensure equitable development of quantum technologies? Where could a consensus be reached?
- 10) What do you think about the effectiveness of international regulations or standards?

11) In your experience, which one was more helpful in developing and disseminating the previous emerging technology: soft or hard regulations? Why?



B. CODEBOOK

THEME	SUBTHEME	CODE	SUBCODE	QUOTATIONS	FREQUENCY
QT RESEARCHER ECOSYSTEM	GLOBAL DYNAMICS	Strategic Positionalities of the countries	Impact of Geopolitical/historical background	Building on strengths / experience/expertise	5
				The effect of Brexit over collaboration	
				The effect of war in Ukraine	
		Structurally embedded inequality		Investment with the expectation of benefit	7
				Investment with the result of protection	
		International Relations	Protective approach	Assets / Secrecy / Competitive advantage / funding accordingly	19
				Direct relationship with investment/effort	
			Closeness in collaboration (reasons other than protection)	Restriction / Isolation / under the name of strategic autonomy / limiting the collaboration	4
				Global interaction/sharing problem	
		Lack of international regulation/standards		Scientific inadequacy of the field	6
				Lack of initiative to build a common understanding	
		International Competition	Political/strategic competition (QRace)	Emphasis on quantity over quality	34
				Motivating QT developing	
				Restricting QT development	
				Narratives of driving force: "Fear of being left behind" & "Losing the race" & "Power dominance"	
			Material competition	Export restrictions to control the global market	6
			Talent competition	Access to talent is an issue	6
				Risk of losing trained to another country.	
				Risk of losing trained people from academy to the industry.	
	LOCAL DYNAMICS	Government/company level involvement	Path of the development	Theoretical vs. Practical research differs across countries	9
				Technology selection differs across countries	
			National administrative approach to international interaction/collaboration	Lack of knowledge of the top managers - Copying trends without knowing the purpose	9
		National capacity		Funding level- funding condition depending on the knowledge level of top level administration	5
				Operational level	
		Researcher Involvement		Involvement develops the field (Less understanding in the top level= less competitive funding= more need for a bottom-to-top justification)	13
				Lack of involvement / Lack of knowledge of the top managers / Exclusion of the researchers from the operation of the research / funding	

THEME	SUBTHEME	CODE	SUBCODE	QUOTATIONS	FREQUENCY
FLUIDITY (Unpredictable elements)	Fluidity in Technological and Scientific Capacity Building	Technology relativity		Two usage of one technology	25
				Two positionalities of one technology	
		Capacity building		Technological-scientific & talent-based	
	Fluidity in meaning creation	Problem of value proposition		Lack of awareness	10
		Hype in QT development		Manipulating media/ public attention	
	Fluidity in adaptation for Strategy of QT Development	Readiness for technological variety		Betting on many technologies at once- knowledge acculation on various technology types	8
		Prioritization of specific QT		Developers adaption to top down guidance	
STRUCTURE & STABILITY (Regime elements: standards/ regulations)	QT-specific	Benefit to the QT development & QT market dynamics		Regime elements push the development of QT & Standardization / For the good of the market dynamics	6
		Creation of an international common interest		Standardization / For the creation of common interest in QT development	5
		Benefit to the Nation		Local regulations serve as protectionism	8
	Non-QT-specific			Local standards/regulation serve as a guidance in national development	
		Living / working conditions		Impact of the structure in social life	4
		Technological development & market dynamics		Regulation as an obstacle for scientific exploration (Russia, China)	10
				Regulation advances the field	
				International standards/regs work over the main course of action in market (weaker one follows the stronger one)	

C. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ APPLIED ETHICS RESEARCH CENTER DUMLUPINAR BULVARI 06800 ÇANKAYA ANKARA/TÜRKİYE T: +90 312 210 22 91 F: +90 312 210 79 59 uam@metu.edu.tr www.uam.metu.edu.tr	 ORTA DOĞU TEKNİK ÜNİVERSİTESİ MIDDLE EAST TECHNICAL UNIVERSITY
Konu: Değerlendirme Sonucu	19 HAZİRAN 2023
Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)	
İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu	
Sayın Arsev Umur Aydınoglu	
Danışmanlığınızı yürüttüğünüz Ayşe Ayda Gerçek'in " <i>Kuantum Teknolojilerinde Jeopolitik: Kısıtlı erişim senaryoları altında sorumlu ulusal politikalar nasıl geliştirilir?</i> " başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0295-ODTÜİAEK-2023 protokol numarası ile onaylanmıştır.	
Bilgilerinize saygılarımla sunarım.	
Prof. Dr. Ş. Halil TURAN Başkan	
Prof. Dr. İ. Semih AKÇOMAK Üye	Doç. Dr. Ali Emre Turgut Üye
Doç. Dr. Şerife SEVİNÇ Üye	Doç. Dr. Murat Perit ÇAKIR Üye
Dr. Öğretim Üyesi Süreyya ÖZCAN KABASAKAL Üye	Dr. Öğretim Üyesi Müge GÜNDÜZ Üye

D. TURKISH SUMMARY / TRKE ZET

Bu alıřma, Kuantum Teknolojilerinin (QT) geliřimini řekillendiren yerel ve kresel dinamiklerin arařtırma ekosistemini nasıl etkilediđini ve bu dinamiklerin arařtırıcıların alıřma pratikleri, iřbirlikleri ve teknolojik ıktılar zerindeki etkilerini incelemektedir. Bu arařtırma, kresel ve yerel dinamikler altında ok boyutlu kuantum teknolojileri geliřimini incelemektedir. Hem ulusal hem de uluslararası dzeyde QT'yi řekillendiren dinamiklere kapsamlı bir bakıř sunmayı hedefler. Mevcut gidiřatı analiz ederek, bu teknolojilerin potansiyelini en st dzeye ıkarmak iin odaklanılması gereken kritik alanları tespit etmeyi amalamaktadır. Kısacası, bu alıřma, ulusal ve uluslararası dinamiklerin ve QT geliřiminin birbirini nasıl řekillendirdiđi iliřkisini sorgulamaktadır. Bařlangı noktası, kuantum teknolojilerinin sahip olduđu byk bir etki potansiyeli ile yerel ve kresel dzeyde eřitli toplumsal, politik ve ekonomik faktrlerle nasıl řekillendiđini anlamaktır. Bu temelleri inceleyerek, QT'nin geleceđini ve etkisini daha iyi kavrayabilmek mmkndr.

