Report

The Ecosystem Surrounding Quantum Technology

Important Considerations and Key Takeaways

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For Kongsberg Gruppen

Open

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Content

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Foreword

Over the course of the last 10 weeks, I have had the pleasure of researching quantum technology, its ecosystem and talking to over 20 experts, culminating in this report. I have learned a lot, and I hope the report can contribute to promoting quantum technology and spark good conversations. I would like to use this opportunity to thank all the interview candidates, who selflessly sat aside time from their busy schedules to partake in this work. These conversations have been instrumental in the creation of this report, and I am impressed by all the knowledge and expertise these people possess. All contributors are listed in Appendix A.

I would also like to extend my gratitude to Kongsberg Gruppen that made this report possible. Kongsberg Gruppen is and will continue to be one of Norway's most important enterprises within technology, and I hope this report helps you navigate the quantum jungle. I would also like to extent a heartfelt thanks to Terje Nilsen, undoubtedly one of Norway's leading experts on quantum technology for making all of this possible.

Thank you.

Abstract

This report explores the evolving ecosystem surrounding quantum technology (QT) in Europe, with a particular emphasis on Norway. It highlights the complex and manifold landscape of QT, influenced by grassroots initiatives, rapid global investments, and numerous activities happening in Norway, the Nordic, EU, NATO and on a global scale. For Norwegian businesses aiming to develop or implement QT, this ecosystem presents both opportunities and challenges.

Quantum in Norway

The Norwegian quantum community broadly agrees that the most important step in preparing the country and its businesses for the imminent quantum revolution is a QT strategy. The creation of such a strategy needs to address central aspects of future QT endeavors. Two aspects widely regarded as crucial are funding and strategic differentiation. While the recent allocation of the annual 70 million NOK for QT initiatives is a step forward, this funding is by many considered insufficient when compared to investments in neighboring countries, let alone on a global scale.

Strategic differentiation is needed to decide which areas within quantum technology Norway should prioritize. This prioritization will help steer the funding towards selected areas, maximizing its impact and reach. For Norway, quantum sensing is by many seen as the most viable path, building on existing expertise and experience. Other areas suggested for prioritization is quantum software and algorithms. Achieving a globally recognized position within one or more specialized QT niches could establish Norway as a key player, enabling it to leverage strategic partnerships and collaborations. Such a position could further strengthen Norway's influence in joint efforts and provide competitive advantages.

While a national strategy will be important considering funding, alternative approaches to securing financial resources should also be explored. The report highlights the increasing focus of public-private collaboration in advancing QT. Drawing inspiration from European and NATO approaches, several experts promote greater emphasis on dual-use cases, strengthening ties between academia, research institutions, and industries. Such partnerships can accelerate the commercialization of QT and attract private investments, ensuring sustainable development and deployment of the technology. Moreover, standardization will

play an important role in transitioning QT from theoretical concepts to practical, real-world applications.

There are several national documents, strategies and plans expected to impact QT advancements. Apart from the national Digitalization strategy, several Norwegian Official Reports, the imminent roadmap for Technological industries, the long-term plan for the Norwegian Armed Forces and the long-term plan for research and education are examples of such documents. Furthermore, several other activities like the grass-root initiatives from Quantum Network Norway and QC Norway and their 2023-publications can provide important insight into the likely trajectory of Norwegian QT development. Moreover, initiatives like the recent agreement between the University of Oslo and the Niels Bohr Institute, the creation and subsequent prolonged existence of several Norwegian quantum hubs and the different funding opportunities available for QT are important to know about. Hence, this report aims to provide clarity on existing activities within Norway.

Collaboration

Norway's QT activities must also actively pursue alignment with the Nordic countries, EU and NATO as future QT efforts are inevitably influenced by their development. Sweden, Denmark, and Finland have already made significant advances, supported by EU initiatives such as EuroQCI and the European Declaration on Quantum Technologies which are both exclusive to full EU members. As a non-EU member, Norway faces barriers to accessing certain QT resources, further underscoring the need for closer Nordic collaboration. Pooling efforts with the Nordic countries could amplify the region's impact on the global QT stage.

The European Commission's ambitions to establish itself as the world's "quantum valley" and NATO's prioritization of QT reflect the global significance of this field. Given Norway's ties and alliances, the country's QT development and subsequent deployment will be greatly impacted by its partners' already existing endeavors. A wide array of initiatives, funding opportunities and projects are available for Norwegian businesses. While likely to provide substantial opportunities, these partnerships will largely lay the premises for Norway's QT advancements, given that they exist, as opposed to the Norwegian QT strategy.

The next five years are likely to see tremendous opportunities in quantum technology. This becomes evident by the global positioning: Countries and businesses alike are preparing themselves to become quantum ready by changing legislation, building production facilities, hiring talent and investing heavily in research, infrastructure and enabling technologies. If

Norway wants to be a part of the journey, it cannot wait for the ChatGPT-moment. Becoming quantum ready requires long-term planning and considerable investments. For many countries and businesses alike, that process started years ago. It is time for Norway to do the same.

For a full summary of the report, please see chapter *4 Conclusion* and its adjoined PESTEL-inspired table.

Please note that this is the **OPEN** version of the report: ‘Part II Key Takeaways’ has been removed in its entirety as it contains information exclusive to Kongsberg Gruppen. Besides that, no alternations have been made.

Introduction

The unprecedented amount of attention on artificial intelligence has left other significant technological breakthroughs with a disproportionally small amount of media coverage and general interest. Despite the lack of interest and attention, several impactful breakthroughs have happened over the last few years – many of which are found in quantum technology (QT). Despite media and most companies' attention on AI, large enterprises such as IBM, Microsoft and Google and governmental institutions of China, US and the European Union have positioned themselves to leverage the momentum of quantum. Large investments, infrastructure and research and development are actively deployed and developed with quantum technology in mind.

This report aims to examine and understand ongoing initiatives on QT and its effect on and for Norwegian businesses, in particular Kongsberg Gruppen. This will be further elaborated under subchapter *Scope and Focus*. Hence, this report can be considered a whitepaper on the quantum technology ecosystem. Its focus is to provide a better understanding of quantum technology from a business perspective rather than shed light on a specific and narrow thesis. This also allows the report to utilize a flexible and investigate approach, enabling rapid incorporation of important information whenever it is uncovered or needed.

In June of 2024, the report "*The Ecosystem of Artificial Intelligence: Important Considerations and Key Takeaways*" was written for Kongsberg Discovery/Kongsberg Gruppen. It was subsequently completed in August 2024. While the full version of the report was confidential, an open version was distributed to the report's external participants (interview objects). A similar approach is followed in this report; A full confidential version tailored towards KOG's interests, and an open version with the intent of sharing with the interviewees who generously set aside time to partake in the creation of this report will be produced. The first report's disposition, research design and reception proved favorable.

Scope and focus

This report aims to examine how quantum technology can and will impact Kongsberg Gruppen. The focus will be on the business applicability of quantum technology. This encompasses both embedment of QT in products and services, as well as the applicability of quantum technology in business-related endeavors: Value chain, geopolitics, funding, governmental alignment, organizational structure and more. When necessary or suitable, the report will extend its approach to include other features or areas of QT considered of interest for Kongsberg Gruppen. The focus will include all four types of quantum technology as defined by the European Union: Sensors, communication, simulation and computers (European Commission, 2023a). Furthermore, the report will also incorporate related fields such as cryptography, as QT is poised to play an important role in encryption and decryption alike. The report's time horizon is set to 5 years. Therefore, all forecasts, interviews and investigations take aim at forecasting, detecting weak signals, spotting potential inflection points and finding out what will happen by the end of 2030.

Structure

The report consists of two main sections. **Part I, Important Considerations**, explores the QT ecosystem in Norway and the EU, offering a broad overview that sets the stage for the following section. As this part explores the most significant forces that impact the development and utilization of QT, it can be viewed as a comprehensive PESTEL inspired analysis. As such, the report's first part will culminate in a PESTEL-table, offering a schematic representation of the most important considerations. **Part II, Key Takeaways**, builds on the insights from Part I to deliver strategic recommendations tailored to Kongsberg Gruppen. These recommendations are grounded in KOG's strategic interests and priorities. This will be further elaborated when introducing Part II.

Data collection and sources

This report primarily draws on insights from interviews with carefully selected experts, recognized for their contributions to QT discussions and development in Norway. The report also draws on international knowledge and expertise to better understand quantum technology in the European Union. The experts have been selected to represent a wide range of intersecting fields, including but not limited to law firms, educational institutions, Brussels-based offices, scientists, chief executive officers and politicians. A snowball sampling approach was employed to identify additional interview candidates. Supplementary information was gathered from various sources, including extensive reviews of the European Union's websites, reports, strategy documents and more. All sources were cross-checked to ensure the accuracy and reliability of the information.

Ethical considerations

All interviewees listed by name and title in Appendix A have consented to being identified. Those who participated under the condition of anonymity have had their identities protected. It is important to note that all interviewees represent their personal perspectives and do not speak on behalf of their organizations.

Why quantum? Why now?

This chapter gives a brief introduction to quantum technology, how it is understood by the European Union and the potential consequences of its emergence.

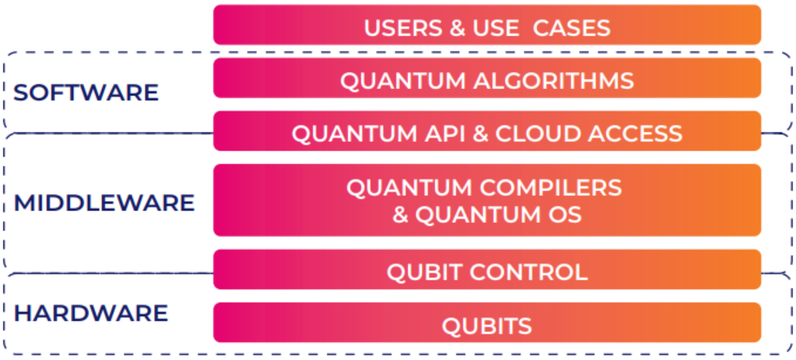
Quantum technology – a brief introduction

Contrary to popular belief, the emergence of quantum technology is several decades old and has already provided substantial growth to modern societies. As Quantum Network Norway write in its whitepaper: "*Recently, the potential of quantum phenomena for technological applications has risen to prominence on the global scene, prompting a surge of activities both at the academic level and by public and private stakeholders. This has been termed by analysts and experts the second quantum revolution, echoing the first one, which can be considered as one of the pillars of modern-day technology, with inventions such as the transistor, the laser, and nuclear magnetic resonance imaging, to name a few*." (QNN, 2023).

As pointed out by QNN, a second quantum revolution is imminent and has the potential to revolutionize several industries and find new areas of improvement in others. According to a report on the future impact of quantum technology published by Boston Consulting Group (BCG) in 2024, QT has a wide range of use cases. From simulations in drug discovery, material design and solar conversion to optimization tasks within risk management. Optimizing route and traffic efficiency in all forms of transport and logistics is projected to be greatly impacted as well. Quantum technology is also expected to play a significant role in further development and enhancement of artificial intelligence and security applications such as cryptography and safe communication. These examples are by no means exhaustive.

Quantum computers also have the potential to significantly influence the green transition by addressing one of the biggest challenges of traditional supercomputers: Energy consumption. Classical supercomputers require enormous amounts of power to perform complex calculations. Quantum computers, by contrast, leverage the principles of quantum mechanics to perform certain types of computations exponentially faster, which could reduce the energy required for specific tasks. If harnessed effectively, quantum computers could make solving such energy-intensive problems more sustainable. However, quantum computers themselves are not without environmental concerns. They require highly controlled environments, such as near-absolute zero temperatures, which demand significant energy to maintain.

In addition to areas of applicability mentioned in the previous paragraphs, the BCG report emphasizes the concept of emerging use-cases, as adding substantial financial impact. This can be compared to the network effects and complementary use-cases deriving from the introduction of the smart phone. It is unlikely that Steve Jobs, when he introduced the iPhone in 2007, realized the ramifications of the smartphone on banking, traveling, entertainment and transport - or deciding when to summon your electric car from the parking lot. Similarly, the 2024 SRIA-publication by the Quantum Flagship and the European Commission highlighted the importance of system stacking/synergy effects within the QT ecosystem. Such synergies add to the complexity of predicting QT's actual capabilities and possibilities (QF, 2024e). Safe to say, the possibilities of quantum technology are already vast, but its impact and use cases are likely to grow and develop alongside its continued development.

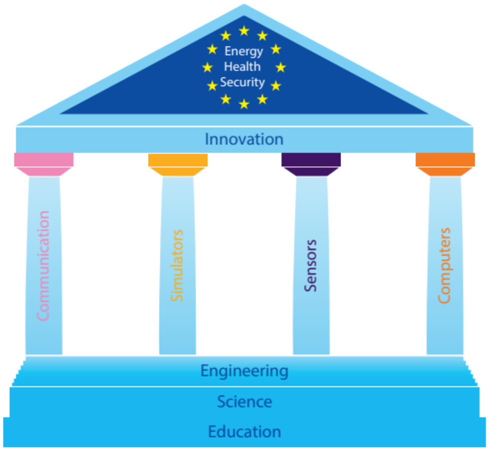


Print screen: The Quantum Flagship's visual illustration of 'Quantum Computing Stack Levels' (QF, 2024e).

QT is projected to have a substantial impact on economic development. The BCG report predicts that quantum technology can produce upwards of 200 billion USD in value creation annually between 2030-2040. From 2040 and onwards, the number exceeds 1 trillion USD (BCG, 2024). McKinsey has published a similar report, projecting that QT could create value of 2 trillion USD by 2035 (McKinsey, 2024).

The four types of quantum technology

In the European Union's *Quantum Manifesto*, four key areas of quantum technology are defined. These are: (Quantum) Communication, Simulators, Sensors and Computers. It is worth noting that upon reading a significant number of quantum technology papers, a high percentage of papers operate with three types of quantum technology: Computers, communication and sensors. As such, it seems as if the global quantum community has not yet agreed upon fundamental categories or definitions. The work on standardized terminology will be addressed in chapter *3 Standards*. This report uses the European Union's Quantum Manifesto's categories.



Print screen: The four pillars of quantum technology, as illustrated in the European Union's Quantum Manifesto (EU, 2016).

Quantum communication (QCom): QCom utilizes the principles of quantum mechanics to ensure secure data transmission, with Quantum Key Distribution (QKD) being a primary application. QKD enables two parties to establish a shared, random secret key, providing security through the fundamental property of quantum systems, where any attempt to intercept or measure the transmission alters its state and becomes detectable (EU, 2016). This approach ensures a level of security beyond what classical cryptographic methods can achieve.

Quantum Simulators (QS): The design of complex objects often relies on supercomputers, but these systems struggle to predict the behavior of materials at the atomic level or simulate chemical reactions accurately. Quantum simulators, based on quantum physics, address these limitations by replicating the behavior of materials under quantum phenomena, such as at very low temperatures. Unlike general-purpose quantum computers, quantum simulators are specialized and simpler to construct, as they do not require precise control of every component. Current prototypes have already surpassed supercomputers in solving specific problems, such as exploring the origins of high-temperature superconductivity—a discovery with transformative potential for energy efficiency in storage, distribution, and transportation (EU, 2016).

Quantum Sensors (QSen): QSen uses superposition states, which are highly sensitive to changes in their surroundings, make it possible to create very precise quantum sensors. These sensors are likely to dramatically outperform current state-of-the-art sensors, both in longevity and precision. Improvements in materials, lower costs, and smaller components like lasers have made these sensors ready for many practical uses. Furthermore, quantum sensors may not need to rely on GPS or satellite communication to provide exact locations, making them particularly valuable in environments where GPS signals are weak or unavailable, such as underwater, underground, or in space (EU, 2016).

Quantum Computers (QC): QC represents one of the most ambitious and transformative advancements in quantum technology and arguably in the history of technology altogether. It is often mistakenly used synonymously with quantum technology, but as demonstrated in previous paragraphs, QT encompasses more than just QC. Unlike classical systems, quantum computers utilize qubits, which can exist in multiple states simultaneously, enabling large parallel computational powers far beyond the capabilities of traditional supercomputers. As classical computation approaches its physical and technological limits, global interest in quantum computing has surged, with major IT companies and research institutions such as Google, Microsoft, IBM and Amazon investing heavily in its development. Several countries have also embarked on creating quantum computers.

There are several subfields supporting the four main categories of quantum technology as well. As such, these categories work as umbrella terms for more specialized work in semiconductors, infrastructure, mathematics, physics, engineering and numerous other fields. Several QT-related studies and productization-processes will also be intersectional, encompassing additional fields of study and experts from various professions. As with artificial intelligence, there are bound to be several debates and initiatives on QT policy making, law, equality, change management and many other arenas. Successful operationalization of QT rests on other enabling technologies and competence.

Part I: Important Considerations

2025 Outlook: Navigating the Quantum Revolution in 2025 and Beyond

Quantum Xchange
1,589 followers

December 23, 2024

Forbes

Perhaps The Most Disruptive Technology In History Is Coming And It's Expected To Change Everything. Busi… …d Mark…

VOA

GY

VOA Mandarin: Quantum technology a key battleground in US-China competition

How businesses are preparing for the quantum revolution

New Scientist
61,061 followers

December 18, 2024

1: Norwegian influence

This chapter explores the Norwegian sources of influence on development and deployment of quantum technology. The chapter starts by examining the government's role and position, and its creation and subsequent release of the new Digitalization strategy. Moving on, other national initiatives ranging from Norwegian Official Reports (NOU) to scientific consortiums will be introduced and elaborated.

1.1 The government

During the interviews, it became evident that the Norwegian government is not currently seen as a strong enough force of impact regarding quantum development and deployment. The lack of QT initiatives, few guiding principles and too little funding provided to scientific institutions were regularly mentioned as barriers for the community and Norway's continued growth in the field. The negligence of QT in the new Digitalization strategy was also a frequent topic of debate, but will be dealt with in chapter *1.2 Strategies*. A considerable amount of scientists and QT experts solicit a clear governmental approach as this would help guide the development of Norwegian quantum initiatives (personal communication, 2024). This position was also made clear with the position paper published in 2023 by QC Norway. Their report will be discussed in chapter *1.4 National initiatives*.

One of the most reoccurring arguments for more governmental involvement is that QT investments is costly and will require both substantial investments and international collaboration. These are challenging areas to work with without thorough support from politicians and governmental institutions. Furthermore, the rather broad scope of possible QT endeavors calls for a narrower approach, promoting prioritized key aspects. Hence, trade-off and strategic differentiation were actively promoted by several experts. To better help Norway and its potential partners gain a competitive edge, the national initiatives should be centered around areas in which Norway can claim a strong position. As one interviewee puts it: "*With companies like IBM and Google pouring billions of dollars into quantum computing every year, it is unlikely that Norway will ever stand a chance in building our own quantum computer to challenge these companies*." (personal communication, 2024).

1.2 Strategies

The much-anticipated Digitalization strategy appeared in September 2024. Before its inception, in 2023, The department of Digitalization and Public Governance initiated a 'call for initiatives period'. Approximately 160 contributions were made to the strategy. The contributions were made from large international corporations, scientific institutions, private individuals and public sector domains alike. While their contributions greatly differed in content in key areas such as data centers and artificial intelligence, most contributions had one thing in common: They did not address quantum technology. Less than ten contributors mentioned QT, and the statements were brief and without much elaboration. Some of the statements follow:

«*Norges kompetanse og nasjonale initiativer må økes i møte med fremvoksende teknologier. Det nasjonale senteret for anvendt kryptologi ble opprettet hos NSM i oktober 2023. Ambisjonen er å videreutvikle kryptosenteret til et innovasjonssenter for sensitive teknologier. Et slikt senter, initiert av staten, kan samle interessenter fra myndigheter, akademia og industri og stimulere til kompetanse og industriutvikling på viktige teknologiområder som kunstig intelligens, kvanteteknologi mm*.» (NSM, 2023).

«*En underliggende infrastruktur skal ikke kun tilby bredbånd (inkl. fremtidige 5 og 6 G-nett), men både data- og kjøreressurser (f.eks. HPC og generativ KI), gjerne geografisk spredt, men virtuelt tilgjengelig. Dette er en forutsetning for en omfattende digitalisering, ikke minst for grenseoverskridende samhandling. Også infrastruktur for fremtidig kvanteberegninger må med i kontekst av infrastruktur*.» (SINTEF, 2023).

