A WORK PROJECT, PRESENTED AS PART OF THE REQUIREMENTS FOR THE AWARD OF A MASTER'S DEGREE IN MANAGEMENT OR BUSINESS ANALYTICS FROM THE NOVA SCHOOL OF BUSINESS AND ECONOMICS

SCENARIO ANALYSIS: A FUTURISTIC DAY WITH FULL-SCALE QUANTUM COMPUTING IN THE CYBERSECURITY INDUSTRY

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Group Part

Abstract

This master's thesis analyzes the consensus between the academic literature and expert opinions on the topic of potential real-life applications of quantum computing in the healthcare, finance, mobility, energy, and cybersecurity industries. Literature-based scenarios are formulated and presented to the experts for revisions. Additionally, an end user perspective survey is conducted. The results reveal that the literature is more confident toward the role that quantum computing could play in technological innovation compared to the opinions expressed by experts. End users are excited for new technologies to emerge and are mostly not worried about the changes that quantum computing could bring.

Please note that this document only provides the specific insights into the cybersecurity industry.

Keywords: Quantum Computing, Technology, Technology Adoption, Innovation, Scenario, Healthcare, Finance, Mobility, Energy, Cybersecurity

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List of Abbreviations

AI	Artificial Intelligence
AV	Aerial Vehicle
EuroQCI	European Quantum Commmunication Infrastructure
EV	Electric Vehicle
MCS	Monte Carlo Simulation
NISQ	Noisy Intermediate-Scale Quantum
OEM	Original Equipment Manufacturer
QC	Quantum Computer
QKD	Quantum Key Distribution
QMC	Quantum Monte Carlo
Qubit	Quantum Bit
RSA	Rivest-Shamir-Adleman

1 Introduction

Quantum computing expert Matt Langione wrote in 2021, “In a world such as ours, the demands of innovation cannot be put off for another day. Leaders must act now” (Langione 2021). Quantum computing is on the verge of creating a technological revolution that could exponentially increase the capacity and speed of the world’s data processing and problem-solving capabilities. The motivation for this topic is multi-faceted: It includes the business perspective with an expected value of $450 billion to $850 billion, the contribution to sustainability and climate protection, the fascination of a future-oriented technology, and personal commitment. The aim of this master’s thesis is not only to explore the theory of quantum computing, but also to shed light on its practical application in everyday scenarios in the fields of healthcare, finance, mobility, energy and cybersecurity.

1.1 Relevance of and Motivation for the Topic

Over the past decade in particular, both scientific research and commercial interest in quantum computing have grown rapidly (Elsevier 2022). Based on the laws of quantum mechanics, quantum computers (QCs) exhibit fundamentally differencess in their physical processes from classical computers used today and enable novel algorithmic techniques (Biondi et al. 2021). The potential lies in their ability to perform calculations at much higher speeds and to solve tasks that are too complex to be tackled by conventional computers (IBM 2023). It is estimated that QCs will outperform today's fastest computers, operating 158 million times faster (Marr 2022). To access this wide range of potential benefits, the machines must meet highly complex technological requirements, such as quantum bits (qubits), which require storage temperatures lower than those found in outer space (Fraunhofer Institute 2023a), and which are currently highly susceptible to errors (Giles 2019). Therefore, most QCs currently exist in laboratory environments (Buchholz, Golden, and Brown 2021) and use cases are mostly experimental

(Biondi et al. 2021). However, due to the rapid pace of advancements, experts predict that quantum technologies will “migrate from research labs to real-world commercial environments within this decade” (Buchholz, Golden, and Brown 2021).

The motivations for the engagement with this master’s thesis topic are highly diverse but can mainly be divided into four main aspects: the business perspective, novelty and future orientation of the topic, sustainability, and finally personal motivation. The possibilities seem enormous in every facet and, therefore, could be summarized as follows: According to O’Brien (2022) quantum computing could “open up solutions to problems that would otherwise forever be impossible to solve.” Other experts in the field go even further, describing possible breakthroughs as “an explosion of algorithmic power […] that hold[s] the power to reshape our world (Ruane, McAfee, and Oliver 2022)”.