Kuantum teknolojilerinin mekanik, toplumsal ve felsefi ynlerden etkilerini deđerlendirmek olduka karmařık bir iřtir. Ancak bu geliřmenin gnlk yařamda yarattıđı yeni g dinamiklerini gzlemlemek ve "daha iyi/ilerlemiř bir yařam" anlayıřıyla mevcut konumları yeniden deđerlendirmek de aynı derecede gereklidir.

Felsefi olarak, kuantum teorisinin evremizi algılayıř biimimizi radikal řekilde deđeristirme gc, kuantum ve klasik teori arasındaki temel farktan anlařılabilir. Kısaca aıklamak gerekirse, Newton ve Galileo tarafından 17. yzyılda formle edilen klasik mekanik, nesnelerin makroskobik leklerde hareketini inceler ve determinist ilkelere dayanır; bir sistemin gelecekteki durumu, bařlangı kořulları biliniyorsa kesin bir řekilde tahmin edilebilir (Chow, 2013). te yandan, kuantum mekaniđi, atomlar ve altatomik paracıklar gibi mikroskobik leklerdeki paracıkları inceler ve esasen sıcak cisimlerden yayılan ıřık spektrumunu anlamayı amalar, bu da siyah cisim radyasyonu olarak bilinir. Vermaas (2017), klasik fizikte

fiziksel sistemlerin ya parçacıklar ya da dalgalar olarak kategorize edildiğini belirtirken, kuantum teorisinin bu sistemlerin hem parçacık hem de dalga davranışı sergilemesine olanak tanıdığını vurgular. Bu, partiküllerin konumları ve hızları klasik fizikte kesinlikle tanımlanmışken, kuantum teorisinin belirsizliği ve süperpozisyon gibi kavramlarla bunu sorgulayan bir durum yaratır. Ayrıca, Heisenberg'in belirsizlik ilkesi, konum ve momentumun aynı anda tam olarak bilinemeyeceğini önerir; bu da fiziksel sistemlerin deterministikten olasılıksal bir anlayışa doğru kaydığını gösterir. Kuantum mekaniğinin temelleri, 20. yüzyılın başlarında birçok fizikçinin katkılarıyla atılmıştır. Büyük çabaların sonucunda, kuantum teorisinin ve onunla bağlantılı gelişmelerin iki devrimsel aşama olarak kategorize edilmesi yaygındır: Birinci ve ikinci kuantum devrimleri. Kuantum teknolojileri genellikle birincil ve ikincil devrimler olarak sınıflandırılmakta ve bu dönüşüm sürecini yansıtmaktadır. Birinci kuantum devrimi, 20. yüzyılın başlarında başlamış ve teknolojiler ile günlük yaşam üzerinde derin bir etki yaratmıştır. Erwin Schrödinger ve Werner Heisenberg gibi vizyonerler, kuantum mekaniğini tanıtarak bu dönemi başlatmış, bu teori dalga fonksiyonları, belirsizlik ilkesi ve kuantum olaylarının öngörülemez doğasını ortaya koymuştur. Bu, lazerler ve bilgisayarlar gibi ilerlemeleri getiren bir bilimsel devrimi ateşlemiştir (Shankar, 1994; Schleich et al., 2016). Birinci devrimle bağlantılı teknolojiler, nükleer manyetik rezonans (NMR) ve süper iletken kuantum girişim cihazları (SQUIDS) gibi temelleri atmıştır. Ancak "kuantum teknolojileri" terimi, genellikle bir sonraki kuşak gelişmelerine işaret eder (Dowling & Milburn, 2003). Kuantum teknolojileri, üç ana dalda sınıflandırılabilir: Kuantum Hesaplama/Simülasyonu (Kuantum Bitleri, Kuantum Algoritmaları), Kuantum İletişim Sistemleri (Kuantum Şifrelemesi, Kuantum Anahtar Dağıtımı) ve Kuantum Algılayıcılar, Görüntüleme & Ölçme (Kuantum Radar, Kuantum Simülasyonu, Kuantum Mikroskopu, Kuantum Metroloji) (EC, 2016; HLSC, 2017; Seskir ve diğerleri, 2023). Dolayısıyla, bu çalışma, ikinci kuantum devrimi döneminde, ulusal ve uluslararası dinamiklerin QT gelişimini ve benimsenmesini nasıl şekillendirdiğini incelemeyi amaçlamaktadır. Bu, jeopolitik bağlamların ve etkileşimlerin, QT geliştirme süreçlerine ilişkin ulusal stratejiler ve öncelikler üzerindeki etkilerini analiz etmeyi içerir. Çalışma, ekonomik, sosyal ve politik etkiler dahil olmak üzere bu varyasyonlara katkıda bulunan faktörlerin, bu teknolojilerin tasarımı ve erişimi ile bu teknolojilerin gelişiminden elde edilen varlıkların dağılımı üzerindeki etkilerini

ortaya çıkarmayı hedeflemektedir. Bu hedef doğrultusunda şu iki soru araştırmanın temel sorularıdır:

- Araştırmacılar, kuantum teknolojilerinin gelişimini şekillendiren yerel ve küresel faktörleri nasıl değerlendiriyorlar?
- Bu faktörler, araştırma ekosistemini nasıl etkiliyor?