The call for initiatives period and the stakeholders' lack of statements concerning quantum technology indicates that this topic was not addressed properly by neither public nor private sector in 2023. However, it is important to note that suggestions were also put forth to politicians outside of the stakeholder documents now made available. For example, Abelia hosted a multi-stakeholder workshop where several discussions on quantum technology were made prior to crafting the strategy. As politicians partook in the event, they have been presented with numerous examples and recommendations concerning quantum technology (personal communication, 2024). The negligence of quantum technology may be the result of an overwhelming focus on artificial intelligence, which has been given substantial space in the new strategy – and in the stakeholder initiatives that helped form it. The Digitalization strategy itself describes quantum technologies three times. These are:

"*Kvanteregningsteknologi gir nye muligheter, men byr også på utfordringer for nasjonal og digital sikkerhet. Sikkerhetsdepartementet i USA anslår at de første kvantedatamaskiner vil være i stand til å knekke dagens krypteringsteknologi i 2030. Potensialet i kvanteteknologien har ført til at flere land har etablert nasjonale strategier for denne teknologien. Regjeringen vil derfor at Norge skal satse på forskning og utvikling på dette feltet.*» (Digitalization strategy, p. 65).

«*De såkalte «dype teknologier» omfatter teknologier som KI, autonome systemer, robotikk og kvantesystemer. De representerer muligheter for innovasjon for både samfunnet og næringslivet. I en rapport som Samfunnsøkonomisk analyse AS har utarbeidet for NHO med flere, understrekes det at rask implementering av avansert teknologi, blant annet KI, kan resultere i en betydelig økning i næringslivets verdiskapning*.» (Digitalization strategy, p. 77).

REGJERINGEN VIL

- at 80 prosent av offentlige virksomheter skal ha tatt i bruk KI i løpet av 2025, og 100 prosent innen 2030
- jobbe for å videreutvikle en nasjonal infrastruktur for KI som skal gi tilgang til grunnmodeller tuftet på norske og samiske språk og samfunnsforhold
- utrede behov for tungregnekraft med utgangspunkt i kjente behov i forskningssektoren, offentlig sektor og næringslivet
- gjennomføre KI-forordningen i norsk rett
- etablere en nasjonal tilsyns- og forvaltningsstruktur for KI
- gjennomføre endringer i sektorregelverket som følge av utbredelse av KI i samfunnet
- utrede hvordan man kan bruke data og tekst fra offentlige virksomheter til etisk og trygg trening av nasjonale språkmodeller
- klargjøre hva som er lovlig bruk av åndsverk og andre vernede arbeider i tekst- og datautvinningsprosesser
- utrede om datagrunnlaget i Lovdata kan gjøres tilgjengelig, blant annet for trening av språkmodeller
- styrke veiledningsarbeidet for ansvarlig utvikling og bruk av KI, blant annet gjennom regulatoriske sandkasser
- sikre ansvarlig utvikling og bruk av KI i offentlig sektor
- bidra til bedre og enklere tilgang til helsedata og bruk av kunstig intelligens for videreutvikling av vår felles helsetjeneste, forskning og næringsutvikling
- legge til rette for innovasjon basert på KI i næringslivet gjennom det næringsrettede virkemiddelapparatet
- at Norge tar en aktiv rolle internasjonalt for å påvirke regelverksutviklingen på KI-området, særlig når det gjelder etisk og trygg bruk av KI
- etablere forskningssentre for utvikling og bruk av KI i samfunnet
- styrke forskningen på kvanteteknologi

Print screen: The only specific goal tied to quantum technology in the new Digitalization Strategy.

The underwhelming representation of QT both in contributions and throughout the new Digitalization strategy, has left most experts with the assumption that a new Quantum strategy is likely to emerge. Such a new strategy is poised to drawn inspiration from other Nordic countries, which have prioritized quantum technology more than Norway. Sweden, Finland and Denmark have all released or started working on QT strategies, showing a strong commitment to levering the technology. Denmark is often seen as a Nordic frontrunner in QT considering their comprehensive focus and prioritization on the matter. A QT strategy is also likely to draw inspiration from the European Union's QT strategy and NATO's QT strategy, both of which will be examined later in the report.

During the presentation of the new Digitalization strategy in September 2024, the Minister of Digitalization and Public Governance stated that the strategy is a living document and that it would be revised when needed (SINTEF, 2024). No formal system is currently in place to help edit the strategy or organize stakeholder consultations. Several interviewees doubt such revision will take place, for several reasons: The upcoming parliamentary election of 2025 will likely tune politicians to focus on larger political issues. Should the election result in a new government, most political commentators believe that they would prioritize a new QT strategy over revising an existing strategy with the aim of incorporating more quantum related information. For those reasons, several interviewees consider it unlikely that significant changes will be made to the Digitalization strategy considering QT. Instead, the creation of a new QT strategy is seen as more likely (personal communication, 2024).

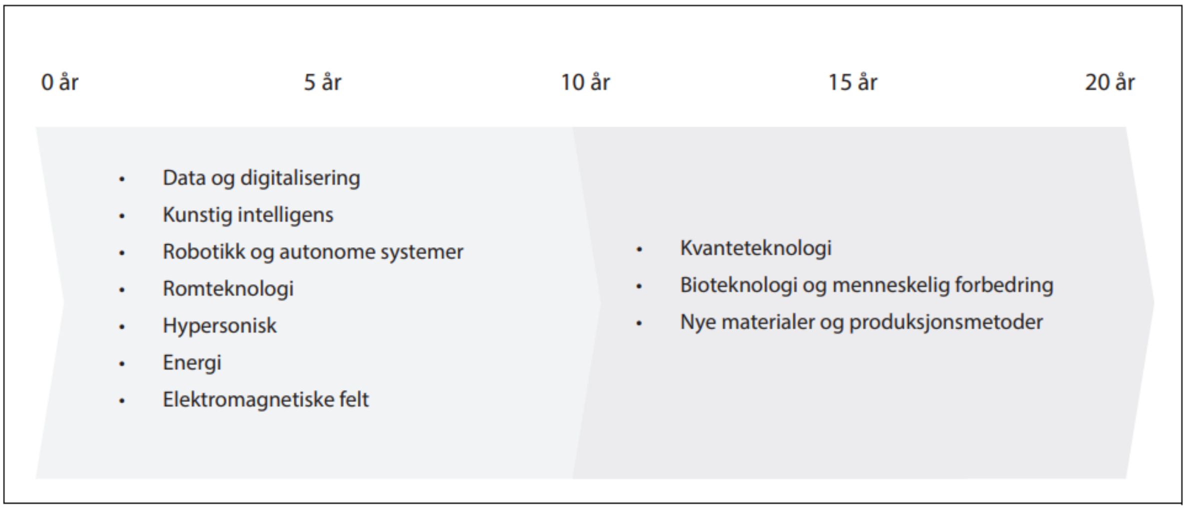
1.3 Other important plans and documents

1.3.1 Norwegian Official Reports

In addition to strategies, numerous other initiatives and publications can forecast or shape the government's QT policies and efforts. For Norway, various Norwegian Official Reports (Norges Offentlige Utredninger/NOU) may play a key role in shaping how quantum technology is advanced and implemented.

Two of the Norwegian Official Reports, *Totalberedskapskommisjonen* and *Forsvarskommisjonen*, are likely to have significant influence over the coming decade. These two NOUs collaborated to evaluate both civilian and military preparedness for emergencies and potential threats. Following their assessment, they proposed several recommendations, one of which was the establishment of a national security and preparedness strategy (The Norwegian government, 2023). If the government chooses to pursue this recommendation, artificial intelligence, along with related domains such as computational capacity, energy resources, and digital infrastructure, is expected to play a central role. As attention to QT gains momentum, it is likely it too would play an important role in the creation of such a strategy. Furthermore, quantum technology is mentioned in both the NOUs. While *Totalberedskapskommisjonen* only briefly mentions QT, *Forsvarskommisjonen* actively takes a stand:

"*Samtidig åpner IKT opp nye sårbarheter for trusler og angrep i cyberdomenet og påvirkningsoperasjoner. Flere andre brytningsteknologier som laservåpen, bioteknologi, materialteknologi og kvanteteknologi har stort potensial, men er umodne teknologier der gjennombrudd de neste 10–20 år er usikkert*.» (Forsvarskommisjonen, 2023, p. 124).



Print screen: Forsvarskommisjonen's visualization of threats for the next 20 years. The report was published in 2023 and states that QT is unlikely to pose a significant threat until minimum a decade has passed (Forsvarskommisjonen, 2023, p. 124).

Forsvarskommisjonen clusters all quantum technology into one category and does not differentiate between quantum computing, communication or sensors. While several reports suggest that quantum computers may not be available until 2040, this still poses a significant threat to encryption and confidentiality. NATO's "DIRECTIVE ON THE SECURITY OF NATO CLASSIFIED INFORMATION" states that "*In all cases, NATO Classified Information will be subject to review for declassification and public disclosure after 30 years (50 years for Intelligence and Nuclear Information) in accordance with the Policy for the Public Disclosure of NATO Information (C-M(2008)0116)*" (NATO, 2020).

Since encrypted information can be intercepted and stored, it may be decrypted long before the standardized 30 years have passed. For example, if foreign intelligence intercepts NATO communication considered classified, it may be decrypted 15 years from now – long before such actions were intended. The same principle applies to other enterprises too: Many companies operate with a standardized encryption period of 20 years (personal communication, 2024). As such, classified information may be accessible several years before its classified state expires. Some experts even argue that quantum computers may be able to decrypt today's classified information already in 2030 which makes the situation even more alarming (Engh-Hellesvik, 2023). In a report published in 2023, Chinese researchers claimed to having broken encryption using quantum computers. The report was later withdrawn, and there is wide consensus in the scientific community that the report's findings were illegitimate (Waters, 2023).

1.3.2 The government's roadmap for technology industries

In January of 2024 the now late Minister of Trade and Industry Jan Christian Vestre and the Minister of Digitalization and Public Governance Karianne Tung announced a roadmap for technological industries. While both the roadmap and the Digitalization strategy will help guide the technological development for Norwegian businesses, the documents simultaneously serve somewhat different purposes. While the Digitalization strategy encompasses all sectors and all technologies, the roadmap's aim is narrower and centered around industries and the technology sector (personal communication, 2024).

In the government's press release concerning the roadmap for technology industries, it is stated that it focuses on deep technologies. In this context, deep technologies include but are not limited to: Robotics, artificial intelligence, automated systems and quantum technology. Furthermore, the roadmap aims to put forth guidelines to help harness these technologies for swift adoption, creating new jobs and increase value creation while making sure the development is not detrimental to society (Norwegian government, 2024b).

As part of the roadmap's creation, the government hosted an open multi-stakeholder consultation, aimed at collecting important input. The event unfolded in May 2023, giving Norwegian companies the ability to promote their opinions and arguments to help form the content. Several corporations promoted focus on QT, envisaging its upcoming influence and impact. Abelia's submission, for instance, highlights the ever-growing presence of QT and uses international efforts to shed light on the matter:

"*Storbritannia lanserte i mars 2023 sin nye nasjonale strategi for kvanteteknologi – en 10års strategi med mål for kompetanse, forskning- og utvikling, næringsliv, regulering og adopsjon av kvanteteknologi i samfunnet. Andre land, som USA, Canada, Danmark og Australia har også egne nasjonale strategier for kvanteteknologi. Abelia mener det er på høy tid at også Norge får på plass en nasjonal strategi for kvanteteknologi, en prosess som gjerne kan sees i sammenheng med et veikart for teknologinæringslivet. Strategien bør ta utgangspunkt i de tidligere strategiene fra våre naboland, men også tidligere faglige innspill, som Simula, OsloMet og Sigma2s Bidrag til ein norsk strategi for kvanterekning.*» (Abelia, 2024).

While the roadmap is yet to be released, it is expected to address quantum technology and other deep technologies in a more direct manner compared to the Digitalization strategy. As its impact on development and deployment is still too early to tell, former roadmaps can provide clues to its upcoming role. In 2022 the government published its roadmap for green industry and subsequently updated the map in 2023. In the document, one can read that:

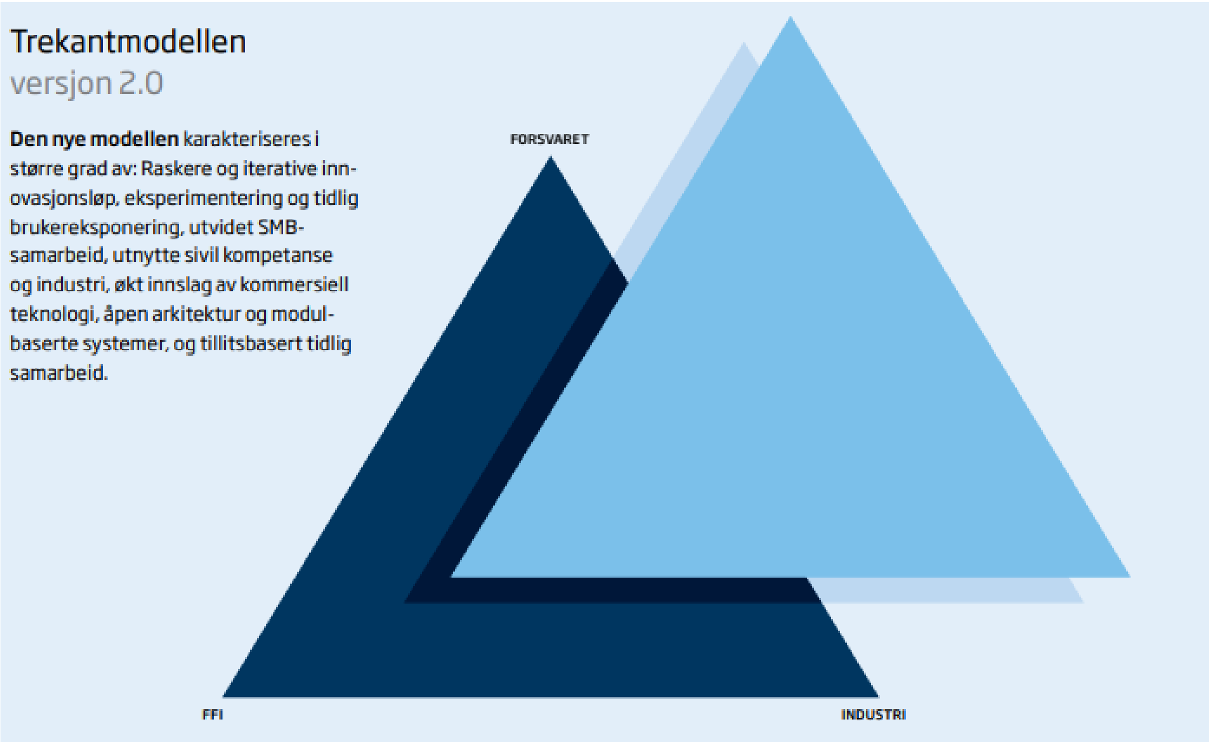
"*Det er i stor grad industrien selv som må være i front for å gripe mulighetene og løse utfordringene i det grønne skiftet. Regjeringen skal imidlertid aktivt legge til rette for å utløse private initiativer gjennom gode rammebetingelser og en aktiv nærings- og industripolitikk, der staten og næringslivet spiller på lag for å realisere mulighetene.*» (Norwegian government, 2023).

If the roadmap for technology industries is similar to that of green industry, the government will promote collaboration between private and public sector and utilize its role to facilitate more effective development and deployment. What this constitutes in practice remains to be seen. The roadmap is expected to arrive in 2025.

1.3.3 The long-term plan for the Norwegian Armed Forces

The new long-term plan for the Norwegian Armed Forces was decided upon in June 2024 and will become active in 2025. Projected to last until 2036, the new plan will steer the armed forces' investments and priorities over the next 12 years. The plan outlines a substantial investment plan in the armed forces, aiming to spend 1624 billion NOK over the next 12 years (Norwegian Government, 2024c). While QT is not mentioned specifically in the government's preposition, it was mentioned in *The Military Advice of the Chief of Defence 2023*: "*Quantum technology will eventually be able to offer more secure communications and better sensors*." (Norwegian Armed Forces, 2023).

While short, the statement acknowledges future impact of QT. The long-term plan will also be of great interest for all parts present in the The Norwegian Defence Research Establishment's (Forsvarets Forskningsinstitutt) presentation of the military sector's new innovation model. The new model promotes quicker adaptation of technology for military purposes, increased collaboration (includes SMEs) and an increased focus on commercial products and their potential for military-use cases. This broadening of the military sector's horizon also extends to research and scientific endeavors. This dual-use mentality was also presented by Kenneth Ruud, administrative director at The Norwegian Defence Research Establishment during the Research Council's webinar on the annual 70 million NOK in early December 2024.



Print screen: The Norwegian Defence Research Establishment's (NDRE) new and enhanced three-part model aims to promote a more efficient collaboration between the Armed Forces, NDRE and industries. The latter is now prone to more SME-collaboration and incorporation of commercial products (NDRE, 2024).

Since Norway is a member of NATO, the defense alliance's QT initiatives will also impact the Norwegian Armed Forces and its investments. This will be further covered in chapter *2.7 NATO*.

1.3.4 The long-term plan for research and education

The Norwegian government's Long-Term Plan for Research and Higher Education 2023–2032 outlines a strategic framework to enhance Norway's competitiveness, drive technological innovation, and address pressing societal challenges. By fostering excellence in research and education, the government aims to equip Norway to meet global demands, strengthen its knowledge-based economy, and position itself in terms of emerging technologies. A key focus within the plan is quantum technology, recognized for its transformative potential across multiple sectors.

As a prioritized area, quantum technology is expected to play a pivotal role in revolutionizing fields such as energy efficiency, cybersecurity, and computational capabilities. The government emphasizes the importance of targeted investments in research infrastructure, interdisciplinary expertise, and international collaboration to ensure Norway remains competitive in the QT domain:

The Government will:

- give particular priority to the following areas of research and research-driven innovation:
  - basic research in areas necessary to the development of enabling and industrial technologies
  - artificial intelligence, quantum technology and neurotechnology
- give particular priority to the following areas in higher education and skills:
  - necessary specialist expertise in emerging and converging technologies of particular strategic importance

Print screen: The government's prioritized areas in research and higher education. Alongside artificial intelligence and neurotechnology, QT is considered one of three areas with the highest priority (Norwegian Government, 2023).

The fact that QT is considered one of the government's top priorities in the Long-Term Plan for Research and Higher Education 2023–2032, should help QT become a prioritized area of research, investment and funding.

1.4 National initiatives and research

This chapter examines the different initiatives on quantum technology in Norway. The main focus will be on universities and other research facilities. The chapter will also include two of the most prominent contributions from the quantum community in Norway: QC Norway's Position Paper aimed at contributing to the creation of a national QT strategy and Quantum Network Norway's Whitepaper on Funding for QT. The subchapters also highlight other important initiatives but is by no means exhaustive.

1.4.1 Quantum science in Norway

Several Norwegian universities and research facilities are exploring the opportunities within quantum technology. The University of Oslo (UiO), Oslo Metropolitan University (OsloMet), the University of South-Eastern Norway (USN), The Norwegian University of Science and Technology (NTNU) and the University of Bergen (UiB) are all examples of universities that perform research on QT. Research labs and facilities such as SINTEF and Simula play a crucial role in QT research as well. In addition, other organizations such as Oslo Science City, NHO and its adjoined trade organization Abelia have voiced their interest in quantum technology and actively promote it.

Several bilateral collaborations between these institutions have been established to conduct research on QT. The Gemini Center on Quantum Computing, a collaboration between NTNU, SINTEF and UiO, is one such example. The center's recent renewal was announced in November 2024, which enables continued funding throughout 2028 (SINTEF, 2024b). While Norway, as an emerging QT community should strive for increased national collaborative efforts, strengthening international efforts remains an important part of QT research.

Strengthening quantum research and collaboration within Europe is and will continue to be a top priority according to several interviewees (personal communication, 2024). One of the leading arguments for this statement is the heavy investment in QT by large economies such as the United States, China and several other strong economies. If Europa is to have a fighting chance on the world stage, it is through collective efforts. Furthermore, increased Nordic collaboration is a high priority since Norway's neighboring countries are investing heavily in quantum technology. The QT community is unambiguous: To ensure the Nordic countries' presence both on the European stage and on other international stages, these countries should work together. Some interviewees argue that the Nordic countries should specialize in different niches of QT, and thus complement each other. This is among the mandates of Nordic Quantum which will be discussed further in chapter *2.6 Nordic Countries*.