Firstly, QCs have significant potential from a business perspective. According to Boston Consulting Group, the annual value created by quantum computing across all industries at full capacity is expected to range from $450 billion to $850 billion in annual value by 2040 (Bobier et al. 2021). This is to be achieved through various use cases including optimized investment strategies, improved encryption, and newly discovered products. Developments such as these could lead to both cost savings and increased sales for businesses (Van Rijmenam 2022). A large number of investments, interest from the private and public sectors from the private sector, and mathematical and scientific talent are currently being devoted to quantum research. For some years now, quantum computing has seen a surge in venture capital funding, from an estimated $225 million in 2019 to $1.8 billion in 2022 (Ward 2023). Both the research and development giants such as IBM and Honeywell and, more recently, several start-up companies are in the race to deliver the next quantum breakthrough. In addition, consulting firms are building deep talent pools in support of their clients (Ruane, McAfee, and Oliver 2022).

The enormous help that quantum computing technology could offer in reducing greenhouse gas emissions and, thus, counteracting global warming also motivates further exploration of this topic with regard to possible climate-related use cases (Cooper et al. 2022). To remain within the 1.5-degree of the Paris Agreement, a legally binding international treaty on climate change, major developments in climate technology are needed. However, developing the best computers alone will not be enough, but rather QCs could be revolutionary. Knowledge and understanding are key to the development of innovative climate solutions, as is the ability to simulate and analyze complex systems to recognize underlying interdependencies (Buchholz et al. 2023). Examples of cases in which quantum computing could have a strong positive impact on climate change range from catalysts and batteries for weather forecasting to electrical grid and vehicle routing optimizations. According to Cooper et al. (2022), quantum computing has the potential to help save an additional seven gigatons of CO_2 emissions, which represents a major step towards meeting the 1.5-degree target.

A further attraction and relevance of this research is the novelty and future orientation of the QC topic. As there is still little awareness within society, it is a personal concern for the team to bring more attention to this important technology and to highlight it not only from the scientific side, but especially with regard to the many possible use cases. The focus here is on educating not only end users about how they are affected, but also, and more importantly, on businesses and their adoption capabilities. While quantum computing technology is still in the early stages of commercialization, it is imperative for businesses to begin preparing now. However, most business leaders have merely expressed interest in the technology without actively identifying practical use cases or taking initial action (Campbell 2023). A “wait-and-see” approach could cause companies to fall behind and face the risk of major losses in market power (Buchholz, Golden, and Brown 2021). To capitalize on the benefits of quantum computing in the future, it is crucial for business leaders to adopt a proactive stance and take the first steps today (Buchholz, Golden, and Brown 2021).

Finally, there is also a personal motivation behind the team's interest in the field of quantum computing. Being fundamentally interested in innovation and technology, the team has increasingly encountered this topic in recent years. However, an in-depth examination of such a complex issue requires uninterrupted focus and the support of external experts. After recurring encounters with the topic in the course of the master's program, the aim was to choose a focus for the final work that would both fascinate and challenge the team. After an intensive examination of existing literature, a promising attitude toward the topic and its impact emerged and the interest in participating in the research arose. The personal interest here is to gain deep understanding of the topic and explore its potential impact to obtain a realistic approach to how this technology might affect the team members' personal lives. To summarize, the aim is to open up and add a new perspective to the topic of quantum computing and its use cases, as there are still many gaps in the research, and a direct comparison of literature to expert opinions as presented in this master's thesis does not yet exist in this form.

1.2 Research Question and Objectives

By presenting outstanding examples based on ongoing research complemented by innovative ideas, and by placing them in an everyday context, this work project strengthens the imagination and access to the mostly theoretical topic of quantum computing. Consequently, the following research question is to be answered consequently: "A futuristic day in the life of quantum computing: What scenarios could be realistic in a future with full quantum computing capacity focusing on the healthcare, finance, mobility, energy, and cybersecurity industries?"