Çalışma, kuantum teknolojilerinin olaylarını ve etkilerini incelemek için teorik bir çerçeve olarak Sosyal Teknoloji Şekillendirmesi (SST) teorisini kullanmaktadır. Sosyal Teknoloji Şekillendirmesi (SST) çerçevesi, bu çalışmanın QT'nin gelişimi ve benimsenmesi üzerindeki ulusal ve uluslararası dinamiklerin etkilerini nasıl anlamlandırdığına dair teorik bir temel sağlar. Howcroft & Taylor (2023) göre, SST teorisi, teknolojinin gelişimi ve uygulanmasının daha geniş sosyoekonomik faktörler ve politik bağlamlarla nasıl etkilendiğini analiz etmeyi mümkün kılar. SST teorisine göre, teknoloji gelişimi yalnızca teknik unsurlarla değil, aynı zamanda sosyal, ekonomik ve politik faktörlerle de şekillenir. Bu bakış açısı, QT'nin küresel çapta nasıl şekillendiği, hangi koşullar altında uygulamaya alındığı ve nasıl farklı ülkelerde benimsenip dağıtıldığı konusunda önemli ipuçları sunmaktadır. “Araştırmacılar, kuantum teknolojilerinin gelişimini şekillendiren yerel ve küresel faktörleri nasıl değerlendiriyorlar?” sorusu, teknolojik gelişmenin doğal olarak içinde yer aldığı sosyal bağlamlar tarafından etkilendiği SST'nin varsayımından doğmaktadır. SST, sadece teknolojiyle ilgili olan değil, onu şekillendiren aktörlerin (özellikle araştırmacıların) rolleriyle de ilgilenir. Bu bağlamda, SST, aktörlerin konumlarını, etkileşimlerini ve bu etkileşimlerin teknolojinin şekillenmesindeki etkisini anlamada kritik bir çerçeve sunar (Jørgensen ve diğ., 2009). Dolayısıyla, bu çalışmada QT gelişiminin dinamik özellikleri, teknolojinin öngörülemeyen yönleri, aktörler arasındaki ilişkilerin değişkenliği ve QT'nin spesifik yapısal faktörleri ele alınmıştır. Bu faktörler, tüm gelişim sürecinde birbirini tamamlayan bir etki yaratarak QT'nin evrimini yönlendirmektedir. SST'nin, yalnızca yeni teknolojilerin yaratılmasını değil, aynı zamanda benimsenmesini şekillendiren bu güçleri nasıl ele aldığına dair vurgusu, farklı ülkelerin QT'ye yaklaşımındaki eşitsizlikler ve benzerlikleri araştırmak için kritik bir çerçeve sunmaktadır, bu da farklı ülkelerin karşılaştığı önceliklerin ve kısıtlamaların çeşitliliğini yansıtmaktadır.

Bu tezin mevcut literatüre katkısı QT gelişimi ve benimsenmesi üzerinde yerel ve küresel dinamiklerin etkisini analiz etmektir. Mevcut literatür genellikle QT'nin teknik yönlerine odaklanmakta, sosyal, ekonomik ve politik boyutları ise kısmen ele almaktadır. Ancak, araştırmacıların çalışma ortamları ile QT'nin geniş çaplı gelişim süreci arasındaki etkileşime dair özel bir araştırma yapılmamaktadır. Bu açığı doldurmayı amaçlayan bu çalışma, yerel ve küresel faktörlerin, özellikle finansman yapıları, politika çerçeveleri ve uluslararası işbirliklerinin araştırma ortamı ve QT gelişim süreci üzerindeki etkilerini incelemeyi hedeflemektedir. Araştırmacıların deneyimlerini analiz ederek, bu faktörlerin teknoloji gelişimindeki ve uygulama biçimlerindeki etkileşimlerini daha derinlemesine anlamak amaçlanmıştır.

Araştırma soruları çerçevesinde, sosyal, ekonomik ve politik faktörlerin, QT geliştirme sürecini şekillendirmede farklı ülkelerden araştırmacıları nasıl etkilediğini incelemek için bu çalışmada nitel araştırma yöntemi uygun bulunmuştur. Çünkü nitel yöntem, araştırmacıların deneyimlerinden ayrıntılı anlatılar sunarak analizlere derinlemesine içgörüler sağlar ve bu, çalışmanın en önemli veri kaynağı olan araştırmacıların deneyimlerine dair detaylı anlatılar sunar. Bu detaylı anlatılar, mevcut dinamiklerin ilişkilerinin karmaşıklığının en iyi şekilde kendini göstermesini beklemektedir. Dolayısıyla, niteliksel bir yaklaşımla araştırmacıların QT ile ilgili geliştirdikleri, araştırdığı veya uygulamaya koydukları projelere dair deneyimlerini anlamayı amaçlanmaktadır.

Çalışmada, amaçlı örneklem yöntemi kullanılmıştır. Bu yöntem, belirli seçme ölçütlerine dayalı olarak katılımcıların seçilmesini sağlar ve bu sayede veriler, çalışmanın amacına uygun, ilgili ve derinlemesine bir biçimde elde edilir. Katılımcılar, akademik kurumlarla ya da sektördeki deneyimleriyle, belirlenen coğrafi bölgelerde çalışan uzmanlardan seçilmiştir. Ülke seçiminde coğrafi faktörlerin de önemlidir, çünkü yerel politikaların ve ekonomik dinamiklerin araştırmacıların deneyimlerini şekillendirebileceği düşünülmektedir.

QT geliştirme çalışmalarında bulunan ülkeler, QT'ye yapılan yatırım düzeylerine göre sıralanmıştır. QT'ye yapılan yatırımlar; hem teknoloji gelişimi için araştırma ve geliştirme kapasitelerini artırmak hem de küresel ekonomik güçle rekabet avantajı

sağlamak adına kritik rol oynamaktadır. Ülkelerin, ekonomik büyüme, teknolojik ilerleme gibi stratejik hedefler doğrultusunda bu yatırımları nasıl kullandıkları ise, bu alandaki önceliklerini ve küresel rekabetteki yerlerini göstermektedir.