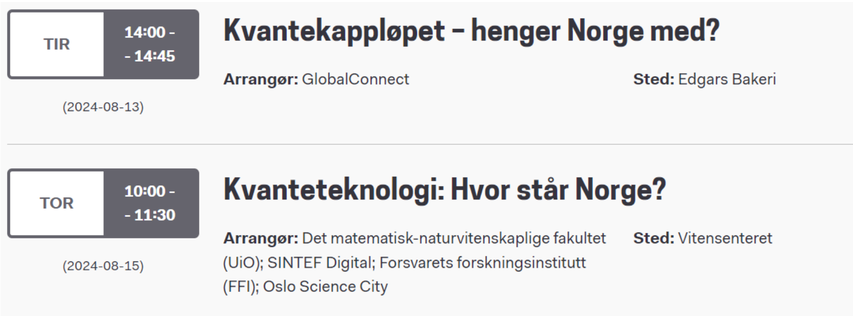
There are several previous, ongoing and upcoming quantum technology projects in which Norwegian institutions, businesses and experts play a central role. QNN's whitepaper elaborates this thoroughly. The authors write: "*Although there has not been a dedicated thematic call on quantum technology so far, in a presentation at the end of 2022, Pål Malm from RCN estimated that there were slightly over 30 funded RCN projects that were in some way related to QT, considering the period 2017–2022, and two Centers of Excellence with activities in the field (QuSpin at NTNU, 2017–2027, 266 MNOK and Hylleraas at UiO/UiT, 2017–2027, 7 275 MNOK). Currently, we count 7 active Researcher Projects within QT, out of a total of 1 681 Researcher Projects funded by RCN*." (QNN, 2023). Norwegian research facilities are also involved in several international projects.

International collaboration is a hallmark of the Norwegian quantum technology community, with funding programs like QuantERA playing a pivotal role. Future initiatives should consider instruments to foster global partnerships including but not limited to the European countries. Norwegian researchers are already active in Nordic and European projects, such as NordiQuEst, which connects Nordic quantum computing infrastructure, and LUMI-Q, focused on European quantum computer integration (QNN, 2023).

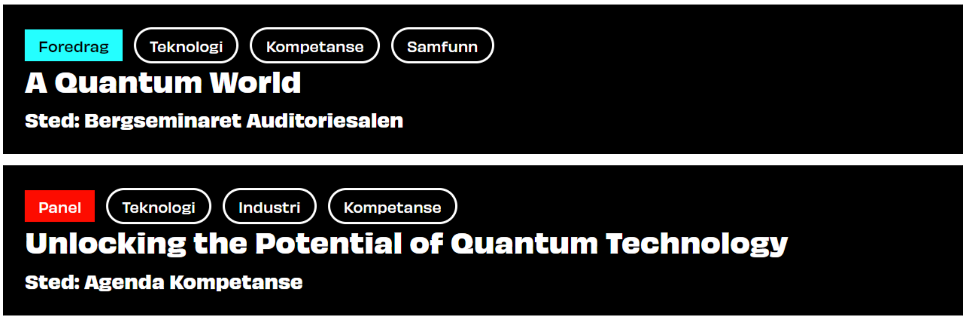
Several QT projects have also been initiated by Norwegian private and public companies alike. Ruter works on quantum annealing to optimize processes such as ticket controls, while the Norwegian Metrology Service (Justervesenet) participates in the project 'QuAHMET'. The project "*will develop, characterize and evaluate thin films for QAHE and devices made from them, leading to a detailed metrological assessment from sub-K to above 1 K, currents from below 100 nA to above 1 μA and over a wide range of external magnetic fields up to several Tesla*.» (Norwegian Metrology Service, 2023). Moreover, the beforementioned quantum center, The Gemini Center on Quantum Computing, has led several successful projects like Qombine, NeQst and QC4DS (SINTEF, 2024).

Several QT workshops and events have been organized over the last years. The most notable was held by NHO in November 2023. The event gained significant attention and took its aim at promoting QT and its ever-growing presence both in Norway and globally (NHO, 2024).

Quantum technology was also a debated topic under Norway's two largest technology events in 2024: Kongsberg Agenda and Arendalsuka. Several interviewees expect QT to continue to increase its presence throughout 2025 (personal communication, 2024).



Print screen: Some of the QT events at Arendalsuka 2024 (Arendalsuka, 2024).



Print screen: Two QT events were held during Kongsberg Agenda (Kongsberg Agenda, 2024).

The QT community in Norway has also seen setbacks. On the 9th of December the Nordic Quantum Computing Group (NQCG), a Norwegian QT-based company founded in 2000 ceased its operations. In its press release, it listed several key challenges for closing down, the primary being the lack of a national QT strategy. NQCG's argues that without a national QT strategy, the field is too wide to approach. Norway needs to differentiate itself in specified areas within QT. This differentiation should also be the basis of funding. The company continues by arguing that the already insufficient annual 70 million NOK will be distributed over a too wide range of fields within QT, failing to leverage Norwegian expertise (NQCG, 2024). Furthermore, the company argues that acquiring talent is difficult under current tax, visa and work regulations.

1.4.2 Collaboration between UiO and Niels Bohr

In May 2024, during the inaugural Danish royal visit to Norway, the Danish King and Queen visited several research facilities working on quantum technology. During their visit, the University of Oslo formalized a collaboration agreement with Denmark's Niels Bohr Institute

(NBI), a leading European research institution in quantum technology. This partnership aims to enhance cooperation in critical emerging technologies, with a significant focus on quantum research. The agreement facilitates researcher exchange and joint projects, aimed at leveraging the complementary strengths of both institutions (Oslo Science City, 2024).

The newly signed agreement was welcomed by the Norwegian QT community, and is arguably one of Norway's most important joint efforts in bolstering the nation's competence in QT research and readiness. As Christine Wergeland Sørbye, the CEO of Oslo Science City put it: "*Together, the Nordic countries have the potential to assume a leading position in the quantum field and contribute to deploying this technology in a socially beneficial manner, aligned with our shared values. We already possess a solid foundation for this in the Nordics, with robust research communities and substantial public and private funding sources. Now, we must build on this and foster a Nordic quantum success story*." (Oslo Science City, 2024).

1.4.3 A Norwegian innovation District

Oslo Science City (OSC) is Norway's first innovation district, a new form of collaboration that aims to harness human capital and physical assets alike. The innovation district shares several similarities with more traditional industry clusters and innovation hubs. However, the innovation district has a more open-ended approach to its joint efforts. OSC encompasses a variety of members, representing a wide range of industries, all with a common goal of creating new and thriving opportunities. Unlike traditional clusters or hubs, the innovation district is not bound by restraints on specificity, rather, broad collaboration across different fields is encouraged. OSC has been one of the frontrunners for QT in Norway, and as stated in the previous subchapter, it played a pivotal role in the agreement between UiO and NBI. Oslo Science City draws inspiration from Innovation District in Copenhagen (personal communication, 2024).

Similar to that of OSC, The Innovation District Copenhagen (IDC), formerly known as Copenhagen Science City, is an innovation district drawing on the combined knowledge and strength from more than 40.000 researchers, students and staff distributed throughout various location in and around Copenhagen (IDC, 2024). The IDC plays a central role in Denmark's QT activities, coordinating and facilitating various projects. Furthermore, QT is IDC's top priority, and this commitment is further enshrined in Denmark's QT strategy, which has earmarked several billion DKK over the next years to QT research and projects (Danish government, 2024). IDC also receives substantial funding from the Novo Nordisk Foundation.

1.4.4 A Norwegian Funding Strategy for QT

Throughout 2023, several Norwegian research institutions and facilities created joint efforts to promote and accelerate quantum technology initiatives in Norway. Two of these are the Quantum Network Norway and QC Norway.

Quantum Network Norway (QNN) mapped out and collected information about Norway's ongoing QT endeavors. Subsequently, this information, combined with key insight from international QT development, resulted in the network's report: "*Quantum Technology in Norway. Proposal for a National Funding Strategy*." The report lays the foundation for continued work on QT as a collective effort, and urges the government to actively engage with and promote QT: "*We evaluate Norway's current position in the global, European and Nordic landscape of quantum technology, and based on this we suggest a funding strategy which, if followed, could keep Norway on track to partake of the upcoming technological revolution*." (QNN, 2023).

QNN argues that two fundamental funding initiatives are vital to ensure effective Norwegian participation in the QT race: "*through the Research Council of Norway: (i) a thematic area within a call and (ii) a dedicated call for projects within quantum technology*." (QNN, 2023). Not only should the Research Council of Norway open calls earmarked for QT, but more money should also be allocated to quantum research altogether. QNN compares the money spent on QT research by other Nordic and European countries, and Norway is far behind. See chapter *1.4.5 Funding* for more information about Norway's financial assets on QT compared to that of other countries.

The report also thoroughly examines how the different quantum technology communities are built up both in Norway, the Nordic and Europe. Another key take-away from their report, is the call for international collaboration and joint efforts. As the report points out, the vast sums invested in QT both by nations and tech-giants alike, makes it a challenging domain for small countries to face by themselves. By enabling close international collaboration both with Nordic countries, the European Union, through NATO and other partners, Norway has the potential to manifest its role as an international and attractive QT contributor (QNN, 2023).

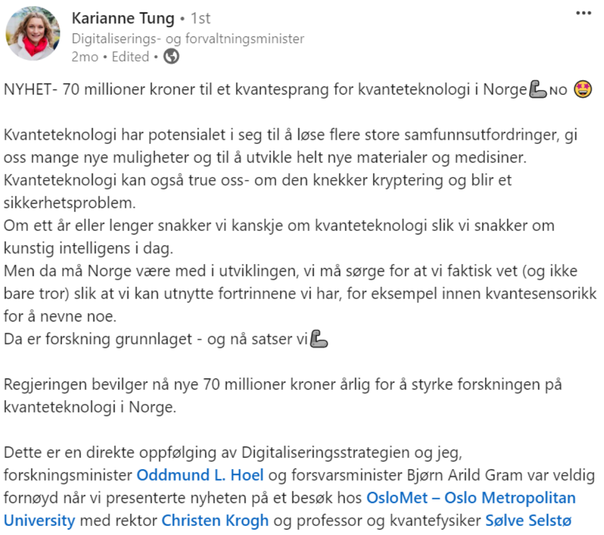
1.4.5 QC Norway's position paper

QC (Quantum computing) Norway was a collaborative effort between Simula Research Laboratory, Sigma2, Oslo Metropolitan University (OsloMet), the Norwegian Research Council and SINTEF (QC Norway, 2023). Its aim was to promote quantum awareness and create discussions around the necessity of a Norwegian quantum strategy. In November 2022 QC Norway hosted a workshop, aimed at gathering key insights to help guide the creation and spark the interest for a national QT strategy. The result of the workshop was published in a position paper: "Contributions Towards a Norwegian Quantum Computing Strategy". The report outlines several key areas in which Norway should focus its attention considering quantum computing. In its executive summary, the authors state that "*Norway lacks a national strategy and corresponding investments for the development of its own expertise on quantum computing through educational programmes, active research, business creation, and support from technical infrastructures*." (QC Norway, 2023).

The report points out that a significant portion of international research and investment is done in quantum hardware. As these investments primarily is done by large economies and some of private sector's largest tech-companies, QC Norway argues that Norway ought to focus on quantum software and algorithms (including adjoint fields such as quantum information theory, quantum error correction, fault-tolerant structures and quantum error mitigation). Apart from the ongoing race in hardware, their arguments are founded on Norway's previously strong communities and experience within software, mathematics and algorithmic development. The authors also point out that quantum software is somewhat of a 'blue ocean' not yet saturated with competitors. As with QNN's report, QC also emphasize the importance of international collaboration – especially with the Nordic countries.

1.4.6 Funding

As described in chapter *1.4.1 Quantum science and research in Norway,* several projects have already been initiated on QT with existing funding options. However, these means are not earmarked QT, and quantum research makes up a disproportionally low percentage of the total projects reviewed, despite being a prioritized area in the long-term plan for research and higher education. As previously pointed out in the chapter concerning the newly adopted Digitalization strategy, the only goal concerning QT directly, is to strengthen research on quantum technology (Digitalization strategy, 2023). However, this goal began its fruition in the matter of weeks as the Government announced an annual grant of 70 million NOK earmarked for QT research:


Karianne Tung • 1st
Digitaliserings- og forvaltningsminister
2mo • Edited •

NYHET- 70 millioner kroner til et kvantesprang for kvanteteknologi i Norge NO

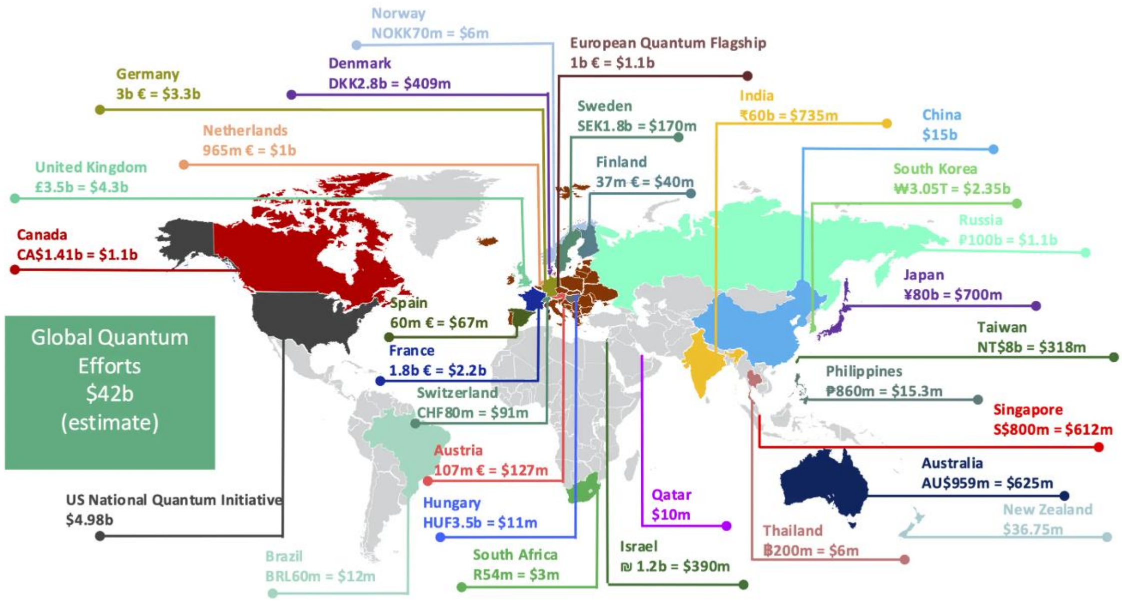
Kvanteteknologi har potensialet i seg til å løse flere store samfunnsutfordringer, gi oss mange nye muligheter og til å utvikle helt nye materialer og medisiner.
Kvanteteknologi kan også true oss- om den knekker kryptering og blir et sikkerhetsproblem.
Om ett år eller lenger snakker vi kanskje om kvanteteknologi slik vi snakker om kunstig intelligens i dag.
Men da må Norge være med i utviklingen, vi må sørge for at vi faktisk vet (og ikke bare tror) slik at vi kan utnytte fortrinnene vi har, for eksempel innen kvantesensorikk for å nevne noe.
Da er forskning grunnlaget - og nå satser vi

Regjeringen bevilger nå nye 70 millioner kroner årlig for å styrke forskningen på kvanteteknologi i Norge.

Dette er en direkte oppfølging av Digitaliseringsstrategien og jeg, forskningsminister Oddmund L. Hoel og forsvarsminister Bjørn Arild Gram var veldig fornøyd når vi presenterte nyheten på et besøk hos OsloMet – Oslo Metropolitan University med rektor Christen Krogh og professor og kvantefysiker Sølve Selstø

Print screen: Norway’s Digitalization and Public Governance Minister Karianne Tung announced the news on LinkedIn in October (Tung, 2024).

The annual 70 million budget does not fall out of the sky. The QT community has been lobbying for years to secure funding (personal communication, 2024). While the 70 million is well received by the community, the experts also argue that more is needed. When compared to annual figures by other countries, 6 million USD is comparably a small figure. For instance, Denmark has an annual QT spend of 409 million USD – almost 70 times over that of Norway.



Print screen: A map showing global quantum investment. According to Qureca, the annual global spend on QT now exceeds 40 billion USD (Querca, 2024).

The Research Council of Norway's webinar on the 6th of December: Late last year, The Research Council of Norway hosted an open webinar where different stakeholders were invited to share their thoughts and opinions on how the newly added 70 million NOK should best be used. The initial round was arranged by pre-planned appeals by prominent people in the QT community of Norway. The second part was an open stage, where various stakeholders provided their points of views. As a whole, the event showed a strong uniformity in the community, and how the annual 6 million USD should be invested:

- Norway needs a national QT strategy. This should be influenced by other similar Nordic strategies, and emphasize Norway's abilities to gain a competitive advantage on an international stage.
- To best secure a competitive advantage and make Norway a sought-after partner, niches should be sorted out and prioritized. Quantum algorithms, software and sensors in particular were the areas widely supported by the community.
- Norway needs to strengthen the educational system around QT: More Ph.D candidates, more fundamental research, more Ph.D initiated by industry partners, more general public knowledge and awareness.
- Increased Nordic, European and international collaboration. Partnerships should also be seen in relation to geopolitical tensions and security.
- Infrastructure and in particular Norfab, should be prioritized as an area for continuous investment. Norfab was also mentioned numerous times as the most urgent place to prioritize the 2025 investments.
- Establishing a national team in QT.
- Increased collaboration between private industries, the government and scientists. Science and technology should be viewed for its potential dual-use and productization: If research can provide real-world applications, the likelihood of financial support by the private sector significantly increases.
- There is no time to lose, QT initiatives should be a top priority – for all.

The Norwegian Research Board (Forskningsrådet) is seen as a crucial part in QT research and development, however, its financial model is by several viewed as an obstacle. When grants and funds are given to projects, they are usually provided annually without a rollover-effect. As a result, the annual 70 million NOK to QT, must be spent every year. This means that surplus money cannot be allocated from one year to another. As a result, the budgets must be finely tuned and timed precisely. The lack of flexibility is often seen as a hinderance for long-term planning (personal communication, 2024).

1.4.7 Creating awareness - Promoting quantum technology

Educating the public and creating awareness is often seen as a crucial step in implementing new technologies. This has been mentioned numerous times by interviewees and it was emphasized during the Norwegian Research Board's webinar and in by both QNN and QC Norway's Position papers:

"*Quantum computing, like its origin in quantum mechanics, has so far been curriculum only for the particularly interested, and usually at advanced levels of physics and chemistry. This needs to, and is about to, change. World-wide, universities are developing new courses at undergraduate and graduate levels to educate young students. This is desperately asked for by a very rapidly growing quantum industry, which cannot afford waiting for the five years it takes to train a high school graduate to a master's degree*." (QC Norway, 2023).

The focus on creating awareness and interest for QT expands far beyond that of students in physics and other STEM fields. One of the questions asked to several interviewees was "How can a company prepare for quantum technology?". The most frequent reply was to educate the workforce and to create trust in new technologies (personal communication, 2024). Creating understanding, interest and awareness both in the workforce and the general public is by many seen as a pivotal step in maturing Norway for the pending quantum revolution. As such, several initiatives have already begun, for instance The OsloMet Quantum Hub organizes events to help promote QT (The OsloMet Quantum Hub, 2024).

This democratization of QT is often compared to the same process seen in artificial intelligence. Since ChatGPT's launch in November of 2022, numerous courses, workshops and events have aimed at educating both the public and the workforce in areas previously exclusive to IT workers. The same process should be started with QT – but, as one interviewee puts it: "*We cannot wait for that ChatGPT moment. Teaching people about quantum technology should have started yesterday*." (personal communication, 2024).

1.5 Summary

The Norwegian government is currently not seen as a strong enough force on the development and deployment of QT. For years, the Norwegian quantum community has been lobbying to promote QT and the need for a national strategy, increased funding options and even stronger international collaboration and increased awareness. Two of the most prominent examples for this ongoing work are QNN's whitepaper for a national funding strategy for QT and QC Norway's Position paper. Both papers were initiated by the QT community and its grassroot-like creation indicates a lack of centralized prioritization. However, it is likely that a QT strategy will emerge, for numerous reasons that will be presented throughout the paper.

Despite being off to a slow start, the focus has started to shift towards increased attention to quantum technology: From the recent annual funding of 70 million NOK to the collaboration between UiO and NBI. NHO and other organizations' increased awareness and involvement, and the pending roadmap for technology industries with its anticipated focus on QT to name a few examples. Despite the recent boost in attention and awareness, more is needed. When comparing Norwegian QT investments to that of other countries, it falls short. As one interviewee puts it: "*Norway can afford to invest more in quantum technology. What we cannot afford, is not to.*" (personal communication, 2024).