To answer this research question, the following four objectives are pursued:

- Analyze current literature on quantum computing and its potential applications to understand challenges and opportunities
- Identify scenarios that could be significant in each industry and assess the potential impact of quantum computing there
- Evaluate with expert opinions and potential end users how realistic the scenarios are in each respective industry
- Develop new scenarios that are more realistic, if necessary, or that agree with the existing ones

1.3 Outline

To answer the research question accordingly, this thesis proceeds as follows: Before discussing the technology of quantum computing and its concrete use cases in the five industries identified, it is necessary to provide an overview of this highly complex innovation through a literature review. On the one hand, the technological background of QCs is introduced, which includes various hardware and software components, capabilities, and obstacles. On the other hand, potential applications in use cases of optimization, simulation, machine learning and cryptography are explored. After that, the research methodology is addressed, which includes the three different methods: building a scenario, interviewing experts, and obtaining an opinion from possible future end users through a survey. These methods are divided into a description and reasoning of the approach, an explanation of both the procedures, and an analysis. In the analysis part, which covers into the five industries, the industry-specific scenarios are analyzed, revised, and discussed on the basis of expert interviews and the survey results. After the individual analysis sections, some ethical concerns are highlighted. Finally, to bring critical findings into perspective, the limitations and future research outlook of this thesis are presented. The thesis' conclusion summarizes the findings and answers the main research question.

2 Literature Review

To present quantum computing in the chosen context, it is important to explore two separate topics: its technological and scientific background and its real-life applications. A multitude of literature, consisting of books, academic papers, articles, and other sources was used to provide a broad introduction to quantum computing and its capabilities. This introduction serves to help the reader to understand the topics discussed in the findings and conclusion of this paper.

2.1 Technological Background on Quantum Computing

Quantum computing was first introduced in 1982 in lectures delivered by Nobel Prize winner, Richard Feynman at Massachusetts Institute of Technology (Feynman and Hey 2023, 180). In his attempt to simulate quantum physical systems, Feynman realized the need for a controllable quantum environment, which would later become the foundation for QCs (Feynman 1982, 469). Quantum computing is a combination of quantum mechanics, which is the study of behavior of particles at the microscopic level in relation to physics; traditional computer science; and mathematics (Hirvensalo 2004. Feynman's new findings suggested that an operational QC could solve traditional computational problems exponentially quicker than a classical computer (Hirvensalo 2004). To understand the opportunities offered by QCs, it is important to understand the underlying technological concepts introduced in the following section.

2.1.1 Classical Computing Versus Quantum Computing

The smallest unit with which information is processed in classical computers is a bit. These data units are binary and, therefore, can assume exactly two conditions, "0" or "1". QCs, by contrast, are powerful computing devices based on fundamentally different physical processes than conventional computing methods. They work with qubits instead of bits (Sutor 2019, 1-

8). These qubits are typically subatomic particles such as electrons or photons and can be any so-called superposition state between “0” and “1” (Giles 2019) .

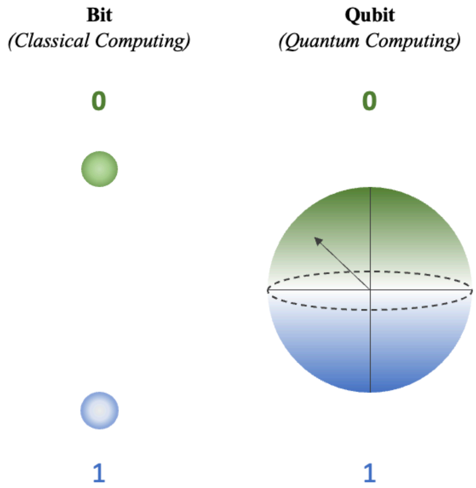

Figure 1: Comparison Bit vs. Qubit and Their States

In replica of Dumon 2019

Superposition

Superposition is a central phenomenon of quantum physics and the basis of quantum computing It allows qubits to exist simultaneously in multiple states (Sigov, Ratkin, and Ivanov 2022). The double-slit experiment can be used to illustrate superposition, and its results emphasize two key principles of quantum theory. First, the experiment involves wave particle duality, which states that entities such as light and matter have the properties of both particles and waves. Second, it affirms the principle of superposition, which states that particles can exist simultaneously in different states and possibly in multiple locations (Sinha 2020). In the context of the double-slit experiment, it is of central importance that, at the end, an interference pattern becomes visible; therefore each particle not only crosses one slit at a time but also is in a superposition while crossing.