İkinci aşama olarak, ülkelerin strateji ve ulusal QT politikaları da göz önünde bulundurulmuştur. Bazı ülkeler, bu teknolojiler için stratejik planlar oluştururken, diğer ülkeler daha az yapılandırılmış bir yaklaşım benimsemişlerdir. Ülke örnekleme, bu farklı yaklaşımların QT'nin gelişimindeki etkilerini karşılaştırabilmek için çeşitlendirilmiştir. Çalışma, gelişmekte olan ekonomiye sahip ülkelere kadar bir yelpazeyi kapsayarak, coğrafi ve ekonomik bakımdan daha geniş bir perspektif sunmayı amaçlamaktadır. Bu kapsamda, bu çalışmada seçilen ülkeler, QT'ye yapılan yatırımların yanı sıra, coğrafi konumları, ulusal stratejilerinin varlığı ve ekonomik gelişmişlik düzeylerine göre farklı kıtalardan çeşitlendirilmiştir. Böylece, ülkelerin QT'ye yaklaşımı ve bu alandaki stratejileri hakkında farklı perspektifler elde edilmesi hedeflenmektedir.

Seçilen ülkelere 10 çevrimiçi görüşme gerçekleştirilmiştir. Katılımcı profilleri şu şekilde ayrılmaktadır: 1 endüstri çalışanı, 4 akademi ve araştırma alanlarında çalışan, 3 akademi ve endüstri kesişiminde yer alan, 1 politika yapıcı ve 1 akademi ve politika yapıcı kesişiminde olan katılımcı bulunmaktadır. Görüşmeler, yarı yapılandırılmış formatta olup, katılımcıların kuantum teknolojileri ile ilgili çeşitli boyutlara dair görüşlerini derinlemesine araştırmaya yönelik açık uçlu sorular içermektedir.

Bu çalışmada, veri analiz süreci, tümdengelimsel (deductif) bir yaklaşımla teorik tematik analiz kullanılarak yönlendirilmiştir. Teorik tematik analiz, kodlama ve analiz sürecini yönlendirmek için önceden belirlenmiş bir teorik çerçeve kullanan bir yöntemdir. Sosyal Teknolojinin Şekillendirilmesi (SST) çerçevesi, temel teori olarak kullanılmıştır; akışkanlık (fluidity) ve yapısalılık (structure & stability) kategorileri, analiz için temel temalar olarak belirlenmiştir. Bu temalar, kuantum teknolojinin gelişimini, yerel ve küresel düzeyde şekillendiren faktörleri incelemek amacıyla kullanılmıştır. Araştırmacıların çalışmalarını ve yenilikçi pratiklerini şekillendiren dinamik ve belirsiz unsurlar ile stabil ve yapısal bileşenlerin etkileşimi araştırılmıştır.

Transkripte edilen görüşmeler, MAXQDA yazılımına aktarılmış ve sistematik bir inceleme için detaylı kodlamalar yapılmıştır. Kodlama, satır satır gerçekleştirilerek verilerle derinlemesine ve dikkatli bir etkileşim sağlanmıştır. "Akışkanlık" ve "Yapısallık & Stabilite" teorik kategorileri ve bunlara bağlı alt temalar, kodlama sürecine yön vermiştir. Bu deduktif yaklaşım, analiz sürecinin teorik perspektife odaklanmasını sağlamıştır. Analiz, "QT Araştırma Ekosistemi", "Akışkanlık" ve "Yapısallık & Stabilite" ana temalarını belirlemiştir. Bu ana temalar yedi alt tema, 16 kod ve 22 alt kod ile analiz edilmiştir; 41 alıntı kümesinden sonuçlar türetilmiştir. SST çerçevesine dayanan bu deduktif yaklaşım, analiz sürecinin teorik hedeflerle uyumlu kalmasını sağlayarak, QT gelişimini şekillendiren faktörlerin detaylı bir şekilde incelenmesini mümkün kılmıştır. Böylece, öngörülemeyen sosyo-teknik etkileşimler ve yeniliği yönlendiren yapılandırılmış çerçeveler arasındaki etkileşimin incelenmesi QT'nin büyümesinin, sosyo-ekonomik ve jeopolitik dinamikler tarafından nasıl şekillendiğini incelemek için bir zemin sunmaktadır.

Birinci ana tema olan araştırma ekosistemi, QT'nin gelişimini destekleyen aktörlerin, kurumların, politikaların ve kaynakların oluşturduğu bir ağıdır. Çalışmanın sonucuna göre ekosistemin temel bileşenleri küresel ve yerel dinamiklerdir. Küresel dinamiklerin araştırma ekosistemi üzerinde gösterdiği etkiye göre, tarihsel ve jeopolitik bağlamlar (örneğin Brexit ve Ukrayna savaşı), araştırmacıların stratejik önceliklerini ve uluslararası iş birliklerini etkiler. Buna ek olarak, ülkelerin, endüstriyel ve teknolojik miraslarından faydalanarak QT araştırmalarını mevcut güçlü yönleri ile uyumlu hale getirdikleri, yani teknolojik gelişim süreçlerini halihazırda sahip olduğu güçlerin üzerinde ilerlettikleri anlaşılmıştır. Buna ek olarak görüldü ki, küresel araştırma ekosistemindeki yapısal eşitsizlikler ise, daha büyük yatırımların daha fazla fayda, erişim ve nüfuz sağladığı yatırım-fayda mantığı nedeniyle normalleşmektedir. Küresel QT araştırma ekosistemindeki eşitsizlikler, yatırımların eşitsiz dağılımı ile şekillenmektedir. Daha büyük yatırımlar daha fazla faydayı, erken erişimi ve daha büyük etkiyi, daha büyük fayda ve etki ise daha fazla korumacı yaklaşımın oluşmasını beraberinde getirir. Bu mantık, eşitsizliklerin normalleşmesine ve yatırım-fayda ilişkisine dayalı bir yapısal dengesizliğin sürdürülmesine yol açar. Korumacı politikaların, kaynak bakımından zengin ülkelerin gelişim süreçlerini yönlendirdiği ve küresel araştırma gündemini belirlediği

eşitsizlikleri pekiştirdiği ortaya çıkmıştır. Bu tarz davranışların QT inovasyonu üzerindeki rolü değerlendirilmiş, veri paylaşımı ve bilgiye erişim konularında ortaya çıkan sınırlamalar irdelenmiştir. Araştırmacılar, çalışmalarını ulusal hedeflerle uyumlu hale getirmek ve bu eşitsiz ortamda yönlerini bulmak için yöntemlerini uyarlamaktadır.