2: European influence

The European Union is poised to greatly influence Norwegian development and deployment of quantum technology, and is therefore an important arena to examine considering the ecosystem of QT. Hence this chapter will dive into several relevant aspects of the EU. The chapter starts by examining the most central EU institutions and bodies concerning past, present and future QT endeavors. Moving on, central EU documents such the overall plan for digitalization, political guidelines, the Quantum Manifesto and more will be explained and elaborated. This also includes recent reports, such as Mario Draghi's report on European Competitiveness. The chapter moves on to examine the different funding initiatives and current scientific projects and collaborative efforts. The final subchapters highlight the Nordic countries and NATO as they too are important to consider when planning for QT.

2.1 European institutions, bodies and agencies and their relationship to QT

The European Union encompasses over a hundred different institutions, bodies, and agencies. Among these, seven are designated as core institutions, with four recognized as primary decision-makers. Of these, the European Commission is the only executive authority and thus plays a crucial role in forming the EU's approach to QT.

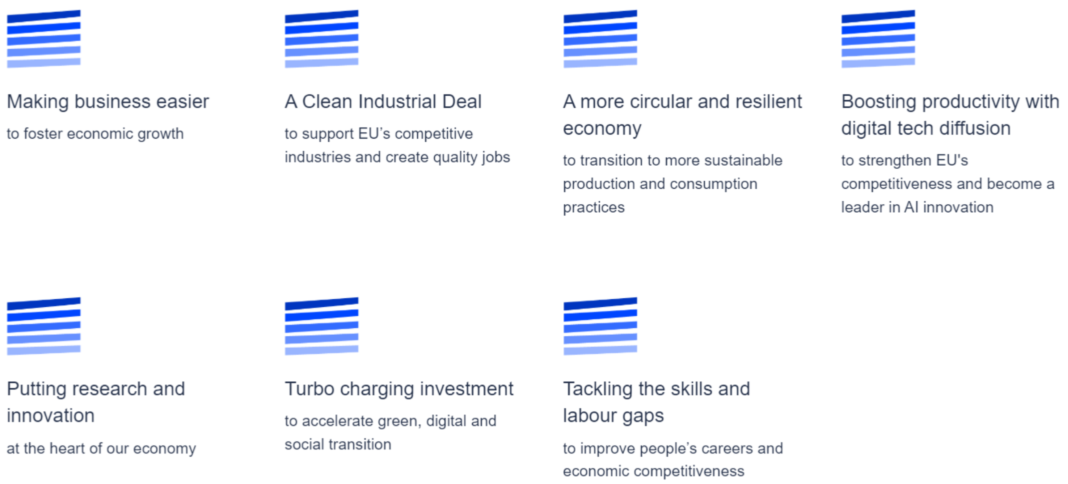
The European Commission: One of its primary responsibilities is to introduce legislative proposals to the Council of the European Union and the European Parliament through its exclusive 'right of initiative.' Due to this unique ability, the Commission is widely regarded as one of the EU's most influential bodies, if not the most powerful. Consequently, the re-elected President of the Commission, Ursula von der Leyen, is often seen as the de facto leader of the EU, even though no official leadership authority is vested in any individual or position (European Commission, 2024a).

Ursula von der Leyen's reappointment as president is by many regarded as a triumph for the European Union, as it ensures continuity for the Commission. Although von der Leyen has been criticized for insufficient transparency, she is broadly acknowledged for her stability and competence in addressing complex challenges. During her 2023 campaign for re-election as President of the European Commission, her address to the Parliament emphasized several key policies and priorities, including green and renewable energy, security, resilience, and advancements in industry and technology: *«And I will propose a new European Competitiveness Fund. It will be focused on common and cross-border European projects that will drive competitiveness and innovation… It will ensure that we develop strategic tech and manufacture it here, in Europe"* (von der Leyen, 2023).

Von der Leyen's outspoken focus on competitiveness and innovation projects a new and more offensive position for the European Union towards innovation, resilience and competitiveness. In a recent speech in relation to the new College of Commissioners to the European Parliament, she expressed herself clearly: "*This unity [That of Europe] will be all the more important in today's contested world. A world in which every weakness is weaponised, every division pounced upon and every dependency exploited*." (von der Leyen, 2024).

However, this tendency (the focus on resilience, reduce harmful dependencies and increased competitiveness) has been evident for several years. The Chips Act, the Critical Raw Materials Act, the European Green Deal, The Critical Medicines Act, the REPowerEU plan and the Net-Zero Industry Plan. All these initiatives take a significant aim to reduce Europe's harmful dependencies and to increase its resilience. Similarly, acts and strategies in the making share many of the same tendencies: Reduce harmful dependencies, increase Europe's resilience and make Europe more innovative and competitive. While these areas have been among EU’s focal point for years, they are likely to gain additional momentum for the foreseeable future. This is made painstakingly clear in the Commission's Political Guidelines for 2024-2029.

In the Commission’s Political Guidelines for 2024-2029, technology, including but not limited to QT is mentioned as an area of increased focus. In the guidelines, one can read that “*Europe’s competitiveness – and its position in the race to a clean and digital economy – will depend on starting a new age of invention and ingenuity. This requires putting research and innovation, science and technology, at the centre of our economy*.” (EC, 2024b). To achieve this, the European decision-maker institutions have vowed to make innovation easier, more approachable and more entrepreneur-friendly. This is also expressed thoroughly in the Commission’s Competitiveness Compass (EC, 2024c).



Print screen: The Commission’s Competitive Compass has 7 objectives, all aimed at making the European Union more competitive, innovate and resilient in a global perspective (EC, 2024c).

In addition to the Commission, the European Council, the European Parliament and the Council of the European Union are important institutions in the legislative process. As such, they too hold significant power in shaping the future of Europe. With its *Strategic Agenda for 2024-2029*, the **European Council** sets the scene for which direction the European Union develops (European Council, 2024a). As with the Commission’s Political Guidelines, the Council emphasizes the importance of European resilience, competitiveness and innovation. This is made evident numerous places in its agenda: “*We will strengthen our economic security, reduce harmful dependencies and diversify and secure strategic supply…*” The

Council continues: "*We will build up our own capacity in sensitive sectors and key technologies of the future, such as defence, space, artificial intelligence, quantum technologies, semiconductors... Promoting innovation and research, as well as leveraging tools such as public procurement, is crucial in this endeavour*» (EC, 2024a). The European Council's stand and prioritizations are unambiguous.

The European Parliament: The European Parliament is the only legislative body directly elected by the citizens of Europe. Alongside the Council of the European Union and the Commission, it enacts new laws, making it a key player in shaping the EU's political and legislative framework. Its current five-year term began in July 2024 and will continue until July in 2029. While Roberta Metsola was reappointed as the Parliament's president, providing a sense of continuity, nearly half of its members—50%—are serving their first term (EP, 2024). While the Parliament seems to have many of the same prioritizations as the European Council and the Commission, the election of the new College of Commissioners in November 2024 was by many seen as a thriller. The Commission was elected with the lowest level of support since 1993 (by the Parliament). Hence, disagreements between the three legislative institutions may occur.

The Council of the European Union: Through a procedure known as the trialogue, it collaborates with the Commission and the Parliament to adopt new legislation. The Council's members are ministers from each member state, with the specific minister varying based on the issue being addressed. Consequently, the composition of a nation's government directly influences who represents it in the Council. The Council of the European Union does not have a strategic agenda or political guidelines of its own, but adheres to the European Council's Strategic Agenda for 2024-2029. Several other bodies, agencies and organizations representing or otherwise affiliated with the European Commission have weighed in on QT as well. From the European Metrology Network (Euramet, 2024), to the European Space Agency (2023). Though interesting, these will not be elaborated here.

2.2 European Competitiveness

In a highly anticipated speech by France's president at the Sorbonne University in Paris in April 2024, Emmanuel Macron painted a bleak picture of Europe's future. He argued that both China and the United States have and continue to corrupt free markets and trade. He argued that massive subsidization of industries and increased protectionism have a detrimental effect on European and other international businesses alike (Macron, 2024). He calls for action, and as with von der Leyen's appeal to the European Parliament, Macron's statements are clear: "*the era when Europe bought its energy and fertilizers from Russia, had its goods manufactured in China, and delegated its security to the United States of America, is over*." (Macron, 2024).

The European Union's determination to focus on competitiveness, innovation and resilience has called for initiatives to help guide its development. Several reports have been written about Europe's ability (or lack thereof) to promote innovation and development. Arguably, the three most impactful reports written on the matter are: Enrico Letta's report on the European Single Market, Mario Draghi's report on European competitiveness and Manuel Heitor's report on European innovation and research. These three reports will be the topic for the this subchapters.

2.2.1 Enrico Letta's Report on the Future of the Single Market

In 2023, the European Council called "*for an independent High-Level Report on the future of the Single Market to be presented at its meeting of March 2024*" (EC, 2024d). Enrico Letta's report, "Much More Than a Market," examines the future of the European Union's Single Market, emphasizing its role as a cornerstone of European integration and values. The report highlights the need for the Single Market to adapt to a rapidly changing global landscape, addressing challenges such as technological advancements, geopolitical shifts, and the necessity for sustainable development. Among its key recommendations, is the proposal to introduce a fifth freedom to the 'new' single market. The fifth freedom centers around research, innovation, research and data:

"*The fifth freedom could come to complement this framework to catalyse advancements in areas such as R&D, data utilisation, competences, AI, Quantum Computing, Biotech, Biorobotics, and Space, among others. Such fields could greatly benefit from the inclusion of the fifth freedom within the Single Market framework, the freedom of investigating, exploring and creating for the benefit of humankind without disciplinary or artificial borders and limitations*." (Letta, 2024).

The report has sparked significant discussions among EU institutions and member states regarding the future direction of the Single Market. Its recommendations have been acknowledged in various forums, influencing policy debates on enhancing the Single Market's resilience and modernization to accommodate for 21s Century's many developments. The European Union's legislative institutions welcomed the report and invited current and future representatives to advance work based on its recommendations (Metsola, 2024). Overall, "Much More Than a Market" serves as a strategic blueprint for modernizing the EU's Single Market, aiming to bolster its competitiveness and cohesion in a complex global environment.

2.2.2 Mario Draghi's Report on European Competitiveness

Arguably the most famous of the 2024 reports on Europe's global stance considering competitiveness, resilience and innovation is Mario Draghi's report, titled "The Future of European Competitiveness". It was handed over to Ursula von der Leyen in September 2024. Her reception was overwhelmingly positive, and the Draghi report has already had a significant impact on European politics. In von der Leyen's speech to the '*European Parliament Plenary on the new College of Commissioners and its programme*', as cited earlier in this chapter, von der Leyen brought up the creation of The Competitive Compass, as a direct result of Mario Dragi's report on European competitiveness (von der leyen, 2024b). Draghi identifies three areas "for action to reignite growth": (i): "*First – and most importantly – Europe must profoundly refocus its collective efforts on closing the innovation gap with the US and China, especially in advanced technologies*." (ii): "*The second area for action is a joint plan for decarbonisation and competitiveness*." and (iii): "*The third area for action is increasing security and reducing dependencies*" (Draghi, 2024).

The report starts by sounding off the alarm: "*The problem is not that Europe lacks ideas or ambition. We have many talented researchers and entrepreneurs filing patents. But innovation is blocked at the next stage: we are failing to translate innovation into commercialisation, and innovative companies that want to scale up in Europe are hindered at every stage by inconsistent and restrictive regulations*." (Draghi, 2024). The report goes on to describe numerous flaws in the European innovative processes: Too high electricity bills, too little collaboration between scientific communities and private sector, overregulation and a myriad of bureaucracy. The lack of venture capital is also seen as a big hinderance. These are mere examples, as the report itself contains several more challenges for European innovation and competitiveness. The report also provides several recommendations to how the EU can position itself to help accelerate the three beforementioned areas to reignite growth, the first being to accelerate innovation. To accomplish this, the report recommends harmonizing strategies and initiatives across EU's member states.

This would help align Europe's priorities, approaches and boost uniformity across national borders. This recommendation, exacerbates Letta's call for a fifth freedom: If a fifth freedom is to be established and subsequently be effective, the movement of research, data and other scientific resources must be compatible across borders. Moving on, Draghi also provides several other recommendations, ranging from boosting the funding for EU's research and innovation, closing the skills gap found in European education and its workforce, increase the EU's promotion of green transitioning and to promote deeper integration of capital markets to enhance investment flows within the EU to name a few. Overall, the Draghi report will serve as a blueprint for revitalizing the European Union's competitiveness and innovation capabilities, and will therefore have a crucial impact on emerging technologies such as QT.

2.2.3 Manuel Heitor's Report on EU Research and Innovation

Manuel Heitor's report "Align, Act, Accelerate: Research, Technology and Innovation to Boost European Competitiveness," offers strategic recommendations to enhance the impact of the European Union's research and innovation initiatives and programs. The report emphasizes the need for a transformative agenda to position Europe as a leader. The report makes 12 deep rooted recommendations. The recommendations are comprehensive with several underpinning suggestions. Some of the most relevant for QT are:

- Greater alignment between EU and national strategies to promote collaboration
- "Introducing disruptive innovation programmes into the EIC, together with the capacity to attract more private co-investment of disruptive ideas and firms"
- "Stimulate industrial RD&I investment in Europe by creating an Industrial Competitiveness and Technology Council to effectively engage eminent practitioners and experts who will ensure the framework programme's attractiveness and relevance to industry"
- "Foster an attractive and inclusive RD&I ecosystem in the EU by: Implementing a strategy to secure long-term investment in world class research and technology infrastructures that serve the needs of researchers, industry and the public sectors, including in the digital area…"
- "Recognise that countries can be partners, competitors or systemic rivals and that the same country could be all of these in different domains of RD&I (e.g., climate change, electric vehicles or high technology semiconductor chips). This requires a utilitarian approach, asking "Who are our partners for which RD&I domain/question?" (Heitor, 2024).

The Letta, Draghi and Heitor reports are likely to significantly impact how the European Union will address emerging technologies, including quantum technologies. The reports all point to the same direction: The European Union must quickly pick up the pace to have a fighting chance to remain relevant on the global scale of technology, industry and digital solutions. The reports' recommendations call for substantial investments, increased collaboration, less bureaucracy and a more governmental-friendly approach to research, development and innovation. If the legislative powers in the EU choose to pursue these recommendations, several intriguing opportunities are likely to rise for both public and private sector alike.

2.3 Strategies and other significant documents

This subchapter describes some of the most important European documents aimed at quantum technology and adjacent priorities, such as innovation and digitalization.

2.3.1 The Quantum Manifesto

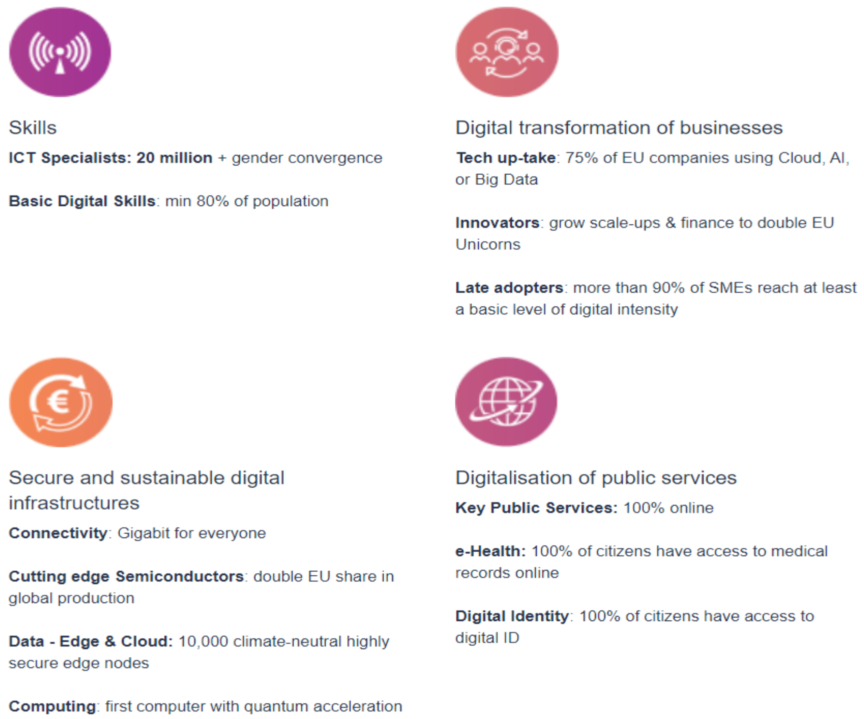
The European Union's Quantum Manifesto was introduced in 2016 as a strategic initiative to establish Europe as a global leader in quantum technologies. Developed through collaboration among leading scientists, policymakers, and industry stakeholders, the manifesto serves as a foundation for a coordinated effort to advance quantum research and innovation. Its creation reflects a recognition of the need for a unified European approach to harness the unprecedented potential of quantum technologies and secure Europe's competitiveness in an emerging technological landscape (EU, 2016).

The manifesto outlines a comprehensive framework aimed at fostering the development of quantum computing, simulation, communication, and sensing technologies. It highlights the importance of substantial public and private investment, cross-border collaboration, and the establishment of a robust research infrastructure. By prioritizing education, innovation, ecosystems, and industrial applications, the Quantum Manifesto sets the stage for breakthroughs with far-reaching societal and economic impacts. Its implementation has led to significant initiatives, such as the Quantum Flagship program, a €1 billion ten-year effort to accelerate quantum research and bridge the gap between fundamental science and practical applications. This will be further elaborated in *2.4 Funding*. The manifesto also outlines several goals, sorted by their chronological order. Some of these, such as the creation of a Quantum Flagship Program have been realized while others have not yet come to fruition. One such instance is the creation of quantum credit cards (EU, 2016).

2.3.2 The Digital Decade

The European Commission's Digital Decade can be considered a governance framework to guide technological and digital development as a whole within the European Union and the EEA. The framework puts forth several goals for the union with the time horizon set to 2030. The Digital Decade focuses on four key areas: (i) skills, (ii) Digital transformation for businesses, (iii) Secure and Sustainable digital infrastructures, (iiii) Digitalization of public services (EC, 2024e).

The Digital Decade works in tandem with other European initiatives aimed at steering and otherwise bolster the European digitalization efforts, including but not limited to the European Commission's Digital Strategy. These documents influence national strategies and digitalization efforts alike. All EU countries must submit their own strategic roadmaps in relation to the Digital Decade. In Denmark's Digital Decade Roadmap, QT is mentioned almost 80 times and plays a significant role in the country's plan onwards to 2030 (Digitaliserings og ligestilingsministeriet, 2023). The documents will also help steer both EU and national countries' funding and prioritizations and they will play an important role in the Commission's future endeavors. (EC, 2024e).



Print screen: The European Commission's Digital Decade goals. QT is only explicitly mentioned under "Secure and Sustainable Digital Infrastructures" – but that is unlikely to slow down the growing focus on quantum technology. Rather, QT's ever-growing initiatives, may exacerbate a revision sooner rather than later in the Digital Decade (EC, 2024e).

2.3.3 The European Commission's QT strategy

The European Commission does not have its QT strategy contained in one single document, rather, it is distributed between several interdependent initiatives:

(i) The Digital Decade: As described in subchapter *2.3.2 The Digital Decade*, this initiative is the Commission's overall long-term goals for technology and digitalization in the EU and EEA. See the previous subchapter for more information.

(ii) The Quantum Flagship: A result of the beforementioned Quantum Manifesto, the quantum flagship is the European Commission's 10-year long initiative to help boost European knowledge and innovation in QT. The Quantum Flagship is the most important QT initiative in the European Union. Founded in 2018, the QF is a "*set of research and innovation projects selected through a thorough peer-review process. Calls for projects are issued based on the Flagship's Strategic Research Agenda, thus ensuring that all actors are aligned in the pursue of the Flagship's goals*." (QF, 2024). Hence, the quantum flagship stands at the center of European QT research and funding alike. Central to the Quantum Flagship, is its Research and Innovation Actions (RIA) document. It outlines the focal points of the initiative, including but not limited to QT infrastructure and ecosystems:

- *Quantum-ready advanced fabrication facilities* to develop and prepare prototyping and production of scalable devices for various QT applications, ranging from quantum processor chips, to key laser components, to chips for neutral atom based sensors.
- A *Quantum Communication infrastructure* will provide a sufficiently large-scale testbed for quantum communication and related technologies as well as access to industry for a wide range of application development, e.g. in health, finance and critical infrastructure.
- A *Quantum Computing/Simulation infrastructure* will offer maintenance, operation and access management of quantum computers/simulators hard- and software, and remote access for users, combined with access to classical High Performance Computing.
- A *Time and Frequency Transfer (TFT) infrastructure* will connect optical clocks and major research infrastructures to deliver high-precision timing for scientific and commercial use. Particularly, transportation, traffic, communication, energy distribution, safety and security rely on exact time and frequency information.
- A *European open-access Sensing and Metrology infrastructure* to develop, calibrate, test, validate and certify large- and small-scale quantum sensors and to develop and make accessible compact and easy-to-use quantum measurement standards of the revised SI units.