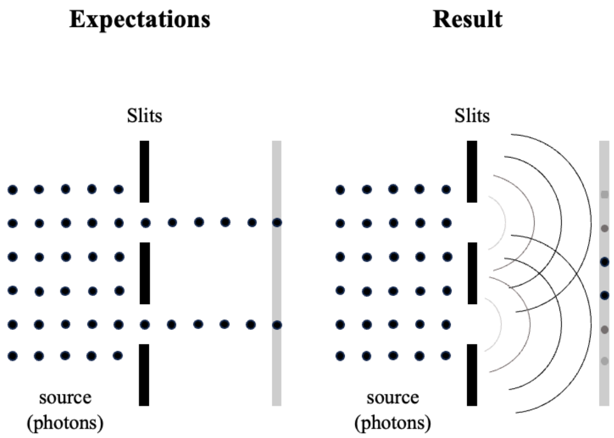

Figure 2: Double-Slit Experiment

In replica of Metwalli 2023

Much like the waves in a pond when the surface of the water is tapped simultaneously at two points, complex state patterns can be created by the superposition of qubits. Mathematically, this is expressed in wave functions that describe the probabilities of certain states of a quantum object (Caltech 2023). Superposition allows QCs to simultaneously perform multiple calculations simultaneously, making them exponentially faster than today's classical computers (Qauntum Inspire 2023; Forcer 2002). Despite this enormous computational power, a qubit collapses into a particular state of “0” or “1” when measured. Schrödinger's famous thought experiment, in which a cat is locked in a cardboard box, illustrates the apparent possibilities of quantum superposition, in which an object can exist simultaneously in multiple states until it is observed. As long as the cat's cardboard box is not opened, the cat can simultaneously assume the two states of "dead" and "alive" (Gharibyan 2023).

Entanglement

The entanglement of qubits is an essential and counterintuitive phenomenon of quantum mechanics that plays a crucial role in the field of quantum computing. This phenomenon refers to a unique correlation between two or more quantum particles, such that the state of one particle immediately reflects the state of another particle, regardless of the spatial distance between them (Bahman 2023). The Einstein-Podolsky-Rosen paradox originally highlighted the puzzling nature of this phenomenon and drew attention to its non-local properties (Akhouri 2023). Quantum computing makes use of entanglement to achieve a higher degree of computational connectivity. In practice, the entanglement of qubits means that a change in the state of one qubit leads to an immediate change in the state of its entangled partner. This synchronicity allows quantum algorithms to explore multiple solution paths at the same time, which significantly increases the efficiency of computations (Tabb, Gawrylewski, and DelViscio 2021). Furthermore, entanglement forms the backbone of quantum teleportation and has implications for secure quantum communication protocols such as quantum key distribution (QKD) (Shannon, Towe, and Tonguz 2020). While classical systems depend on unique states and conventional logical gates, quantum systems, aided by entanglement, transcend these boundaries and promise computational capacities and secure communication channels previously considered unattainable in classical paradigms (Bub 2023).

2.1.2 Models

In the evolving field of quantum computing, the choice of model can impact profoundly affect the theoretical possibilities and practical implementations of quantum systems. Current QCs can be divided into two classes: universal, gate-based QCs and quantum annealers (Large 2023). Due to space limitations, only the most important model of each class, the circuit model and quantum annealing, are discussed in this chapter. Subsequently, the different computational strategies are examined, along with their relevance to current technology and their potential for future developments.

Circuit Model

The quantum circuit model was the first model of quantum computation developed, mirroring classical circuits with bits replaced by qubits and logic gates by quantum gates (Nimbe, Weyori, and Adekoya 2021). Classical computers can implement Boolean operations using logic gates; for example, they can be used to perform calculations and to store information. Logic gates are small transistors that can pass on a signal or refuse to do so. Transistors always have a data input, a control input, and an output (TechTarget Contributor 2020). Some transistors pass the signal from the input through to the output when the control input is 1. Others, by contrast, switch the signal through when the control input is 0. The best-known logic gates are AND, OR and NOT Boolean circuits (Tesch 2013). Not all logic gates are reversible; if the result "0" is obtained at the end of an AND transistor, for example, it is not possible to clearly assign what the previous inputs were (O'Donnell 2015).