Araştırmacılar küresel dinamiklerde uluslararası rekabetin etkisini, siyasi/stratejik, maddi ve yetenek tabanlı olmak üzere üç ana kategori üzerinden tartışıldı. Siyasi/stratejik rekabet, araştırma ekosisteminde "Kuantum Yarışı" (QRace) olarak adlandırılmıştır ve ülkelerin bu yarıştaki pozisyonlarına atıfta bulunur. ABD, Çin ve Avrupa ülkeleri ana aktörler olarak görülmektedir. Araştırmacılar QRace'i medya tarafından yönlendirilen bir anlatı olarak tanımlarken, bazı ülkeler sıralamada belirli hedeflere ulaşma çabalarını açıkça belirtmiştir. QRace'in pozitif etkileri arasında araştırmacılar için motivasyon kaynağı olması ve hızlı teknolojik ilerlemeyi sağlaması öne çıkmıştır. Yarışı kazanmanın veya yarışta yer almanın, piyasa avantajı sağlama ve standart belirleme gücü sunduğu ifade edilmektedir. Ancak bu yarışın, miktar/nicelik odaklı başarının niteliğin önüne geçmesi, iş birliğini ve bilgi paylaşımını engellemesi gibi olumsuz etkileri de olduğu önerilmiştir. Yarışın, politikacıların ve finansörlerin kısa vadeli, ölçülebilir çıktılara odaklanmasına yol açtığı belirtilmiştir. Bu durum, anlamlı ve uzun vadeli katkılar sağlayacak temel araştırmaları arka plana atmakta ve bilim insanlarını daha güvenli, ancak yenilikten uzak projelere yönlendirmektedir. Bilim insanları, bu baskının kariyer risklerini artırdığını ve gerçek inovasyon yerine "nicel büyüme" odaklı çalışmalara sebep olduğunu ifade etmektedir. Bu çelişki, yatırımcıların ve araştırmacıların hedefleri arasındaki farktan kaynaklanmaktadır: araştırmacılar yenilik ve keşif odaklı çalışırken, yatırımcılar ulusal veya ekonomik kazançlara daha fazla önem vermektedir. Araştırmacılar QRace'te bulunan ülkeleri iki kategoriye ayırmışlardır: "Öncü / uyumlu (aligned)" (ABD, Çin gibi liderliği hedefleyen) ve "Takipçi / uyumsuz (unaligned)". Öncü ülkeler yarışta "kaybetmeyi" önlemek adına rekabetçi inovasyona yoğunlaşırken, takipçi ülkeler "geri kalma korkusu" ile daha açık bilgi değişimi ve stratejik iş birliklerine yönelmektedir. Bu kategorilerin stratejik motivasyonları, araştırma ekosistemlerinin nasıl şekillendiğini etkilemektedir. Özellikle ülkeler arasındaki endişeli yaklaşımlar, araştırmaları kapalı hale getirmekte

ve gelişimi yavaşlatmaktadır. Ancak genel tablo, asimetrik fakat birbirine bağımlı bir küresel QT geliştirme ekosistemi oluşturmaktadır. Maddi rekabet de QT ekosistemini etkileyen bir diğer dinamik olarak öne çıkar. Araştırmacılar, kuantum teknolojisi için gerekli ekipman ve malzemelerin az sayıda ülke tarafından üretilmesi ve ihracat kısıtlamaları nedeniyle uzun teslim süreleriyle karşılaştıklarını belirtmişlerdir. Ayrıca, QT alanında yetenek rekabeti büyük bir etkiye sahiptir. Gelişmiş ülkeler daha fazla yetenekli insan gücüne erişebilirken, bu durumun yetenek göçüyle diğer ülkelerin araştırma kapasitelerini azalttığı ortaya konmuştur. Gelişmekte olan ülkeler, altyapı ve finansal kaynak yetersizliği nedeniyle teknolojiyi baştan geliştirme yerine mevcut gelişmelere erişmek zorunda kalmaktadır. Bu ülkelerde üniversiteler, yetenek çekme ve elde tutma konusunda zorlanırken, özel sektör daha iyi koşullar sunduğu için araştırmacıların akademiden ayrılmasına neden olmaktadır. Sonuç olarak, QRace'in dinamikleri küresel araştırma ekosisteminde maddi ve sosyal eşitsizliklere yol açarken, "güç elde etme" motivasyonu araştırmaların sosyal faydadan çok gösterişli çıktılar elde etmeye odaklanmasına sebep olmaktadır. Rekabet, teknolojik ilerlemeyi teşvik etse de uzun vadeli temel araştırmaların ihmal edilmesine, yeteneklerin adaletsiz dağılımına ve gelişmekte olan ülkelerin rekabetten kopmasına neden olmaktadır. Bu bağlamda, ekonomik ve sosyal faktörlerin QT ekosisteminin biçimlenmesini doğrudan etkilediği söylenebilir.

Veriler, araştırma ekosistemini şekillendiren yerel dinamiklerin, devlet kurumlarının ve diğer fon sağlayıcıların yanı sıra araştırmacıların karar verme sürecine katılım düzeyine ve bu katılımın doğasına bağlı olarak değişiklik gösterdiğini ortaya koymaktadır. Hükümetler ve şirketler, QT araştırmalarının yönünü ve kapsamını belirlerken, bilgi ve kaynakların paylaşımında esneklik, fonlama sistematigi ve düzenlemelerin küresel ve yerel rekabet ortamına etkisi gibi konulara da müdahil olmaktadır. Araştırmacılar, hükümetlerin QT'ye olan bağlılığının ve bu alana sağlanan desteğin ülkelerin hızlı ilerlemesinde etkili olduğunu vurgulamaktadır. Ancak, bu durum bazıları için büyük bir fırsat yaratırken, diğerleri için çeşitli engeller oluşturabilmektedir. Yerel araştırma ekosistemlerinin yukarıdan aşağıya (top-down) bir yaklaşım çerçevesinde şekillendirilmesi, yönetim stratejisine bağlı olarak, ekosistemi besleyip geliştirici ya da kısıtlayıcı bir rol oynayabilir. Araştırmacıların süreçte yer alması, onların destek algısını ve araştırma ortamını