Print screen: The Quantum flagship highlights the importance of QT infrastructure in its RIA (QF, 2019).

(iii) EuroIQC: The initiative is a collaborative effort launched in 2019 to develop a secure quantum communication network across the European Union. Its primary aim is to integrate quantum-based systems into existing communication infrastructures, ensuring robust cybersecurity for sensitive data. The EuroQCI initiative involves all 27 EU Member States, working together with the European Commission and the European Space Agency (ESA). As stated by the Commission: "*The QCI will help Europe to secure its critical infrastructure and encryption systems against cyber threats, protecting smart energy grids, air traffic control, banks, healthcare facilities and more from hacking…The long-term plan is for the QCI infrastructure to become the backbone for Europe's Quantum Internet, connecting quantum computers, simulators and sensors via quantum networks to distribute information and resources securely all over Europe*.» (EC, 2024h). The EuroIQC is also considered an integral part of the new EU Secure Satellite Constellation (IRIS2).

(iiii) The European Declaration on Quantum Technologies: The Declaration was introduced in 2023 and aims to harness the potential of QT by making the EU "the quantum valley of the world". To achieve this, the declaration emphasizes the importance of national initiatives, stating that the EU cannot carry this commitment by itself. Hence, the vast majority of all EU member countries (not EEA) have signed the declaration. By signing it, the respective country vows to follow nine principles, highlighting the importance of collaboration, investment and coordination in the QT ecosystem. As the declaration puts it: "*[The] EU Member States are signing to indicate that they recognise the strategic importance of quantum technologies for the scientific and industrial competitiveness of the EU and commit to collaborating on the development of a world-class quantum technology ecosystem across Europe, with the ultimate aim of making Europe the 'quantum valley' of the world, the leading region globally for quantum excellence and innovation."* (EC, 2024g).

(iiiii) SRIA 2030: In 2024, the Quantum Flagship and the European Commission published its Strategic Research and Industry Agenda (SRIA) called '*SRIA 2030: Roadmap and Quantum Ambitions over this Decade*' (QF, 2024e). The SRIA functions as a roadmap, calling out the most important priorities, visions and goals for the European Union in QT for the next 5 years. The document includes funding priorities, specific goals within the 4 different types of QT as specified in the Quantum Manifesto. The SRIA also highlights the importance of QT system stacking, as described in the "*Why Quantum? Why Now?*" chapter. In its executive summary, the SRIA makes its existence clear:

“*In the last years, global competition in quantum technologies is fiercely intensifying. And while the European Union (EU) currently shows the highest level of public funding, fuelling world-leading research and expertise in quantum technologies, European innovators and industries have not yet fully capitalized on this potential To secure a position of global leadership, safeguard strategic interests, ensure autonomy, bolster security, and avoid technological dependence on third-party nations, the EU must therefore establish an independent capacity for quantum technology development and production. This effort must aim to bridge the transition from laboratory to mass production, creating a world-leading ecosystem supporting a broad array of scientific and industrial applications.*» (QF, 2024e). The SRIA echoes the verdict from the 2024 reports by Letta, Draghi and Heitor.

The European approach to QT is also heavily influenced by other documents, acts and initiatives as well. Many of the undisclosed titles touch upon QT and its ecosystem, without having a role as significant as the initiatives mentioned in this report. An example is how the **European Chips Act** includes measures for low-cost and high-volume manufacturing of quantum chips. Another is how the EU’s **Critical Raw Material Act** will ensure access to critical raw materials to help produce quantum components (EC, 2024g). A third example is the **European Economic Security Strategy** introduced in 2023 by the European Commission. It lists QT as a strategically significant technology and emphasizes the importance of QT-investment from a resilience perspective (EC, 2023).

2.4 Funding

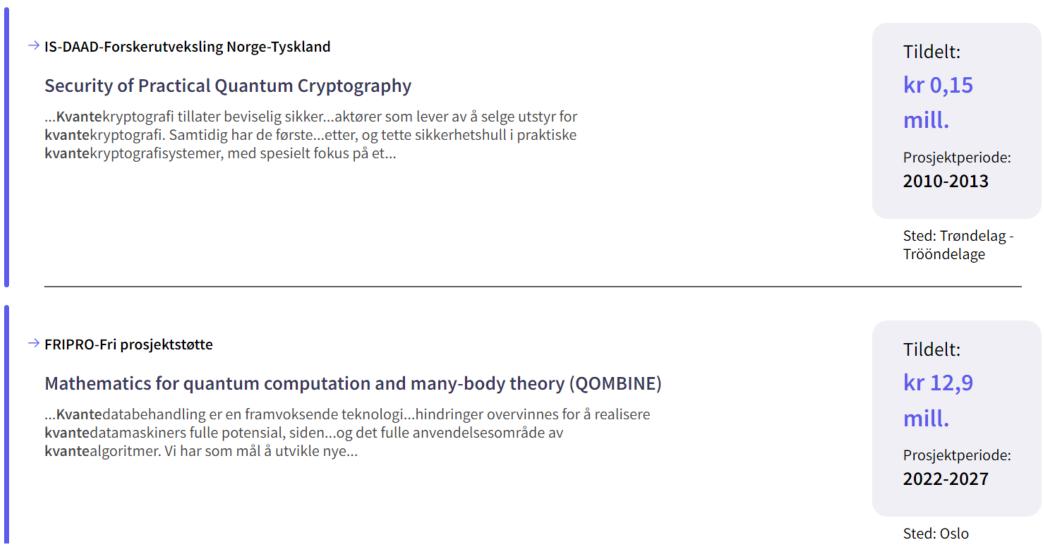
Funding makes up an essential part of the EU’s many goals within technology and digitalization, and is therefore a frequent topic of conversation in relation to QT. The EU has over 80 different funding programs, all listed in the European Parliament’s “Guide to EU Funding” (EP, 2023). Since Norway is not a full EU member, the government must decide which programs to join. For the period 2021-2027 the Norwegian government has chosen to partake in 12 programs (Norwegian Government, 2021). Of these, Horizon and DIGITAL are the most relevant considering QT. Please not that subchapter *2.4 Funding* and 2*.5 Research, Science and Projects* must be seen in tandem since funding and research are usually entwined.

2.4.1 Horizon

Innovation Norway and the Research Council of Norway oversee Horizon in Norway, the ninth major funding program (FP9) in Europe for research and innovation (EC, 2024i). Horizon Europe is structured into three main pillars: (1) Excellent Science, (2) Global

Challenges and European Industrial Competitiveness, and (3) Innovative Europe. The Research Council manages the first two pillars, while Innovation Norway handles the third (NHO, 2024b).

To manage the program, the Research Council and Innovation Norway have designated National Contact Points (NCPs). These specialists focus on specific thematic areas. Altogether, more than 50 experts have been assigned to guide and organize Horizon Europe in Norway. Furthermore, national reference groups play a key role in coordinating Horizon initiatives across various sectors. There are a total of 10 reference groups (The Research Council of Norway, 2024a). The Research Council of Norway's database, known as Prosjektbanken, offers detailed information about ongoing and past research initiatives and the financial support provided (Research Council of Norway, 2024b). Upon searching the register, well over 120 projects were associated with QT. The register shows projects both with and without EU funding.



Print screen: Two of the many projects showing up when searching for "kvante" or "quantum" at the database (RCN, 2024).

Horizon is the ninth (FP9) European Framework Programme for Research and Innovation, running through 2027. Its successor, FP10, is currently being drafted. The Commission is reviewing the beforementioned reports (Letta, Draghi and Heitor) and it is expected that these reports will have a significant impact on the Framework Programme. Furthermore, the Commission has received several statements from various stakeholders trying to impact the content of FP10. One stakeholder is Business Europe, one of the largest business advocacy organizations in Europe.

On behalf of its members (including NHO), it submitted a joint statement for the upcoming FP10. In its proposal, Business Europe echoes that of the three 2024 reports: FP10 must boost European competitiveness, innovation and help mitigate its dependencies on countries outside the EU. To help achieve this, Business Europe advocates for a significant increase in FP10's budget: "*We call on the EU Institutions to significantly increase the current RD&I budget in view of FP10. Such collective EU RD&I investments need to be reinforced in the next EU budget (MFF). National RD&I investments should in parallel be ensured and at minimum meet the target of 3% of GDP, aiming at leveraging private RD&I investments. Committing to EU technological leadership should ensure that proper and timely investments are made*." (Business Europe, 2024). It is widely expected that FP10 will earmark a significant sum of money to QT projects and calls (personal communication, 2024).

Norway has several active and ongoing projects funded by Horizon Europe, however, this is not the case for DIGITAL.

2.4.2 DIGITAL

There is a clear envisioned synergy between Horizon and DIGITAL: Horizon, through its three pillars, focuses on excellent science, scientific development and innovation. Digital on the other hand is broadly seen as the deployment and commercialization phase (European Commission, 2024i). Norway is officially a part of the DIGITAL program, however, the government does not co-fund Norwegian businesses or institutions applying for projects. This makes DIGITAL's Call For Proposals difficult to join, since Norwegian institutions, companies and research facilities do not necessarily have the money themselves to co-fund project participation (personal communication, 2024). Hence, while there has been some Norwegian participation in DIGITAL projects, the participation rate is significantly lower than one might expect.

The new the draft for the work program for DIGITAL for the period 2025-2027 has a substantial presence of quantum technology-related projects and calls for proposals. The various quantum projects include but are not limited to digital quantum skills, post quantum encryption, quantum computers and sensor. In addition, the draft suggests creating a sectoral academy focusing on QT: "*This topic aims to establish sectoral academies in four key digital areas: quantum, artificial intelligence, semiconductors and virtual worlds. The objective of such academies is to complement the existing actions and initiatives in these digital areas and leverage industry to close the talent gap and strengthen the pool of specialists*.» (personal communication, 2024). Thus, if the Norwegian government decides to co-fund participation, or if research facilitates or private companies can afford to co-fund their participation, significant sums can be obtained through DIGITAL-participation in relation to quantum technology.

DIGITAL also provides access to resources, such as the European Digital Innovation Hubs (EDIH) and Testing and Experimentation Facilities (TEFs), however, most of these are centered around artificial intelligence. Furthermore, DIGITAL provides access to the European High Performance Computing Joint Undertaking (EuroHPC JU). Between 2021-2027, The EuroHPC JU will receive 3 million Euros through the Multiannual Financial Framework 2021-2027 (MFF) to research and development on high performance computing. This also extends to quantum computing. These resources are available to Norwegian businesses through EuroHPC JU's Norwegian competency centers, which is led by Sigma2 (Norwegian Digitalisation Agency, 2024).

2.4.3 The Quantum Flagship

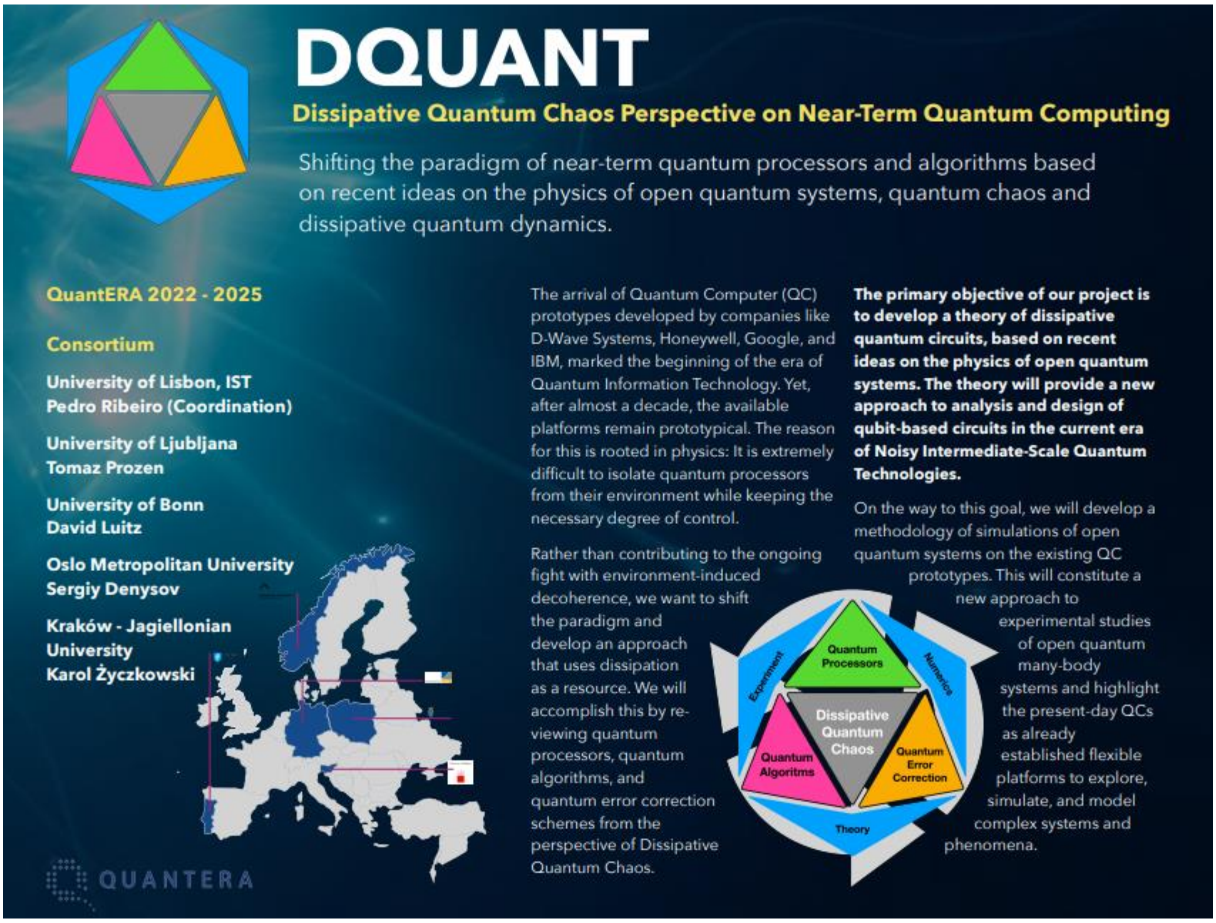
The Quantum Flagship, the beforementioned long-term initiative set about by the Commission to strengthen Europe's global QT position, has a 1 billion funding framework across its 10-year existence. The money comes from DIGITAL and Horizon, meaning these funds are not new. Rather, money from Horizon and DIGITAL have been earmarked for QT through the Quantum Flagship. The QF has its own funding portal, and adjoined calls – similar to that of Horizon and DIGITAL. As of December 2024, few (if any) Norwegian research institutions have participated in QF projects (personal communication, 2024).

Print screen: The Quantum Flagship's funding portal contains several open calls for proposals as of January 2025 (QF, 2024b).

2.4.4 QuantERA

As with the Quantum Flagship, QuantERA does not have its own multiannual financial framework (MFF). Rather, it receives its funding through Horizon and other programs. QuantERA can be considered a network of research and funding organizations specializing in QT research, innovation and competence building (QuantERA, 2024). The QuantERA's calls are submitted every two years. As such, the next calls are likely to be published during Q1 of 2025. Of its 101 past and ongoing projects, Norway has/is partaking in four projects, one being DQUANT where Oslo Metropolitan University (OsloMet) and The Research Council of Norway (Forskningsårdet) are involved. The Research Council of Norway plays an important role in coordinating the project in Norway, as pointed out by QuantERA's consortium overview (QuantERA, 2024c). Furthermore, QuantERA also highlights its collaboration with the Quantum Flagship stating that:

"*Since both QuantERA and the Quantum Flagship focus on the same field, there are strong interactions between both networks as well as some common activities. Mutual efforts focus on speeding up knowledge and technology transfers culminating in putting QT into everyday use and on bridging academic research with engineering endeavours in QT applications. Together with the Quantum Flagship, QuantERA strives towards the reinforcement of Europe's position in the global quantum race*." (QuantERA, 2024d).



Print screen: All projects funded through the QuantERA has posters, showcasing essential information about the projects. In this case, DQUANT is showcased with its Norwegian contact: Sergiy Denysov from OsloMet (QuantERA, 2024b).

2.4.5 Other funding opportunities

The EuroHPC calls: Like the Quantum Flagship, the EuroHPC is funded both by Horizon and DIGITAL but the initiative has its own calls. EuroHPC's 2023 projects were thoroughly described in QC Norway's Position Paper: **"***Recently, EuroHPC announced the funding of the first six initiatives towards building European quantum computers in connection to existing high performance computing centres across Europe. Norway is deeply involved in one of these initiatives, LUMI-Q, with three partners (Sigma2, Simula Research Laboratory, and SINTEF). This project is a strong example of how Norway can benefit from EU-Contributions Towards a National Quantum Computing Strategy & European competence building and infrastructure access for research and innovation in quantum computing*." (QC Norway, 2023). QC Norway also raises concerns about Norway's lack of co-funding for several EU funding projects, and claims that it is paramount that the Norwegian Government commits to co-funding Norwegian participation.

The European Innovation Council's Fund (EICF): Part of the Horizon program, the EICF "*has a budget of €10.1 billion to support game changing innovations throughout the lifecycle from early stage research, to proof of concept, technology transfer…*" (EICF, 2024). As its mandate states, the EICF's fund specializes in early-stage research innovations and 'game-changing innovations' in particular. As such, since QT is a relatively immature technology considering its real-use cases and applicability, the EICF can become a valuable funding program when trying to productize or operationalize QT.

The European Defense Fund: For the period 2021-2027, The EDF has a budget of 8 billion Euros. Its aim is to strengthen both defensive capabilities and defensive industries in the EU. When searching for previously conducted quantum technology-related projects, it becomes clear that QT has already been a focal point for EDF calls for several years.

Print screen: EDF results from 2021. Disruptive technologies including QT received more than 50 million euros for projects (EDF, 2021).

In its 2024 call for proposals, The EDF wrote extensively about QT. In subchapter *2.3.1. EDF-2024-LS-RA-DIS-QUANT-STEP: Quantum technologies*, the indicative budget is set to 24.000.000 million Euros. In the work program, the EDF writes that: "*Quantum technologies count amongst the main emerging and disruptive technologies for defence capabilities. Within these quantum technologies, Quantum Sensing (QS) is one of the most mature domains and has the potential to notably impact defence operations*." (EDF, 2024). The EDF continues its QT focus for the coming years. In the 'Indicative multiannual perspective 2024-2027' the EDF writes that: "*The possession and deployment of quantum technologies for sensing is potentially a game changer in many defence applications, which means that maturing and mastering these technologies is necessary for mission superiority, but also competitiveness*." With its proven and outspoken focus on QT, it is safe to assume that future 'call for proposals' will contain several QT-projects. The next call for proposals is released on the 29th of January 2025.

Nordforsk: This funding program is organized under the Nordic Council of Ministers. One of its main objectives is to strengthen Nordic collaboration in what is considered key strategic areas. For 2025-2030, the Nordic Council has specified 14 areas of great interest. In its political priorities for 2025-2030, the Nordic Council of Ministers emphasize the importance of digitalization but does not explicitly mention QT. However, few if any other technologies are specific in the political priorities. Instead, the wording is open-ended, giving room for interpretation:

"*Norden skal være verdens mest bærekraftige og integrerte region i 2030. Det er en viktig og utfordrende visjon som krever et sterkt politisk samarbeid. Spesielt i en tid der det er geopolitiske spenninger i nærområdet vårt, der klimaet, det biologiske mangfoldet og miljøet lider, og der den digitale revolusjonen…*» (Nordic Council of Ministers, 2024). Furthermore, the draft "*Nordisk-baltiskt samarbetsprogram för digitalisering 2025–2030*» which projects the Nordic Council of Minister's priorities within digitalization does not explicitly mention QT either. However, the ever-growing focus on QT, the already existing collaboration between the Nordic countries on quantum technology is likely to influence the agenda's priorities and thus its funding opportunities for the next five years (personal communication, 2024). Nordforsk is also currently funding QT projects. NordIQuEst for instance, is funded through the Nordic e-Ifrastructure Collaboration (NeIC) which funds projects within high-powered computing, included that of QT (Nordiquest, 2024). The same applies for Nordic Innovation, who recently released its tender to map out the Nordic Quantum Ecosystem. These activities will be further elaborated in chapter *2.6 Nordic countries*.