In QCs, quantum gates are the basic building block for quantum circuits and, thus, for information processing. They can manipulate the state of one or more qubits in a controllable manner and perform a variety of operations (Hannan 2023). The best-known one-qubit gate is the Hadamard gate, which can generate superposition states. Two-qubit gates, such as the CX gate, can be used to create entanglement between pairs of qubits (IBM 2023). In contrast to classical computation, unitary evolution is a reversible process, requiring the input and output to be of the same size (Hagar and Cuffaro 2022). Thus, an n-qubit quantum state evolves to a new n-qubit quantum state via a continuous evolution. A comparison of the efficiency of both concepts indicates that N input qubits can store $2N$ (classical) amplitude coefficients (National Academies of Sciences, Engineering, and Medicine 2019). As a result, information can be stored and obtained much more efficiently in a quantum circuit than in a classical circuit.

Quantum Annealing

Quantum annealing is based on the adiabatic theorem, which states: "A quantum system in its ground state remains this way if the Hamiltonian, the mathetmatical description of the total energy of a system, that controls the dynamics changes gradually."(Grant and Humble 2020).

The model uses quantum mechanics to find the "lowest energy state," which represents the optimal solution among all possibilities in the system. Each possible solution is represented as a state with its own energy level. For example, if the model consists of two qubits, there are four possible states (Gharibyan 2023).

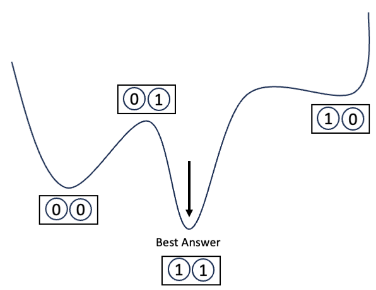

Figure 3: Energy Points in Quantum Annealing

In replica of IBM 2023f

When quantum annealing is performed, the system experiences couplings and biases, and the qubits entangle. Biases are magnetic fields that can influence the state of a qubit, while couplers can determine the correlation between the qubits. Both values can be individually programmed by the user (D-Wave 2023). In contrast to classical calculation, where each energy point must be checked individually, quantum annealing can find the optimum state more efficiently thanks to the quantum tunnel effect and the superposition property of its qubits (Boixo et al. 2016). An optimization problem that illustrates the above is the travelling salesperson example. Here, a businessperson must travel to several cities to sell their goods. The fastest route between, for instance, 70 different locations is being considered. With regular computing, an exponential amount of time is needed to identify the best route in comparison to the number of cities. With quantum computing, all of the different routes could be calculated simultaneously with a solution in just a few seconds. Using the quantum annealing model, the shortest route corresponds to the energy minimum (Jain 2021).

Comparison

The circuit model is a universal quantum computing schema, which means that it can theoretically simulate any quantum computing system (Walimann 2021). Therefore, it can implement, for instance, Shor’s algorithm, Grover’s algorithm, or a quantum error correction. Gate-based models are more versatile and powerful than quantum annealing, but they also require more control and coherence of the qubits (Marchenkova 2023). The circuit model, therefore, is highly sensitive to errors such as noise and decoherence, which plays a particularly important role in the current noisy intermediate-scale quantum (NISQ) state (Schrödinger 2023).

Quantum annealers are technically easier to implement than gate-based models but cannot be applied to all quantum systems, as they usually only provide an approximation of the solution (Walimann 2021). Therefore, they are particularly suitable for solving combinatorial optimization problems such as the traveling salesman problem described above. Calculations with quantum annealing, in contrast to the first model, are considered to be relatively robust against errors such as noise and decoherence (Schrödinger 2023).