nasıl tanımlandığını doğrudan etkiler. Araştırmacılar bu katılımın, ülkelerin bilimsel yeteneklerinin korunmasında ve geliştirilmesinde kritik bir rol oynadığını ifade etmektedir. Ancak, sıkı bir yukarıdan aşağıya yönetim tarzı, araştırmacıların teknoloji geliştirme süreçlerinde etkin roller üstlenmesini zorlaştırabilir. Bazı durumlarda hükümetin alana yönelik farkındalık ve destek eksikliğinin araştırmacıların çalışmalarını teorik düzeyde sınırlı tutmalarına neden olduğunu göstermiştir. Araştırma ortamındaki bu tür sınırlamalar, yöneticilerin farkındalık düzeyi ve bu farkındalığın politika oluşturmadaki etkisi ile yakından ilişkilidir. Farkındalık eksikliğinin, yönetim seviyesinde QT geliştirme süreçlerini kısıtlayıcı hale getirdiği durumlarda, araştırmaların her aşamasını etkileyen bürokratik komplikasyonlar ve işbirliği süreçlerinde zorluklar yaşanmaktadır. Bazı bölgelerde inovasyon uygulamalarının altında yatan nedenlerin tam olarak anlaşılmaması, operasyonel yapıda eksikliklere yol açmaktadır. Bu durum, altyapı eksikliğinin yanı sıra uluslararası standartlara ulaşma çabasındaki boşlukları da göstermektedir. Sonuç olarak, araştırmacıların karar alma süreçlerindeki rolü ve bu süreçteki katkıları, araştırma ekosistemini doğrudan etkilemektedir. Araştırmacıların yaratıcı katkılar sunabileceği ve karar alma süreçlerine dahil olabileceği bir yapının, ideal bir araştırma ortamı sunacağı önerilmiştir.

Araştırma finansman sistemine yönelik zorluklar da QT ekosisteminin önemli bir boyutunu oluşturmaktadır. Pek çok ülkede proje finansmanı almak için başvurulması gereken rekabetçi süreçler, araştırmacıların uzun vadeli planlama yapmasını ve özgün fikirler geliştirmesini zorlaştırabilmektedir. Finansmanın tek bir araştırma grubuna tahsis edilmesi ya da belirli alanlarla sınırlandırılması, QT gelişimini tek taraflı bir şekilde şekillendirebilmekte ve yenilikçi yaklaşımların önünü kapatabilmektedir. Öte yandan, bu tür bir fonlama yapısı, yatırım stratejilerinin dikkatli yönetilmesini ve kaynakların en verimli şekilde kullanılmasını da sağlamaktadır. Bununla birlikte, farklı ülkeler arasındaki QT geliştirme öncelikleri, hem ülkelerin kapasitesi hem de stratejik tercihlerine bağlı olarak değişmektedir. Gelişmiş ülkelerin daha çok uygulamalı teknolojilere odaklanırken, gelişmekte olan ülkelerin genellikle teorik çalışmalara yöneldiği görülmektedir. Ülkelerin QT geliştirme konusundaki hedefleri, var olan ekosistemin korunması ya da güçlü olduğu alanların üzerine inşa edilmesi stratejileriyle ilişkilidir.

İkinci ana tema üzerine oluşan verilerin analizinde QT'nin gelişimi, sürekli değişen bir araştırma ekosisteminin temel unsurlarından biri olan akışkanlık üzerinden ele alınmıştır. Akışkanlık, QT'nin gelişiminin ve sonuçlarının öngörülemezliği ile şekillenen adaptasyon ve dinamik doğasını ifade eder; bu, bilimsel gelişmeler, ulusal öncelikler ve uluslararası işbirliklerinin karışımıdır. Akışkanlık, araştırmacıların fon sağlama, işbirliklerini yönetme ve küresel stratejilere adapte olma süreçlerinde nasıl hareket ettiklerini etkileyerek onları yalnızca yenilikçi olmakla değil, aynı zamanda değişen stratejilere uyum sağlamakla da yükümlü kılmaktadır. Bu analiz üç temel akışkanlık kategorisine odaklanır: teknoloji ve bilimsel kapasite geliştirme, anlam yaratımı, ve QT stratejilerini uyarlama.

QT'nin bilimsel ve teknolojik gelişim süreci henüz başlangıç aşamasında bulunmaktadır. Bu süreç, sabit sonuçlardan ziyade keşif, deney ve kademeli iyileştirmelerle karakterizedir. Araştırmacılar, teknolojinin kendisi ve gelecekteki uygulamalarına dair bilinmeyenlerin fazla olması nedeniyle, şu anda temellerin atıldığını, ancak sonuçların henüz alınmadığını ifade etmektedir. Bununla birlikte, temel/kuramsal araştırma çabalarının yetersiz olduğu belirtilmiştir. QT'nin öngörülemez doğası, aktörlerin sürekli olarak pozisyonlarını yeniden değerlendirmelerini gerektirir. Bilimsel sorulara ve pratik sonuçlara yeterli yanıt verememe, gelişimin sınırlandığı noktaları işaret eder. Aynı zamanda, QRace gibi olgular, ülkelerin birçok teknolojiye aynı anda yatırım yapmasını gerektirir. Ancak sonuçların hangisinin başarılı olacağı konusunda belirsizlik devam etmektedir, bu da ülkelerin QT'nin farklı yönlerinde rekabetçi olmalarını gerekli kılar. Araştırmacılar, QT'nin pratik kullanım olanaklarının henüz sınırlı olduğunu ve bu teknolojiyle teorik potansiyel arasında bir boşluk olduğunu vurgulamaktadır. Ayrıca, QT donanımının geliştirilmesi oldukça karmaşık ve standartlaşmanın henüz mümkün olmadığı bir alan olarak görülmektedir. Bu bağlamda, Güney Afrika, donanım yerine yazılım geliştirme ve uygulama yaratmaya odaklanarak daha stratejik bir pozisyon almayı hedeflemektedir. Bu, düşük maliyetli bir stratejiyle QT küresel ekosisteminde yer edinmeyi amaçlayan "rekabetten kaçınma" yaklaşımıdır. QT alanındaki insan kaynağı eksikliği de önemli bir sorun olarak öne çıkmaktadır. Eğitilmiş iş gücünün yetersiz olması ve özellikle deneysel alanlarda uzmanlaşmış kişilerin azlığı, teknoloji gelişimine yönelik kapasiteyi sınırlayan faktörler arasındadır. Daha büyük

toplumların, yetenekli insan kaynağı oluşturma konusunda avantajlı olabileceği ifade edilmiştir.