2.4.6 How funding is affected by EU policies

There is an intrinsic connection between EU policies and the funding granted to European research and science projects. As stated in the HORIZON and DIGITAL strategies, they are to support the European policies: "*The strategic plan aims to facilitate the implementation of Horizon Europe, serving as an interface between the overarching EU policy priorities and the Horizon Europe R&I activities set out in the Horizon Europe work programmes*." (EC, 2024j). As evidenced throughout chapters *2.1 European institutions, bodies and agencies and their relationship to QT* and *2.2 European Competitiveness,* the European Commission and the rest of the EU apparatus is focusing a significant amount of its efforts on competitiveness, innovation and reducing harmful dependencies. In his report, Heitor suggests a dramatic increase in the FP10 budget; From FP9's 93.5 billion euros to 220 billion euros. (Heitor, 2024).

2.5 Research, Science and Projects

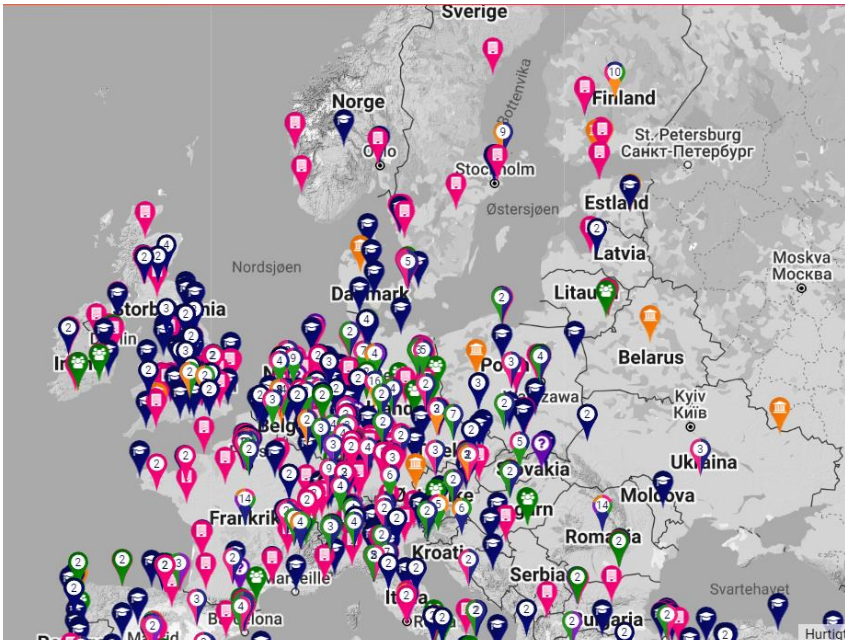
The European Union and its member states are heavily invested in QT research and projects. As previously mentioned, many of the initiatives mentioned under *2.4 Funding* are bound to research and scientific initiatives as well, since the funding granted is predominantly used on these endeavors. There are hundreds of past, ongoing and upcoming QT projects in the EU. This subchapter briefly presents 7 of the largest ongoing QT research projects and programs with no particular attention to its origin of financial backing (other than it being funded by the EU).

Qu-PILOT: The project belongs to the QF initiative, and explores experimental production capabilities in QT. It started in 2023, consists of 21 partners from 9 different European countries and it aims "*to develop and provide access to the first production facilities for quantum technologies in Europe*." (QF, 2024c). The project aims to link and improve existing production capabilities throughout Europe to create facilities able to support production of QT products and services. This in turn will be important considering the Commission and other EU institutions' outspoken focus on the reduction of harmful dependencies. As the EU Chips Act and other initiatives have demonstrated, the EU will produce most of what is considered critical technology and materials within QT itself. The Qu-PILOT project is intrinsically connected to the Qu-TEST project (QF, 2024c).

Qu-TEST: As with the previous project, Qu-TEST is another QF initiative aimed to develop, upgrade, and provide infrastructure for testing and experimentation of quantum technologies across computing, communication, and sensing. Furthermore, Qu-TEST offers testing and validation services to EU-based companies, enabling them to assess and characterize quantum devices and systems. This includes measuring, characterizing, and validating components (QF, 2024d). Some of the key elements of both the Qu-PILOT and Qu-TEST projects is to reduce the time-to-market for QT products and services, retain both talent and companies situated in Europe and to amass crucial competence and experience within QT. As the Draghi report stated: "*we are failing to translate innovation into commercialisation, and innovative companies that want to scale up in Europe are hindered at every stage by inconsistent and restrictive regulations*" (Draghi, 2024). Several experts see these projects as pivotal instruments in translating knowledge to productization and commercialization.

Print screen: The Quantum Flagship's representation of the EU Quantum Ecosystem, showing how different initiatives play together to help build QT competence, research and various projects (QF, 2024

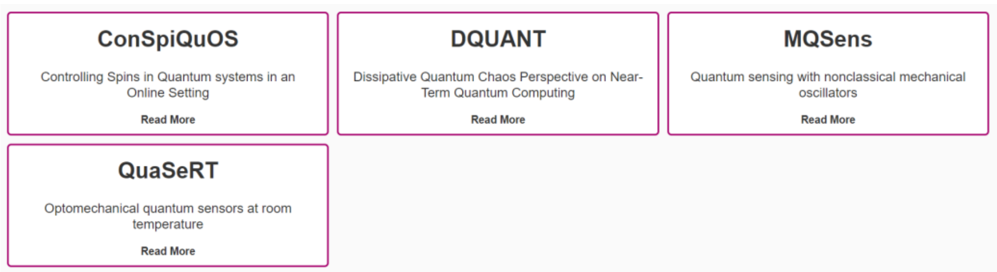
The European Quantum Readiness Center (EQRC): Yet another QF initiative the EQRC "*is dedicated to equipping companies and universities across Europe for the quantum revolution, ensuring they are at the forefront of this transformative technology*." (QF, 2024d). This project is threefold, having divided its portfolio into three main areas: (i) Analysis, (ii) Resources and (iii) Accord. The analysis efforts are further divided into six main areas, ranging from quantum job analysis to quantum startups. Interestingly, the (i) Analysis has a designated area of focus centered around 'Quantum National Strategies'. The EQRC has analyzed over 62 national quantum strategies from around the world and uses this knowledge to find common projections, megatrends and more (QF, 2024e). The EQRC also encourages European collaboration and tries to stimulate to increased international efforts. Through its Ecosystem register, organizations can provide contact information to get in touch with other European organizations invested in QT.



Print screen: The Quantum Flagship's Ecosystem portal provides an extensive view of most companies and educational institutions invested in QT. To be visible on the map, the institution must register in QF's Ecosystem themselves (QF, 2024).

QuantERA:

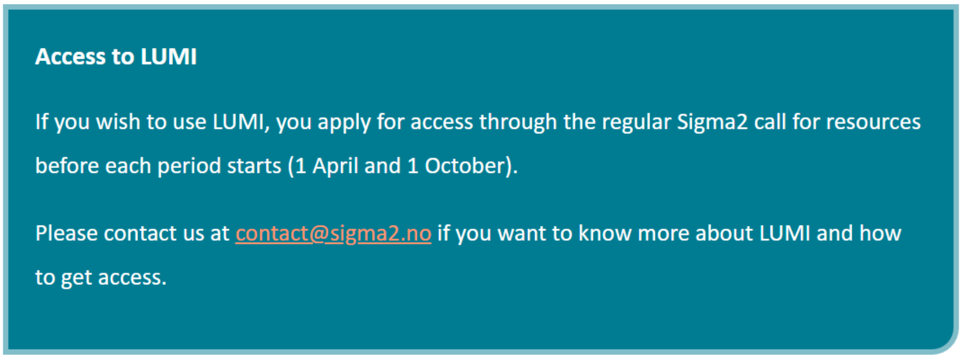
The Quantum Flagship also works closely with QuantERA, a network or consortium of QT-invested institutions and enterprises. The QuantERA's database has 101 QT projects either completed or in progress. As stated in the previous chapter, four of these involves Norwegian participation. The beforementioned DQUANT for example, which will "*develop a theory of dissipative quantum circuits, based on recent ideas on the physics of open quantum systems*". (QuentERA, 2024b). In its description, the project emphasized that while large companies like IBM, Google and Honeywell pour billions of US dollars into building quantum computers, there are several areas in which QT do not receive as much attention but are still nonetheless significant. This echoes the system stacking of quantum computer value chains explained in the SRIA 2030 introduced both in chapters *Why Quantum? Why Now?* and *2.3.3 The European Commission's QT strategy*.



Print screen: The Four QuantERA projects where Norway is represented in the consortiums (QuantERA, 2024e).

EuroHPC JU:

Like the Quantum Flagship and QuantERA, The EuroHPC JU is not a single project. Rather it is a program dedicated to explore high powered computing through several projects aligned and coordinated by the EuroHPC JU initiative. With access to 9 supercomputers, the EuroHPC JU has created its own work program with project calls. While funded through MMFs like Horizon and DIGITAL, this initiative has its own project call portal. From its *Multi-Annual Strategic Programme for 2021-2027*, it becomes clear that Quantum technology is a highly prioritized area within supercomputing and the value chain surrounding supercomputing. For instance, in the MASP's chapter *2.6.2 Growing the quantum applications ecosystem*, EuroHPC JU's strategy addresses the importance of not only quantum computers, but also the ecosystem surrounding it. The program also frequently addresses Horizon calls, such as the call for creating Quantum Excellence Centers (EuroHPC JU, 2024). Norway is connected to EuroHPC JU through DIGITAL and Horizon and its primary coordination goes through SIGMA2 (SIGMA2, 2024).



Access to LUMI

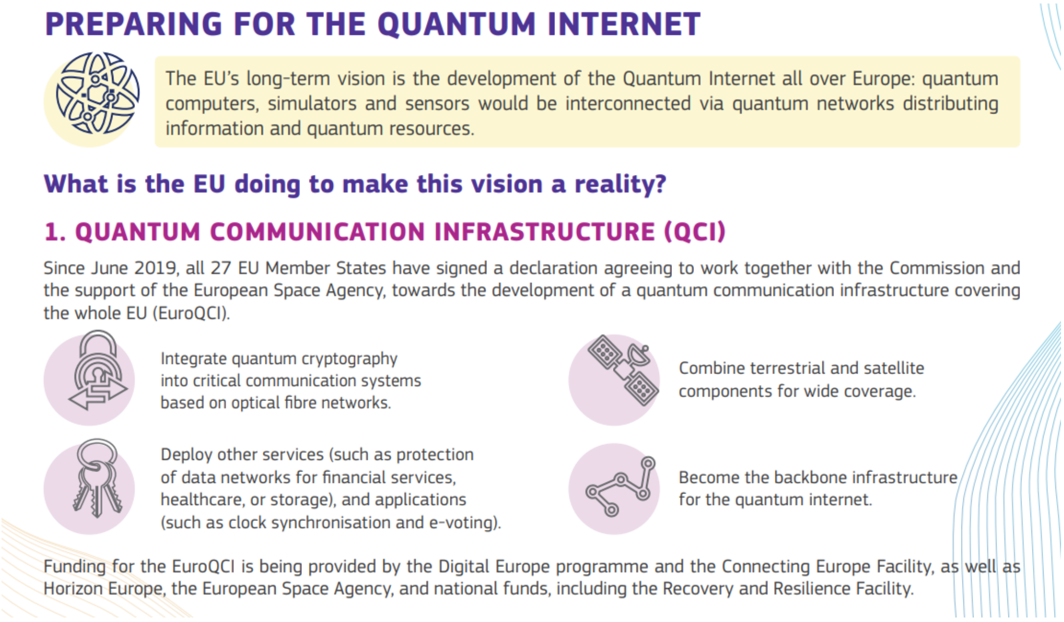
If you wish to use LUMI, you apply for access through the regular Sigma2 call for resources before each period starts (1 April and 1 October).

Please contact us at contact@sigma2.no if you want to know more about LUMI and how to get access.

Print screen: Norway has access to the Finnish supercomputer LUMI through EuroHPC JU (SIGMA2, 2024).

Quantum Communication Infrastructure (QCI):

As with both the QF, the EuropHPC JU and other initiatives, The QCI has a similar approach to QT research: It is not a single project. Rather, it is an initiative containing several projects aimed to reach a goal set by the Commission and the European Space Agency (ESA). All 27 member countries have committed to joint efforts to help build and facilitate the Quantum Communication Infrastructure. Funding comes from Horizon, DIGITAL, Connecting Europe, ESA and other funding programs. As such, it is interlinked to and through a large number of EU institutions and European countries alike. The QCI aims to build quantum encrypted communication across Europe, with significant space-industry involvement.



Print screen: One of the goals of the Quantum Flagship through QCI is to develop the 'quantum internet' – a comprehensive infrastructure to support extensive use of QT (EC, 2024f).

2.6 Ethical and Legal Considerations in QT

This subchapter looks at some of the work that has been published on ethical and legal aspects of quantum technology. Two areas will be covered: Responsible development of QT and patens.

2.6.1 Guiding Principles for responsible QT development

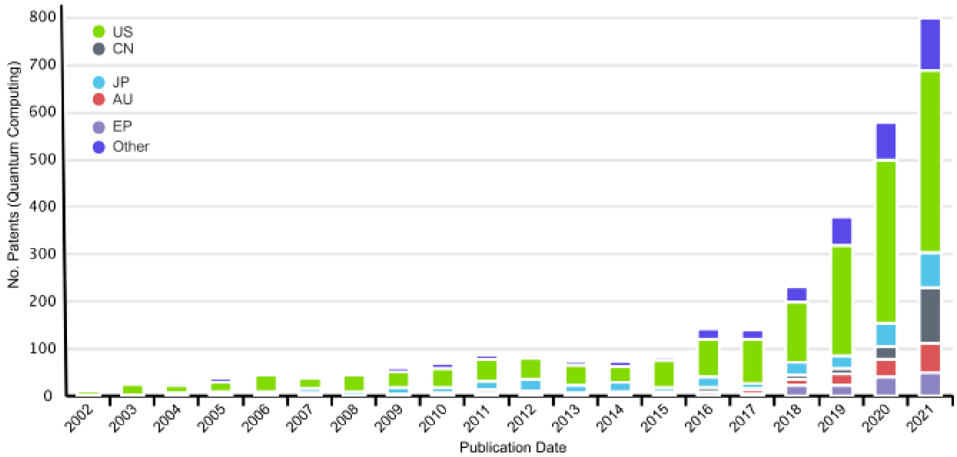
In a 2023 release written by representatives from different universities throughout Europe and North America, the authors introduce 10 guiding principles for responsible QT development. The article organizes its principles into 3 categories: Safeguarding, engaging and advancing (abbreviated SEA). The principles are designed to help address risks, challenges and opportunities within QT. Moreover, the article explains that its three categories are not mutually exclusive, rather they should be seen in tandem: "*Our proposed principles are not designed to be independent of each other. Instead, they are in an interactive relationship and their interplay can be optimized strategically to help create the conditions for sustainable quantum innovation over the long term. Perhaps counterintuitively, their overlap and interconnectedness area feature and not a bug by broadening the available 'solution' space and levers available to work toward responsible quantum innovation.*" (Mauritz Kop et al 2024). The need for guiding principles and frameworks addressing responsible development and deployment of QT is likely to increase over the next few years. Early publications like this article are prone to impact future and similar endeavors, as it has established a necessary groundwork.

Category	Topic	Aim	RRI-value	Principle
Safeguarding	Information security	Addressing security threats	Anticipation & Reflection	1. *Make information security an integral part of QT*
	Dual use	Addressing risks of dual use	Anticipation & Reflection	2. *Proactively anticipate the malicious use of quantum applications*
	Quantum race	Addressing a winner-takes-all dynamic	Anticipation & Reflection	3. *Seek international collaboration based on shared values*
Engaging	Quantum gap	Engaging states	Openness & Transparency	4. *Consider our planet as the sociotechnical environment in which QT should function*
	IP	Engaging institutions	Openness & Transparency	5. *Incentivise innovation while being as open as possible and as closed as necessary*
	Inclusion	Engaging people	Diversity & Inclusion	6. *Pursue diverse R&D communities in terms of disciplines and people*
Advancing	Societal relevance	Advancing society	Responsiveness & Adaptation to change	7. *Link quantum R&D explicitly to desirable societal goals*
	Complementary innovation	Advancing technology	Responsiveness & Adaptation to change	8. *Actively stimulate sustainable, cross-disciplinary innovation*
	Responsibility	Advancing our understanding of responsible QT	Responsiveness & Adaptation to change	9. *Create an ecosystem to learn about the possible uses and consequences of QT applications*
	Education and Dialogue	Advancing our collective thinking and education about QT and its impact	Responsiveness & Adaptation to change	10. *Facilitate dialogues with stakeholders to better envision the future of QT*

Print screen: Ten principles for responsible quantum innovation (Mauritz Kop et al 2024).

2.6.2 Patents

In 2022 Aboy, Minssen and Kop mapped the patent activity on quantum technology to determine the growth of QT patents. The report evaluates the patent landscape for quantum technologies, analyzing trends over the past 20 years. It highlights growth patterns, geographical distribution, top patent owners, and the policy implications of intellectual property rights (Aboy, Minssen, Kop, 2022). The article shows that the last two decades (from 2001-2021) have seen 20.583 filed-for patents from the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO). However, about 50% of these patents have been filed from 2016-2021, showing a distinctive increase. Furthermore, the article points to the skewed geographical representation in the patents filed. As of 2022, the United States had filed the most patents, with China coming in second. The authors argue that "*China is arguably becoming the leader in quantum communications. This is remarkable since most of this Chinese growth in secure quantum communications has taken place in the last five* *years. Thus, it is expected that Chinese quantum networking and communications devices will soon be present in the global markets*." (Aboy, Minssen, Kop, 2022). The rapidly growing number of patent filings may be indicative of strategic agendas promoting competitive advantages at the expense of innovation and fair competition. Keeping track of granted patents will be necessary to avoid legal disputes.



Print screen: This chart shows the amount of patent filings in absolute numbers and by country/region (Aboy, Minssen, Kop, 2022).

2.7 Nordic countries

Throughout the interviews for this report, few areas of quantum technology were so frequently addressed as the need for closer Nordic collaboration on QT. The commitment for a closer and more joint approach to QT for the Nordic region is indicative of its importance. The underlying argument is simple; From a global perspective, the Nordic countries by themselves are small by all measurements. However, through combined strength, the likelihood of global impact is greatly increased. If the Nordic countries manage to work together on QT, they can position themselves as a significant QT partner, not only in Europe but on a global scale.

One might argue that through EU and NATO, the Nordic countries are already members of some of the biggest global QT endeavors. While this is true, several European countries are creating additional and exclusive QT initiatives. For instance, Germany, the Netherlands and France have joined forces to collaborate on QT (Quantum Delta, 2022). Simultaneously, some interviewees argued that if no Nordic collaboration is promoted on QT and the Nordic countries sole QT endeavors are the EU, they run the risk of European hegemony (personal communication, 2024). Hence, while participation in QT activities through the EU is important, it is not enough. To achieve increased Nordic QT influence, close collaboration, alignment and committing projects are needed. This is encompassed well in the Kreutzer report.

In his report «*An integrated and effective Nordic ecosystem for innovation and green growth*", Kreutzer points out several areas in which the Nordic region can benefit from increased collaboration. As Kreutzer points out: "*Joint Nordic efforts will increase the region's competitiveness through common political ambitions and concrete actions. The region can thus become more attractive. This may contribute significantly to job creation…in the Nordic region*." (Kreutzer, 2018). While the report primarily focuses on innovation, job creation and green growth, the same principles and recommendations are transferable to that of quantum technology. Better coordination in policy-making and increased cooperation to promote international investment are both good examples of this. Furthermore, the Nordic region is likely to benefit from better alignment in QT strategy and niche-selection.