2.1.3 Quantum Algorithms

QuTech's, a leading quantum computing research institute, defines a quantum algorithm as a "step-by-step procedure to perform a calculation, or a sequence of instructions to solve a problem, where each step can be performed on a quantum computer" (Quantum Inspire 2023). Quantum algorithms cannot solve problems that are unsolvable on a classical computer, however, they can significantly increase the speed at which complex problems are solved. The two most important algorithms for quantum computing are Shor's and Grover's algorithms, the applications of which are discussed in the next section without explaining how they work from a computer science perspective (Djordjevic 2012, 145). There are hundreds of other quantum algorithms, but these two have the most significant potential for real-life applications, so they are the only ones which are introduced in this paper.

Shor's algorithm was first formulated in 1994 and is used for integer factorization; it was the first time a quantum algorithm demonstrated supremacy over a classical algorithm. Due to the pre-quantum difficulties of finding these integer factors, this method is widely used for internet encryption; in fact, Shor's algorithm allows the user to find the factors of a large number in a matter of seconds (Wong 2023). Therefore, this algorithm has significant implications for modern-day security, as the availability of these factors enables the user to quickly access the encrypted data. More detail on this is provided in Section 2.2.4, cryptography. Walliman characterized the introduction of Shor's algorithm as a breakthrough point for quantum computing, as it presents the first application to a real-life problem with significant implications, thereby increasing researchers' interest (2021).

Only two years later, in 1996, Grover's algorithm was introduced. The second algorithm to represent a major advance for quantum computing, it can be used to search unstructured lists for one or more items faster than classical computers (Walliman 2021). The introduction of this algorithm was the first proof that QCs are faster than classical computers. Classical computers can search for an item in a list one by one, with no possibility of further improvements, while QCs can use quantum parallelism, which enables a simultaneous search of all items in the list (Lavor, Manssur, and Portugal 2008). Grover's algorithm is used mostly for optimization problems, which can be applied to many different real-life applications. To find the optimal output of a problem, one needs to find the minimum value, which is easily done using Grover's algorithm. More on this is presented in Section 2.2.1, optimization (Montanaro 2016). Grover's applications are not limited to optimization problems; they can also assist in quantum simulation by searching for specific states or for machine learning, as the advanced search capabilities can be incorporated into a multitude of machine learning models or tasks (Khanal et al. 2021).

2.1.4 State of the Art

To achieve a fully functioning QC, the above-mentioned hardware, software, models, and algorithms need to interact and perform together, and this interplay results in a substantial technological leap (McKinsey 2022). The current world's current most-advanced QC was introduced by IBM in 2022 and has a processor with 433 qubits. This was a massive hardware leap, as it tripled the number of qubits which that were achieved in the previous model in 2021 (Choi 2022). The optimization power of this computer surpasses that of classical computers. This is often referred to as quantum supremacy; it means that QCs can solve problems that a classical computer could not be able to in an economic timeframe (Gambetta 2022). Google also claimed quantum supremacy in 2019, performing a computation on its QC in under 200 seconds, which would have taken 10,000 years on the most powerful classical computers (Pichai 2019). Nonetheless, these advances do not represent the full range of what QCs might enable, as the computations that are performed under highly specific test environments and for one specific problem. Full quantum computing capacity will increase the performance, speed, and efficiency of computations beyond the reach of even the most advanced features on classical systems. QCs are predicted to exceed the speed of the fastest computers by approximately 158 million times (Marr 2022).

2.1.5 Obstacles

Quantum computing has only recently begun to gain awareness, and its research is still in the early stages. Therefore, there are numerous obstacles must be overcome before it can reach full capacity, the greatest challenge of which is within the hardware, especially decoherence (Giles 2019). Decoherence is the phenomenon in which the quantum state of a qubit is disrupted, resulting in the loss of its coherence. Qubits are highly sensitive, and the quantum environment is easily disturbed by outside factors; overall, this is called noise (Giles 2019). Factors such as electromagnetic radiation, stray magnetic fields, cosmic rays, and temperature fluctuations can introduce environmental noise, while other sources can be imprecise hardware control and manufacturing defects (Rietsche et al. 2022). These factors significantly affect the precision, accuracy, and reliability of quantum computations. Researchers and engineers work to mitigate decoherence through techniques such as error correction codes, quantum error correction, and the use of specialized quantum hardware designed to reduce environmental interference. Minimizing decoherence is crucial for the development of practical and reliable quantum computing systems, as it is needed not only for operating a QC but also for the data storage (Rietsche et al. 2022).