Son olarak, QT teknolojisinin çift kullanım özellikleri, yani aynı teknolojinin hem fayda hem de risk oluşturabileceği durumu, teknolojik görelilik olarak tanımlanmıştır. Örneğin, QT hem veri şifrelemeyi çözebilme hem de bu tür tehditlere karşı koruma sağlayabilme potansiyeli teknolojinin hem saldırı hem savunma aracı olarak kullanılabilirliğini göstermektedir. Araştırmacılara göre teknolojinin faydaları ve risklerinin değerlendirilmesi genellikle fon sağlayıcıların düzeyinde gerçekleşirken, nihai kararların çoğunlukla özel şirketler tarafından verilmesi, QT'nin erişilebilirliğini adil olmaktan uzaklaştırabilmektedir.

QT'nin değer önerisinin belirsizliği, bu teknolojiler etrafında oluşan anlamların akışkanlığını etkilemektedir. QT'nin potansiyel değerini yaratma süreci, gelişmekte olan teknolojiler için karmaşık bir aşamadır. Sosyal Teknolojinin İnşası (SCOT) teorisi, bu anlam yaratma sürecindeki akışkanlığı “yorumlayıcı esneklik” olarak adlandırır. QT'nin anlamı konusunda iki zıt yaklaşım öne çıkmaktadır. Bunlardan ilki QT hakkında bilgi eksikliğinin yarattığı yabancılık ve endişe duygusudur. Bu belirsizlik, QT'yi geleceğe dair korkular ve çekincelerle ilişkilendirmektedir. Hem alan içinde hem de dışında QT ile ilgili algılar genellikle kaygı taşımaktadır ve bunun temel nedeni bilgi eksikliği ile geleceği öngörememe problemidir. Buna zıt yaklaşım olarak QT'nin sadece bir araç olarak görülmesi ve özelliklerinin göz ardı edilerek yaşamı kolaylaştırdığı için değer kazanması önerilmiştir. Bu yaklaşımda QT, doğasında olan potansiyelinden bağımsız olarak yalnızca daha iyi bir çözüm sunduğu için anlam bulur. QT'yi tanıtmak ve benimsetmek için anlam yaratma süreçleri bu iki eğilim arasında bir denge kurmaya çalışır. Ancak, belirsizlik ve pratik faydaların vurgulanması, teknolojinin öz değerinin göz ardı edilmesine neden olabilir. Bu süreçte, QT'ye yönelik aşırı beklentilerin (“hype”) de algıları şekillendirdiği önerilmiştir.

Farklı ülkeler, firmalar ve kurumlar, QT geliştirme stratejilerini belirlerken jeopolitik konumlarına ve tarihsel geçmişlerine bağlı olarak değişken yöntemler benimsemektedir. QT'nin kendi iç dinamiklerinin akışkanlığının da bu stratejilere

yön vererek QT gelişim stratejilerinde akışkanlık oluşturduğu ortaya çıkmıştır. Buna göre ülkelerin, belirli bir teknolojiye öncelik verme ve çeşitli QT türlerine yatırım yapma olarak iki temel stratejiyle hareket ettiği önerilmektedir. İlk modelde teknolojik gelişim süreçlerinde belirli QT alanlarına odaklanılarak bir yol bağımlılığı oluşturulmaktadır. Bu modeldeki hedef, sınırlı kaynaklarla maksimum verim sağlamaktır. İkinci modelde belirsizlikler nedeniyle, birçok ülke ve kurum, QT'nin farklı alanlarında bilgi birikimi oluşturmayı tercih ederek ileride beklenmedik bir gelişmeye karşı hazırlıklı olmak istemektedir. Bu iki strateji, QT gelişimine yönelik rekabeti arttırsa da, aynı zamanda ülkeleri “hazır olma” ve “öncü keşif” arasında bir tercihle karşı karşıya bırakır.

Son ana tema olan yapısalılık/stabilite içindeki tüm faktörler rejim elementleri olarak geçer. QT'nin gelişiminde belirsizliğin yarattığı esnekliği dengeleyecek bir yapı ve çerçeve gereklidir. Rejim unsurları, QT'nin hızla gelişen dinamiklerini yönlendirmek, esneklik ve net bir yön arasında denge kurarak ilerleme sağlamak için temel unsurlar olarak öne çıkmaktadır. Bu elementlerden regülasyonların, özellikle farkındalık yaratma amacıyla hükümetler veya kurumlar düzeyinde etkili olduğu belirtilmiştir. Örneğin, standartlar ve regülasyonlar QT'nin benimsenmesini hızlandırmak ve gelecekteki riskleri azaltmak açısından önemlidir. Standartlar, QT'nin piyasa erişimini kolaylaştırmak ve uluslararası iş birliğini desteklemek amacıyla sıkça vurgulanmaktadır. Öte yandan, QT'nin ulusal politikalara dayalı regülasyonları da, teknolojinin ülkelere sağladığı stratejik avantajların korunması açısından önemlidir. Ayrıca yasal düzenlemelerin, özellikle bankacılık gibi kritik sektörlerde QT'nin benimsenmesini teşvik ettiği ifade edilmektedir. Katılımcılara göre regülasyonlar, QT'nin yaygın benimsenmesini sağlamak açısından gereklidir ve teknoloji geçişlerini kolaylaştırarak gelişim sürecini hızlandırabilir. Ancak düzenlemelerin iş birliğini kısıtlayabileceği de belirtilmiştir. Buna karşılık, farkındalığın ve düzenlemelerin eksik olduğu durumlarda ise QT'nin hem teknolojik hem de ulusal kalkınmaya etkileri olumsuz olabilir. Örneğin, bazı ülkelerde bürokrasi ve yetersiz önceliklendirme nedeniyle QT'ye yönelik ilerlemenin geciktiği belirtilmiştir. Bu bağlamda, erken ve istikrarlı yatırımlar, QT gelişimi için daha sağlıklı bir yapı oluşumuna katkı sağlamaktadır. QT'ye özgü rejim unsurlarından bir diğeri de standartlardır. Veriler, standartların QT'nin gelişiminde hem yerel hem de