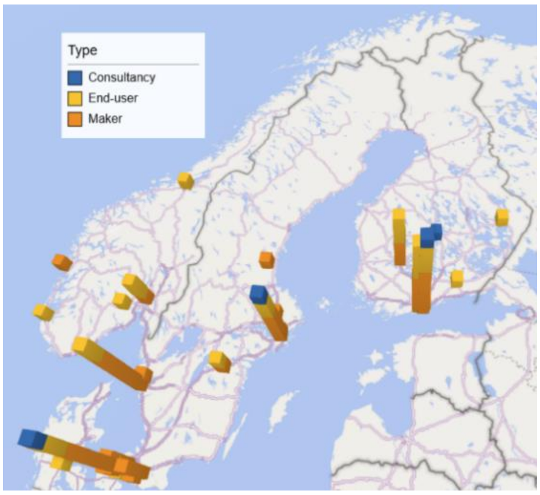
There are several QT initiatives and projects initiated by the EU only accessible to its full members (not the EEA). For instance, the EuroQCI, mentioned in subchapter *2.3.3 The European Commission's QT strategy*, is exclusive to full EU member countries. Since Finland, Denmark and Sweden are all full members of the EU, Norway runs the risk of lagging behind in areas covered by the EuroQCI. This is also true with the European Declaration on Quantum Technologies, as it too is exclusive to full EU member countries. This EU exclusivity also extends to funding opportunities. The Recovery and Resilience Fund is also exclusive for full members and has several pending calls and investments in QT. The same can be said for DIGITAL. Since the Norwegian government does not co-fund projects, DIGITAL's calls are more difficult to join for Norwegian companies, compared to that of full EU members. Even if other EU countries do not provide co-funding, full EU members can use other structural funds for co-funding (personal communication 2024). In this perspective, Norway is at a disadvantage considering European collaboration on QT.

While several experts call for more Nordic collaboration, it is important to point out that there are several ongoing activities. Nordforsk (as mentioned in subchapter *2.4.5 Funding*) has an organization unit called the Nordic e-Infrastructure Collaboration (NeIC). NeIC funds the project NordIQuEst. The project's purpose: "*is to build a Nordic-Estonian e-infrastructure which combines high-performance computing and quantum computing from across Norway,* *Sweden, Denmark, Finland and Estonia.»* (Nordiquest, 2024). Furthermore, in December 2024, Nordic Innovation published a tender to map out the Nordic Quantum Ecosystem. This initiative aims to map out Nordic-Baltic quantum ecosystems and produce examples of use cases in QT to show the applicability for the region's businesses (Nordic Innovation, 2024).

The Nordic Institute for Theoretical Physics (NORDITA), the joint Nordic research institute funded by the Nordic Council, actively promotes closer collaboration on QT and has several difference activities actively promoting QT, from funding opportunities, to a recent partnership with The Novo Nordisk Foundation Quantum Computing Programme (NQCP). NORDITA also plays close attention to and maps out ongoing QT initiatives in the Nordic region.

Print screen: NORDITA's mapping of Denmark's QT universities, institutes, centres and networks. Through its overview, it becomes clear that both Denmark and Sweden has created comprehensive ecosystems around QT (NORDITA, 2024).

Through one of its initiatives, Nordic Quantum, a network for quantum technology activities in Denmark, Sweden, Norway and Finland, has issued a whitepaper for quantum technology. In the whitepaper's summary one can read that: "*The Nordic Quantum network has the ambition to present itself as a global player in quantum technology, while maintaining a close dialogue with other partners both within Europe and outside. This goal will be achieved by establishing a common vision of quantum technology between institutions in Denmark, Finland, Norway, Sweden (and potentially Iceland), strengthening the coordination of activities in the field. Nordic Quantum should be seen from the outside as a world-leading initiative in quantum science and technology, representing a first-tier partner for academic and business activities in the field*." (NORDITA, 2023). The Quantum technology network argues that if the Nordic region is to become a global QT power, collaboration is key – and time is of the essence.



Print screen: NORDITA's quantum network has actively mapped out and keeps track of QT activities in all four countries represented in the network (NORDITA, 2023).

The Nordic Council plays a crucial role both in NordIQuEst and NORDITA's quantum network, let alone most other forms of Nordic collaboration. In its *Political Priorities for 2025-2030*, The Nordic Council of Ministers emphasize the importance of digitalization stating that: "*Through collaboration, we are stronger and better equipped to navigate rapid technological advancements, climate change, and shifting geopolitical landscapes. Together, we will ensure that our region continues to lead the digital transition, enhances global competitiveness for our businesses, and promotes sustainability as well as ensures long-term resilience, prosperity, and welfare*.» (Nordic Council of Ministers, 2024). While QT is not mentioned explicitly, this goes for most other technologies too: The Council's Political Priorities approach digitalization in a general manner. With its aim on continued Nordic development in digitalization and its current funding of QT activities, the Nordic Council and its adjacent bodies hopefully realize the potential of QT and the need for collaboration and future investment. This also applies to the member countries' national governments.

2.8 NATO

In a post dating back to 2022, NATO wrote about quantum technology and its potential as a game-changer on the battlefield. The article titled "NATO Exploring Quantum Technology for Future Challenges" can be considered a careful yet optimistic approach to QT. NATO simultaneously acknowledges its ongoing QT research in quantum sensing, the need to renew communication infrastructure to become quantum-secure and NATO's ever-watchful eye on China and other contenders. The article also warns that QT is not a silver bullet, soon available to solve the alliance's most intricate defensive challenges (NATO, 2022). However, with the 2024-release of NATO's quantum technology strategy, there is little doubt that QT is a high priority for NATO.

2.8.1 NATO's QT strategy

Upon its release NATO wrote that: "*These technologies could revolutionise sensing; imaging; precise positioning, navigation and timing; communications; computing; modelling; simulation; and information science. Quantum technologies have potentially revolutionary and disruptive implications, which can degrade the Alliance's ability to deter and defend. Quantum technologies are therefore an element of strategic competition.*" (NATO, 2024). While the strategy itself is considered confidential and thus not accessible when writing this report, an executive summary has been disclosed. From it, one can extrapolate the following:

- The strategy outlines how quantum technology can be applied to NATO's various areas of interest, including but not limited to: Sensing, imaging, precise positioning, navigation and timing, improve the detection of submarines, and upgrade and secure data communications using quantum resistant cryptography (NATO, 2024).

- NATO's QT strategy will help guide cooperation with industries to develop international and transatlantic QT ecosystems. This also extends to areas to help combat threats posed by QT, such as encryption.

- NATO emphasizes it has already begun QT innovation efforts. 6 of the 44 companies that have joined NATO's Defence Innovation Accelerator for the North Atlantic (DIANA) program are specialized in QT.

- NATO aims to establish a Transatlantic Quantum Community to coordinate QT activities across governmental bodies, industries, academia and other potential shareholders.

- The alliance aims to become quantum-ready. This envelops developmental efforts to create a secure, resilient and competitive quantum ecosystem. The backbone of this vision is to dramatically reduce harmful dependencies and to obtain necessary resources within the alliance's members. Furthermore, NATO aims to be able to counter any and all new competition within QT. To realize this ambitious vision, NATO calls on joint and cohesive investments across its members.

- NATO calls on members to adopt a 'learn-by-doing' approach, emphasizing the operationalization of QT. This also include enabling technologies to move QT from theory to practice. Hence, engineering, infrastructure and expertise within adjacent fields is a vital component to reach this goal.

- NATO’s QT strategy is dynamic and will be influenced by efforts and potential discoveries from DIANA, NATO’s Innovation Fund (NIF) and other QT-related activities.

NATO’s QT strategy is bold, envisioning a state in which the alliance successfully collaborates to create the world’s most advanced QT ecosystem. The alliance emphasizes the importance of acuteness: This strategy must be swiftly acted upon, as NATO fears a technology gap to its adversaries. The strategy’s focus on dual use and increased collaboration while also building domestic expertise are some of many similarities with the European approach to QT. However, as pointed out several times through chapter 2, high-ranking EU officials have stated that the reduction of harmful dependencies also includes the United States. This means that the EU and NATO must find a sustainable way to balance collaboration and joint efforts on one hand while building domestic and in-housing expertise on the other.

2.8.2 NATO’s quantum HQ

NATO has established a center for quantum technologies in Copenhagen. The center, known as the Deep Tech Lab – Quantum, is a part of NATO's beforementioned DIANA program. The center (DIANAQ) aims to increase and maintain the Alliance's technological edge within QT by fostering the development of emerging and disruptive technologies. The center is also a focal point for QT startups, and works closely with BioInnovation Institute (BII). The center works in close collaboration with the other members of the Danish Quantum Community and the Innovation District in Copenhagen, and is distributed between four locations throughout Denmark (Danish Quantum Community, 2024).

2.8.3 Funding and investments

NATO has several ways to fund QT initiatives. This subchapter presents the most prominent. Two of these, DIANA and NIF, were jointly announced in 2021 but they only became operational the last few years. Hence, these programs have not yet seen the same experience as funding opportunities provided by the EU:

DIANA: NATO’s Defence Innovation Accelerator for the North Atlantic (DIANA) is an accelerator program supporting initiatives dedicated to identifying and accelerating dual-use technological innovations across the Alliance. DIANA offers companies resources, networks, and guidance to develop technologies that address critical defense and security challenges. This includes but is not limited to artificial intelligence, space and quantum technology. The organization operates through a network with several accelerator sites and numerous test centers. All NATO nations are represented in DIANA, with governance provided by a Board of Directors consisting of representatives from each allied country.

To get access to the program, companies must apply to DIANA's call for proposals or challenges. For 2024, these were made publicly available in June and the application period ended a few weeks later. It is expected that DIANA will publish new proposals on an annual basis, perhaps even more frequent as the center gains more experience (NATO, 2024b). As mentioned earlier in this chapter, DIANA already supports six QT companies. On DIANAQ's website one can read that: "*The six start-up companies will gain access to a network of top-tier trusted investors, business mentorship, and education from expert staff, and state-of-the-art testing opportunities in BII's office space and laboratories*." (Deep Tech Lab, 2024). The six companies are:

Company	Description:
Astrolight	Uses high-speed lasers for satellite connectivity and deep space exploration.
Aquark Technologies	Provides portability and miniaturization solutions for quantum technology applications.
g2-Zero	Develops single photon sources that are electrical, vibration-resistant, and alignment-free.
QUBITRIUM	Focuses on quantum cryptography, communication, and sensing solutions.
Phantom Photonics	Creates quantum-enhanced 3D imaging sensors with improved range, resolution, power consumption, and acquisition time.
SECQAI	Develops Quantum & Classical Hardware and Algorithms to protect against threats.

Information: This table was created after information found on Deep Tech Lab's website (Deep Tech Lab, 2024).

NATO Innovation Fund (NIF): NIF is "*A standalone venture capital fund backed by 24 NATO allies deploying €1 billion+ in deep tech*" (NATO, 2024c). The fund targets early-stage startups and SMEs operating within technology NATO considers important. As with DIANA, The NIF focuses on a broad spectrum of technological sectors, including artificial intelligence, space and QT. In September 2024, the beforementioned company Aquark Technologies, announced that it received a 5 million USD seed round led by NIF and is therefore the first QT investment initiated by NIF. Aquark specializes in quantum sensors (Aquark technologies, 2024).

NATO's Science for Peace and Security: The NATO Science for Peace and Security (SPS) Programme promotes cooperation between NATO and partner countries through scientific research, technological innovation, and knowledge exchange. The program funds multi-year research projects, advanced training courses, study institutes, and research workshops focused on security and defense challenges. Key priorities include emerging technologies, climate, security and cyber defense. As of 2024, several QT initiatives have been funded. For example, in 2022 the SPS program helped fund research on quantum key distribution (Dargan, 2022). In its annual (2023) report, THE NATO SCIENCE FOR PEACE AND SECURITY SPS PROGRAMME, one can read that: "*As quantum technologies become an increasingly central focus for NATO and governments around the globe, SPS is expanding its portfolio of activities in quantum communications, quantum sensing and quantum computing*." (NATO, 2023b). In its 2024 call for proposals, quantum technology is listed as high priority. (NATO, 2024d). The deadline for submission is the 5th of January 2025 (NATO, 2024e).

NATO Countries

Albania, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Latvia, Lithuania, Luxembourg, Montenegro, Netherlands, the Republic of North Macedonia, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Türkiye, United Kingdom, United States.

Eligible NATO Partners

Algeria, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bosnia and Herzegovina, Colombia, Egypt, Georgia, Iraq, Ireland, Israel, Japan, Jordan, Kazakhstan, the Republic of Korea, Kuwait, Kyrgyz Republic, Malta, Mauritania, the Republic of Moldova, Mongolia, Morocco, New Zealand, Pakistan, Qatar, Serbia, Switzerland, Tajikistan, Tunisia, Turkmenistan, Ukraine, United Arab Emirates, Uzbekistan.

Print screen: NATO's SPS program and its members as well as eligible partner countries (NATO, 2024c).

NATO's EU collaboration: As pointed out in subchapter 2*.7.1 NATO's QT strategy*, there are several similarities between EU's QT activities and those found in NATO. This is no coincidence, as several agreements, commitments and declarations exist to coordinate such efforts. The Berlin Plus Agreement, the European Capability Development Planning, the Joint Declaration on EU-NATO Cooperation and the The Common Security and Defence Policy (CSDP) are all examples of the bilateral agreements between NATO and the EU (NATO, 2018). This is also true for the European Defence Fund, as described in chapter *2.4.5 Other funding opportunities*.

For instance, the European Defence Fund pamphlet as issued by the European Commission in 2021, states that: "*Projects will be defined along priorities set with Member States aiming at contributing to the security and defence interests of the Union, in line with defence capability* *priorities agreed by Member States within the framework of the Common Security and Defence Policy and particularly in the context of the Capability Development Plan, and taking into account, where appropriate, priorities from other regional and international organisations (NATO).»* (EC, 2021). As such, NATO is a contributing factor in what kind of projects that will be prioritized by the European Defence Fund. NATO is in turn heavily influenced by USA, one of (if not the foremost) frontrunner for quantum technology and research. This report will not delve into American QT endeavors, given the report's projected size and time horizon.

2.9 Other important considerations

This subchapter contains other insights about quantum technology in the European Union, that were difficult to place in the chapters above:

Quantum focus in the lobby register: The lobby/transparency register contains information about all corporations and individuals that perform lobbying activities in the EU. Most of these entities are represented in Brussels and other major EU cities. Upon researching QT in the lobby register, a total of 40 registrations were found. The majority of companies in the register with an outspoken focus on QT, are situated in Europe. However, several US companies also state QT as a main area of interest. None of the registrations belonged to Norwegian companies or individuals.

PsiQuantum, Corp.

REG Number	769293192281-53
Status	ACTIVATED
Category of registration	Companies & groups
Location of head office	UNITED STATES
Latest update	14/10/2024

a mission to build the first commercially useful **quantum** computer to solve humanity's greatest challenges...Chicago **Quantum** Exchange American Physical Society American V

Print screen: PsiQuantum, an American company invested in QT lobbying in the European Union as seen in the Transparency Register (EU, 2024c).

Expert groups: The European Commission currently has two active expert groups on QT. The first group, the Quantum Technologies Coordination Group's objective is to coordinate the implementation from the European Declaration on Quantum Technologies. As previously mentioned, this initiative was only accessible for full EU member countries, disregarding Norway through its EEA membership. The second group, Strategic Advisory Board for the Quantum Technology FET Flagship, aims to coordinate the Quantum Flagship program. The expert group register does not have any active calls on QT (EC, 2024b).

Quantum Technologies Coordination Group

Code	E03931
Type	Expert group
Lead DG	DG Communications Networks, Content and Technology

Strategic Advisory Board for the Quantum Technology FET Flagship

Code	E03629
Type	Expert group
Lead DG	DG Communications Networks, Content and Technology

Print screen: The two active QT expert groups (EU, 2024b)

2.10 Summary

The European Commission and other EU entities are unambiguous: Quantum technology is a top priority for Europe. This is evidenced throughout numerous initiatives, strategies and commitments made throughout the last decade. The interest and prioritization for QT is likely to increase onwards, as it plays a crucial role in Europe's quest for better competitiveness, innovation and its reduction of harmful dependencies.

Through initiatives like the Quantum Flagship, EuroIQC and the European Declaration on Quantum Technology, The European QT ecosystem has already reached a reasonable size. However, this is not to be a resting bed since other countries too are investing heavily in QT. Since the EU has proclaimed that it wants to be a global competitor in technology, its funding and initiatives must be continuously seen in relation to that of other countries. Since China, the UK, the US and other countries too are all positioning themselves in the QT race, a growing focus on QT and other potentially disruptive technologies are likely to prioritized in the EU. It is safe to assume that the EU is positioning itself to harness the powers of QT and that large-scale opportunities are bound to present themselves.

NATO is and will likely continue to grow its influence on QT investment and research. Alongside other emergent technologies like AI, QT is seen as a double-edged sword for defensive purposes: It holds significant power while simultaneously posing serious threats. NATO is likely to pursue dual-use projects where the lines between commercial and militarygrade technology is increasingly blurry. Furthermore, the dual-use approach aims to close the gap between research, operationalization and productization. This approach has also been widely supported by several other institutions such as The Norwegian Defence Research Establishment, and large industry companies alike. Shortening the time-to-market frame is seen as crucial when the technological advancements are unfolding as quickly as they are.

The Nordic countries have all expressed a joint desire to work closer together to act as one region considering QT, both in Europe and on the global scene. By themselves, the Nordic countries are small. However, through shared initiatives and collaboration, a joint approach to QT can help position the Nordic countries. By leveraging skills and competence these countries can aim at becoming world leaders in niches within QT, thus securing long-lasting QT impact. While several activities are already in motion, more is needed if the vision is to come to fruition.

3 Standards

The necessity for QT standards is an outspoken priority in the community. This has been addressed both in NATO's QT strategy, by the European Commission and by several interviewees. There are numerous examples exacerbating the need for such work. For instance, the ambiguity of what a logical qubit is and how it should be defined as proven a challenge in recent publications and when benchmarking different products (personal communication, 2024). Proper standardization is crucial in emergent technologies to ensure efficient communication. Without it, coordination and collaboration may become difficult.

Standardization ensures consistency, safety, and predictability across products, services, and processes. It establishes agreed-upon norms, terminology and requirements that industries follow to guarantee quality and compatibility. Standardization is also important throughout the entirety of the value chain as it ensures confidence in the product or service's quality and functionality. This will be particularly important when QT becomes operationalized and productized. Standardization work is divided between different hierarchical orders. The global, European and Norwegian standardization organizations and efforts on QT will be elaborated later in this chapter.

3.1 International standards

At a global level, there are several standardization organizations providing thousands of different standards. Three of these, the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the International Telecommunication Union (ITU) are perhaps the most well-known. Of these, ISO and IEC will be focused on in this report, as they have created a joint technical committee (JTC) for standardization in quantum technology: IEC/ISO JTC 3.

The JTC's work "*includes standardization in the field of quantum technologies, including quantum information technologies (quantum computing and quantum simulation), quantum metrology, quantum sources, quantum detectors, quantum communications, and fundamental quantum technologies. The JTC will coordinate the results of these efforts with relevant committees and subcommittees that have within their scopes the development of specific sector-based applications of quantum technologies.*» (ISO, 2024). On IEC's website, several excluded categories are listed including but not limited to semiconductors and fibre optics (IEC, 2024). These are covered by existing committees given their interdisciplinary nature.

Ad-Hoc Groups	
ahG 2	Quantum terminology and metrics
ahG 3	Quantum Sensors (Sensing, Devices, and Imaging)
ahG 4	Quantum Communication
ahG 5	Quantum Computing and simulation
ahG 6	Quantum Random Number Generator (QRNG)
ahG 7	Quantum enabling technologies

Print screen: The JTC has several expert groups currently working on standardization within QT. As seen on this picture, that also includes quantum sensors (IEC, 2024a).

As of December 2024, only one international standard has been published by ISO and IEC's joint technical committee: The ISO/IEC 4879:2024 for Quantum Computing Vocabulary. This standard "*defines terms commonly used in the field of quantum computing*." (ISO, 2024b). Typically, standards on terminology tend to be prioritized first. Another standard is also on its way: ISO/IEC AWI TR 18157 for introducing quantum computing (ISO, 2024a).

According to several sources, international standardization organizations and in particular, ISO/IEC may be experiencing notable pressure from international competition to influence the development and implementation of these standards. China, for instance, has articulated a strategic ambition to become a significant player in setting global technological standards, including those for quantum technologies (QuantumConsortium, 2022). This initiative is part of China's broader National Standardization Development Program (NSDP), which underscores the nation's commitment to influencing international standards across various sectors.

The NSDP allegedly outlines directives for government bodies, organizations, scientists, and academics in China, encouraging active participation in standards setting as a component of their professional endeavors. This approach reflects a national priority to embed standardization within technological advancements, thereby enhancing China's position in emerging fields such as quantum computing. Upon reviewing the ISO/IEC's expert groups on QT (see the previous print screen), all groups without exception had Chinese representatives.

The emphasis on standards setting is not unique to China; other nations, including the United States and the European Union, have also initiated efforts to assess and arguably increase influence standards related to next-generation technologies (Cory, 2024). For example, the European Commission published its revised Standardization Strategy in 2022 highlighting the need for increased attention to standards, especially within emergent technologies. From the Department of Commerce, American officials write that "*U.S. companies and standards development organizations, particularly those active in emerging technology areas, should continue to closely track relevant Chinese standardization processes*..." (Department of Commerce, 2022).

The strategic pursuit of leadership in standards setting can be interpreted as a means for countries to project geopolitical influence through technological dominance. By shaping the norms and requirements that govern emerging technologies, nations can potentially steer the direction of global technological development to align with their own interests and strengths. This dynamic introduces a competitive element into what might otherwise be a purely collaborative international endeavor, highlighting the complex interplay between cooperation and competition in the realm of technological standardization.

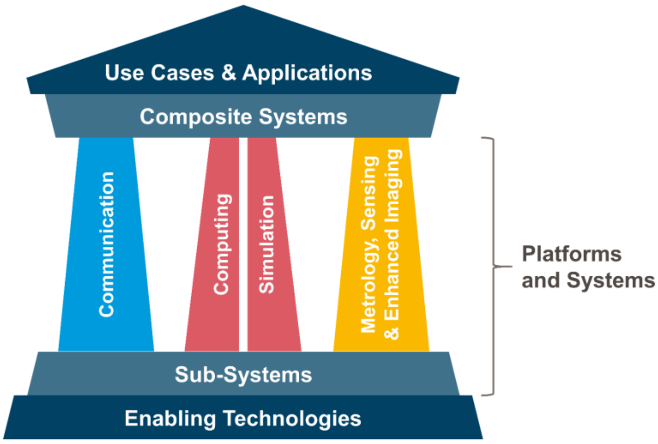
3.2 European standards

Within Europe, there are three principal standardization organizations: the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI). Together, these three are collectively referred to as the European Standardization Organizations (ESO). Of these, CEN and CENELEC will be focused on in this report, as they too have created a JTC: CEN/CLC/JTC 22 (CENELEC, 2024).

The JTC22 was formed on the basis of two documents co-authored by focus groups appointed by the Commission, CEN and CENELEC: 'The Standardization Roadmap on Quantum Technologies' and the 'Quantum Technologies Use Cases' (CEN-CENELEC, 2024). The Roadmap, a comprehensive document points out that not all areas of QT are ready for standardization. In a previous submission by CEN-CENELEC's focus group on QT also stated that:

"*As QT research is very capital intensive, the idea of QT standardization and the question to what extent and when it might be favorable or needed, starts to occupy center stage in the perception of main stakeholders. Future developments in this field are still uncertain… Simultaneously, some QT applications already achieve higher technology readiness levels: quantum key distribution, quantum sensing and quantum computing solutions are starting to become commercially available, the practical realization of these again requiring standardization*." (CEN-CENELEC, 2022). This goes to show that standardization of QT is a challenging task, perhaps made even more difficult with geopolitical tensions and strategic agendas masquerading under ulterior motives as suggested in the previous subchapter.

In 2024 the European Commission and members of the High-Level Forum on European Standardization agreed to prioritize quantum standards as a political priority (CEN-CENELEC, 2024b). Thus, it is expected that several standards may start to appear in 2025 and that work on QT is likely to ramp up onwards (personal communication, 2024). From its websites, it may appear that the first standard on QT from Europe will be the "Quantum technologies - Characterization of quantum technologies – Metrics and terminology". The JTC of CEN-CENELEC has, similar to that of ISO/IEC, formed several work groups focusing on specific areas within QT. As of January 2025, CEN-CENELEC has not published any quantum standards.



Print screen: The backbone of European standardization for QT as illustrated by CEN-CENELEC. Standards can and will be applied to both platforms and systems (CEN-CENELEC, 2023).

The European Commission's prioritization of quantum technology is further exacerbated in the Roadmap for Standardization of quantum technology. In the document, one can read that *"The European Commission is also very interested in boosting standards for quantum technologies"* (CEN-CENELEC, 2023). Furthermore, the Quantum Flagship has been designated to coordinate several of the initiatives related to standardization on QT in joint efforts with CEN-CENELEC. This becomes evident in the Quantum Manifesto *(QF's* predecessor) as it promotes the creation of an advisory boards to promote collaboration on standardization within QT in Europe (CEN-CENELEC, 2023).

As of now, no harmonized standards on QT have been ordered by the Commission. However, in the Annex to the proposed regulation on the Cyber Solidarity Act, the EC states that: "*Co-investment with Member States in advanced cybersecurity equipment, infrastructures and knowhow that are essential to protect critical infrastructures and the Digital Single Market at large. Such co-investment could include investments in quantum facilities and data resources for cybersecurity…*" (EC, 2023b). As pointed out throughout chapter 2, the EC and other EU institutions argue for closer European collaboration. This was likely one of the reasons to why the European Commission ordered harmonized standards for artificial intelligence back in 2023. As attention to QT continues to grow and it approaches operationalization and productization, some experts see it as likely that the EC may order harmonized standards on QT.

3.3 Norwegian standards

As with both international and European, Norway has several standardization organizations, including but not limited to from Standard Norge (SN), Norsk Elektroteknisk Komite (NEK), and the Norwegian Communications Authority (Nkom). These organizations perform a variety of tasks, including conducting public reviews and adapting international and European standards into Norwegian Standards (NS). Additionally, SN, NEK, and Nkom are tasked with nominating Norwegian specialists to participate in both European and global expert committees. Both SN and NEK have created committees on quantum technology.

Standard Norge's committee, *SN/K 617 Tungregning* - *Quantum computing* was the first standardization group within QT in Norway. Recently, NEK established a JTC as well: *JTC 3- Kvanteteknologi*. Both committees aim to mirror, coordinate and influence the QT standardization efforts in ISO/IEC and CEN-CENELEC. As such, both SN and NEK's committees have several tasks: The committees must preserve national interests, passing votes on documents issued by European and international committees respectively, and appoint Norwegian experts to participate in international work (NEK, 2024).

In a presentation issued by SN in relation to an information meeting about QT standards in Norway, information about Nordic collaboration on QT standards was mentioned. The work is led by the Swedish Institute for Standards in collaboration with the Karolinska Institute. The presentation argues that Nordic collaboration on standards is necessary for several reasons: The Nordic community is small and will benefit from collaborative efforts, QT will impact many fields and must therefore be broadly represented, and it will help create a mutually beneficial relationship for the Nordic countries on a global scale (SN, 2024).

Print screen: From SN's pamphlet promoting Nordic collaboration on QT standards (SN, 2024).

A challenge for Norwegian standardization committee members, is that no funding is provided for participation. As such, the employer of the expert must provide all the necessary expenses. This can make participation difficult, especially for SMEs. However, several experts argue that the benefits from partaking in standardization work is worth the cost. Participants gain important information about standardization efforts, the representatives can voice concerns and recommendations thus impacting important development. Furthermore, experts also get access to some of the largest expert networks in the world (personal communication, 2024).

3.4 Summary

Standardization plays an important role in making quantum technology available, trustworthy and ensuring its viability to be operationalized. However, the immaturity of the technology may make these efforts more challenging. This may be further exacerbated by the alleged geopolitical tensions that may impact these developmental processes as well. It is seen as crucial for Norway to partake in the standardization efforts, to help promote Norwegian interests and to keep up-to-date on development within QT standards. Close Nordic collaboration has been highlighted as an important instrument in aligning QT throughout Norway and neighboring countries. This work has already begun. However, as employers have to cover expenses related to expert group participation, this work is often made more difficult – especially for private individuals and SMEs wanting to contribute.

4 Conclusion

The ecosystem surrounding QT is comprehensive and intricate. Various grassroot initiatives, the lack of a clear governmental approach, the fast global investments, secrecy and different subfields of QT all contribute to this. For a Norwegian business looking to develop or deploy quantum technology, there are several areas prone to influence that decision, starting with the national ecosystem on QT. As of now the Norwegian government is less active than many experts would have hoped for. The most sought-after initiative is that of a national QT strategy. The arguments for a national QT strategy are many, from funding, to helping private and public sector prioritize which QT niches to pursue, and to align Norwegian endeavors with that of other Nordic, European and NATO countries. Furthermore, it is expected that the likely creation of a national QT strategy will draw significant inspiration from existing QT strategies in these countries. As one interviewee puts it, "*The lack of a national QT strategy is the real bottleneck. Without it, it is difficult to know where and how Norway should prioritize its investments.*" (personal communication, 2024). This becomes unmistakenly clear in funding.

While the annual 70 million NOK was a much-welcomed initiative, it will lose its impact if spent on too many projects. To make the most of the money, Norway needs to prioritize which niches to focus on. This strategic differentiation will also help promote Norway as an attractive partner in the QT field. Norway needs to become best at one or a few subsets of the quantum umbrella to become and retain its position as an attractive partner. This is where a national strategy is needed, to help sort out and steer the direction of investments. While the new earmarked funding is much needed, more is required.

The 70 million falls short in comparison to other countries, including that of our Nordic neighbors. The low percentage of QT projects as reported by the Norwegian Research Council further exacerbates the need for action considering funding of QT projects. With that said, in the Government's Long-Term Plan for Research and Higher Education, quantum technology has one of the highest priorities in technology research. As the Research Council is obliged to follow the government's prioritizations, more funding towards QT should be possible if applied for. However, the QT community cannot rely solely on funding from the government, private investment is required too.

The debate surrounding QT has been significantly impacted by the need to review and favor dual-use cases, to help build stronger connections between education and research facilities and private sector. This is true for all of Europe, as evidenced by the Draghi report. If Europe is to remain a relevant force in QT, closer collaboration between industry and research is crucial. If QT is to receive more private investment, so too must that investment provide something tangible in return. To achieve this, more focus on operationalizing of QT research is a must.

Norwegian QT endeavors will be heavily influenced by activities done and planned by our neighbors, the EU and NATO. QT is a highly prioritized field of research in Sweden, Denmark and Finland. The Nordic Council has voiced its interest in Nordic collaboration on QT and supported QT projects as well. However, the Nordic countries should strive for even closer collaboration. By themselves, the Nordic countries are small on a global scale. Hence, combining forces will increase the likelihood of a global Nordic impact. A potential disadvantage for Norway, is that Sweden, Denmark and Finland are all full members of EU. This grants our neighbors access to funds and QT initiatives (like EuroQCI and the European Declaration on Quantum Technologies) that are inaccessible to Norway. As such, closer

Nordic collaboration is important for all the Nordic countries, but perhaps most of all for Norway.

The European Commission has initiated numerous QT activities to help position Europe in the quantum race. The EU has an outspoken desire to become the “quantum valley of the world”. This requires substantial investment, coordination and collaboration. Similarly, NATO has expressed interest and concerns about the emergence of QT, making it a top priority for the Alliance’s future investment. As Norway’s political and strategic development is closely linked to that of the EU, Nordic and NATO, QT will continue to increase its importance in Norwegian politics and priorities as well. The sooner Norway takes a clear stance on QT, the sooner it can start to provide premises for its development.

4.1 PESTEL

This report has explored the ecosystem surrounding quantum technology, acting like a whitepaper probing and assessing various projects, opportunities and activities that are likely to influence Norwegian development. This report can therefore be seen as a comprehensive PESTEL inspired analysis (**P**olitical, **E**conomic, **S**ocial, **T**echnological, **E**nvironmental, **L**egal). The reason ‘inspired’ is used, is because this particular PESTEL analysis is fitted to its purpose of summarizing the report. Hence, there are some deviations from a ‘textbook’ PESTEL analysis. This table will schematically summarize the most important considerations from Part I: Key takeaways:

PESTEL (important considerations), QT for Norw. Businesses			
Political	Geopolitical tensions	EU's assertiveness to become a QT superpower	A high NATO priority
	Strategic differentiation – prioritize selected niches	The need for a national QT strategy	Calls for closer Nordic collaboration.
Economic	QT creating > 1 trillion USD annually from 2040	No national co-funding for DIGITAL	Emerging use-cases
	Call for increased funding for Norw. Research. Earmarking	Recommended increase for FP10	Funding options in Norway, EU, the Nordic and NATO
Social	Trust is considered crucial	Ethical concerns, in particular encryption/security	Creating awareness, both professionally and publicly
	The need for new QT education, reskill and upskill	In-housing/domestic talent – and international collaboration	Talent poaching is and will continue to be a risk
Technological	Significant disruptive potential	System stacking and ecosystems will be important	Enabling technologies and fields will play an important role in operationalization of QT.
	QC is likely to be a sort-of mainframe (through cloud)	From theory to operationalization	Dual-use cases
Environmental	May reduce carbon footprint for supercomputing		
	May help solve the climate crisis through powerful algorithms		
Legal	No technology-specific legislation exists – still governed by technology neutral legislation	The rapid growth in patent filings and granted patents	In light of increased European competitiveness, reworking legislation and policies have been suggested
	Standardization efforts and requirements	Encryption and liability	Intellectual property rights

The PESTEL analysis will make up the foundation for strategic recommendations in the next chapter, **Part II Key Takeaways**. As seen by the illustration below, a PESTEL analysis is just one of several analyses necessary to provide a full framework for strategic recommendations.

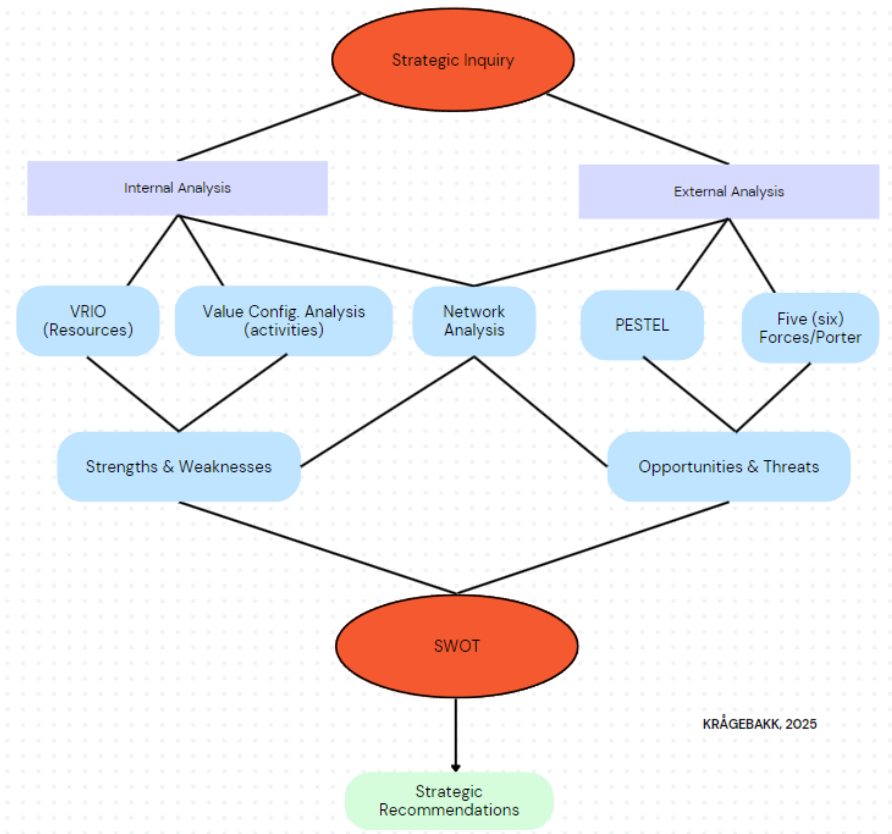


Figure: Made by the author to illustrate PESTEL's position in a wider strategic landscape. Inspired by a similar illustration made by Professor Lars Huemer during a seminar at BI in 2024.

4.2 Closing reflections – Changing The Narrative

As quantum technology advances, its impact on society hinges largely on the narratives we create. Sadly, fear is often used as the go-to narrative, belittling technological advancement as scary and dangerous. Albeit, plenty of opportunities and positive impacts have been attributed to emerging technologies and rightfully written about, but fear is often easier to manifest and understand – especially if advanced technology is not your domain. Narratives promoting fear are also hard hitting, as numerous examples can demonstrate: Geoffrey Hinton, one of the most prominent voices in AI, has stated that the likelihood of AI causing human extinction is somewhere between 10-20 percent within the next 30 years. Similarly, CNN reported that "*42% of CEOs say AI could destroy humanity in five to ten years*." (CNN, 2023). Serious concerns in technology must be properly addressed, but fear mongering is likely not the best way to do this. If fear remains the dominant force guiding our response to QT and other emerging technologies, innovation may be hindered, and trust eroded. John Hagel, in *Beyond Fear*, emphasizes the transformative power of narratives in shaping collective actions and attitudes toward the future. To fully realize the promise of emergent technologies like quantum, the global community should shift from a threat-based perspective to an opportunity-based one, encouraging collaboration, trust, and constructive innovation.

Central to the narrative, is the psychological dynamicism between fear and opportunity. Fear often renders people passive, triggering a fight-or-flight response. When faced with complex technologies like QT, the fight response may manifest as competition, such as arms races with zero-sum perspectives, while the flight response can lead to disengagement, apathy and passivity. Moreover, emotions like fear exhibit a contagious network effect spreading and intensifying collective anxiety (Hagel, 2021). Doomism, the expectation of catastrophic outcomes, amplifies this dynamic, pushing individuals and institutions toward defensive, short-term strategies rather than long-term, opportunity-focused investments. Discouraged by the dangers of new technology, a large percentage of the population may choose not to get involved, making these technologies (and the opportunities they represent) largely accessible only to a small part of the population. This is the opposite of technological democratization.

One thing that became apparent during the interviews and upon reading a considerable amount of QT research papers, is the necessity for democratization. If we want quantum technology to thrive, it must be made accessible to the general population. Perhaps the most important ingredient to democratize quantum technology or other emerging technologies, is trust. If the fear-based narrative continues to dominate the media, it may subvert society into different groups: The people who realize the potential of emergent technologies will seek the opportunities, while the majority of people may avoid it because they fear it.

To counterbalance fear and apathy, we must actively promote narratives and stories that emphasize opportunities. Hagel notes that narratives emerge from sustained action, not just rhetoric. For QT, this means highlighting concrete examples of how the technology can address global challenges—such as optimizing supply chains, accelerating drug discovery, and combating climate change. It also highlights the necessity for knowledge, education and training. These narratives should inspire confidence, demonstrating not only what is possible but also how it can be achieved through collective effort. That is how a society starts its journey to becoming quantum ready, and, as stated in the *Abstract* chapter, that journey needs to start long before the ChatGPT moment.

Part II: Key Takeaways

As described in chapter Abstract, Part II Key Takeaways has been removed in its entirety as it contains information exclusive to Kongsberg Gruppen.

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Appendices

Appendix A

#	Name	Title	Company
1	Ahmed, Waqar	Special Advisor and Research Consultant. National Contact Point for Horizon and Representative for the Chips Joint Undertaking	The Research of Norway (Forskningsrådet)
2	Borsch, Rebekka	Department Director Competence and Innovation	NHO
3	Fuchs, Franz	Scientist, Associate Professor, Leader Gemini Center Leader for the Gemini Center on QC	SINTEF Digital, UiO
4	[redacted]	[redacted]	[redacted]
5	Heyerdahl, Haakon	Project Leader for the committee on Quantum Technology	Standard Norge
6	Hjorth-Jensen, Morten	Professor in Physics	UiO
7	Knutsdatter, Marit S.	Member of Parliament and Leader for the Parliament’s Techno Group	The Parliament of Norway
8	Kreutzer, Idar	Director of International Affairs, Private Ownership, and Digitalization in Public and Business Sectors.	NHO
9	Kvamsdal, Mikal	Risk advisor	Abelia

10	[redacted]	[redacted]	[redacted]
11	[redacted]	[redacted]	[redacted]
12	Minssen, Timo	Professor and Managing Director	University of Copenhagen, Centre for Advanced Studies in Bioscience Innovation Law
13	Nilsen, Terje	Director, Disruptive Technologies	KD
14	Rustad, Gunnar	Research Leader	Norwegian Defence Research Establishment (FFI)
15	Selstø, Sølve	Professor in Physics	Oslo Metropolitan University
16	Sund, Lise V.	Senior Advisor	NHO
17	Sunde-Hansen, Daniel	Director, Center Lead	Center for the Edge, Deloitte
18	Anonymous	Anonymous	Anonymous
19	Viefers, Susanne	Head of Department and Professor	UiO
20	Wergeland, Christine S.	CEO	Oslo Science City
21	[redacted]	[redacted]	[redacted]

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