uluslararası düzeyde ortak bir çıkar oluşturduğunu göstermektedir. Bu standartlar, QT'nin gelişimini yönlendirmek, küresel piyasalara entegrasyonunu kolaylaştırmak, iş birliğini artırmak ve karşılıklı gelişimi teşvik etmek açısından önem taşımaktadır. Araştırmacılar takipçi ülkelerin genellikle öncü güçlü aktörlerin standartlarına uyum sağladığını ve hiyerarşik bir gelişim modeli olduğunu önermişlerdir. Bu dinamik, QT'nin yenilikçi yapısını bir yandan desteklerken diğer yandan iş birliği ve rekabeti birlikte var eden bir sistem oluşturur.

Buna ek olarak QT'ye özgü olmayan rejim elemanlarının, fikri mülkiyet yasaları gibi politikalar, göçmenlik düzenlemeleri, vb. daha geniş araştırma ve yenilik ortamını şekillendirerek QT gelişimini önemli ölçüde etkilediği önerilmiştir. Benzer şekilde, finansman mekanizmaları bazı alanları önceliklendirerek araştırma gündemlerini yönlendirmektedir. Ticaret politikaları ve ulusal güvenlik endişeleri ise hassas teknolojilerin alışverişini kısıtlar ve global işbirliğini yavaşlatan korumacı bir yaklaşım sergiler. QT'nin gelişimi için uygun bir ortam yaratmak, güçlü bir altyapının yanı sıra kaliteli yaşam koşulları da gerektirir. Veriler, araştırmacıların yaşam koşullarının, çalışma ortamlarından daha geniş bir faktör olarak QT gelişimini etkilediğini vurgulamıştır. Ülkeler, yüksek yaşam standartları sunduklarında, küresel yetenekleri cezbetme ve elde tutma konusunda avantaj sağlarlar. Araştırmacı beklentilerine dair daha derinlemesine bilgi sağlamak amacıyla, ideal bir QT gelişim ortamı için gerekli yapısal elemanlara yönelik katılımcılardan öneriler alınmıştır.

Veri analizi sonucunda ortaya çıkan ihtiyaç analizine göre, uluslararası ilişkilerde, koruma önlemleri teknolojik ilerlemenin hızını ve yönünü etkiler. Ayrıca, koruma odaklı yaklaşım, diğer ülkeleri benzer tedbirler almaya teşvik eder ve bu da koruma ihtiyacını arttırarak riskleri daha da büyütür. . Bağımsız bir şekilde pazarda faaliyet göstermek olumluluk olarak görülse de, bunun mümkün olmadığı savunulmuştur. Araştırmacılar, bu süreçte uluslararası standartların önemli olacağına inanmaktadır. Pazar büyüklüğü ve etkisi, standartların belirlenmesinde önemli bir rol oynar. Her ülkenin pazarı farklı olduğundan, tüm ülkeler için geçerli tek bir standardın oluşması mümkün bulunmamıştır. Bu durum, her ülkenin özgün koşullarına göre belirli standartların oluşturulmasını zorunlu kılar. Kaynakları sınırlı olan ülkeler, bazen daha az düzenleme ve finansal engel ile yaratıcı ya da alışılmadık projeler

geliştirebilirler. Ancak bu, verimli olmayan projelere kaynak ayırma riskini taşır. Küçük ülkelerin, daha büyük oyuncularla eş zamanlı olarak teknolojik yeniliklere katkıda bulunabilecekleri örnekler arasında Singapur ve Güney Afrika yer almaktadır. Bu ülkeler, sıklıkla alt düzeyde başlayan ve yaratıcı yaklaşımlar benimseyen bir geliştirme süreci izlerler. Ancak bu, büyük ülkelerle kıyaslandığında, kazançların somutlaşmasının zor olabileceği bir alanı ifade eder. Yine de bu tür girişimler, küçük ülkeler için teknolojiyi hızlıca entegre etme ve pazarda bir yer edinme şansı verebilir.

Mevcut QT gelişiminin durumu, yalnızca bir teknoloji ve bilgi ilerlemesi değil, aynı zamanda yatırımdan ve faydalardan eşitsiz paylaşılan bir süreç olarak görülmektedir. Bu sürecin yönetilmesi, özellikle güvenlik ve korumacılık odaklı yaklaşımların ön planda olması nedeniyle karmaşıktır. QT'nin potansiyelinden tam anlamıyla yararlanabilmek için eşit mesafede bir küresel yönetim organı kurulması gerekmektedir. Bu sebeple bu çalışma iki aşamalı bir politika modeli önerisinde bulunur.

1. Aşama: Küresel QT Standardizasyon Kurumu (GTQTSB) Kurulumu: Bu, QT ile ilgili tüm paydaşlara evrensel bir çerçeve sağlamak amacıyla merkezi ama kapsayıcı bir uluslararası kurum kurulmasını önerir. Bu kurum, standartları belirleyip uygulamak ve toplum düzeyinde benimsenmesini sağlamak için çok paydaşlı bir danışma süreci izler.

2. Aşama: Öncü ve Takipçi Ülkeler Arasında Yapılandırılmış Rol Dağılımı: GTQTSB, teknolojik olarak uyumlu ve uyumsuz ülkeler için tamamlayıcı roller tanımlayacak ve tüm aktörlerin katkıda bulunabileceği ve fayda sağladığı bir ekosistem oluşturmaya yardımcı olacaktır.

Bu model, her ülkenin farklı gücünden yararlanarak QT'nin gelişimini küresel ve yerel düzeyde dengede tutmayı amaçlamaktadır.

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