Another major challenge inhibiting the advance of quantum computing is that the production and associated research are highly expensive (Marr 2022). Engineers, scientists, and software designers who specialize in quantum computing are scarce and, due to their advanced education, receive a salary that ranks them among the top-paying jobs. Furthermore, the hardware necessary to cancel out the previously mentioned noise is very particular; it often needs to be custom-built, which can be costly to produce (Mortensen 2022). Currently, most quantum systems can operate only in cryogenic conditions, in temperatures close to absolute zero. Achieving and maintaining these conditions requires large amounts of energy, which contributes to the high expenses (Zewe 2023, Fraunhofer Institute 2023a). Lastly, quantum computing is a very time-consuming process as the research is only progressing slowly, due to the high error rate and low error correction capabilities (Marr 2022). Consequently, all of these previously outlined expenses will occur over an indefinite timeframe and are expected to grow over time.

If quantum computing is to be fully incorporated into daily routines, it needs to become more scalable. While QCs have demonstrated impressive improvements over the performance of classical computers with regard to highly specific tasks, these applications are still limited. Creating QCs that can perform a multitude of tasks will be a major challenge, as the various inputs can cause more noise to enter the environment, thereby creating higher error-correction challenges (Swayne 2023). Another hurdle in making QCs scalable is the difficulty encountered when transferring quantum data to a classical computer (Sassi, Ouaftouh, and Anter 2019). QCs are not designed to replace classical computers, but with efficient data-transferring methods, they can be a powerful combination. Having practical applications such as simple transferring algorithms will be the next step in making quantum computing scalable.

Quantum computing is only just becoming a topic of interest for organizations and policy makers. This low level of awareness has inhibited the growth of quantum computing, as funding from large companies or governments is required to cover the previously outlined high costs (Awan et al. 2022). To date, there are only a handful of cooperations, between large companies and quantum computing researchers, that try to identify real-life applications that could make

QCs more attractive to other particiapnts in the economy (Rietsche et al. 2022). If the overall interest of companies remains low, this might slow down the development and commercialization of quantum computing, hindering its progress and potential. Moreover, the low level of awareness of governments and policymakers might also create an obstacle for quantum computing, as the type of regulations that might be implemented to control the development of QCs remains unknown (Awan et al. 2022). Quantum-fostering environments could speed up the development, but decision-makers who lack complete knowledge of the topic might overlook the full potential.

2.1.6 Future Outlook

How quantum computing will develop over the next decades is a significant question for researchers as well as companies looking to adopt this technology. The current era is described by Capgemini experts as the NISQ era, in which researchers are still working on enabling stable qubits and reliable QCs. Although ability to sovle specific problems on QCs surpasses the ability of classical computers, the error rates are so high that there are few to no real-life applications yet, and the practical applications remain in the realm of theoretical and experimental work (Tourlet et al. 2023).

The next era that follows the NISQ is the broad quantum advantage era, which is expected to arrive within the next 3-10 years (Hellström 2022). During this period, more reliable and capable QCs are expected, thereby allowing the first real-life applications. The companies that are among the early adopters could benefit from the technical advances that are expected to cause a surge in interest among by the competitors trying to catch up (Tourlet et al. 2023).

The most distnat era is full-scale fault tolerance, in which quantum computing is fully integrated into personal and business routines (Tourlet et al. 2023). At this point, quantum computing will be used across all industries, and there will be regular advances on the range of applications. This can only be achieved only when qubits are fully stabilized and noise is successfully filtered out (Wang 2023). Experts have very different opinions on the time frame for the full-scale fault tolerance era, with the most optimistic research indicating that these developments could be achieved in as soon as ten years. Meanwhile, others predict a timeframe of 20-30 years, and cautious researchers argue that this era might never be reached (Dyakonov 2019).

The launch of its 2022 Osprey chip established IBM as the technology leader in quantum computing, and the company has outlined a roadmap from 2019 to 2026 for its quantum computing development (Appendix A). As of 2023, IBM has achieved its goals, and its future outlook is aligned with the above outlined three quantum eras. The roadmap looks is as follows:

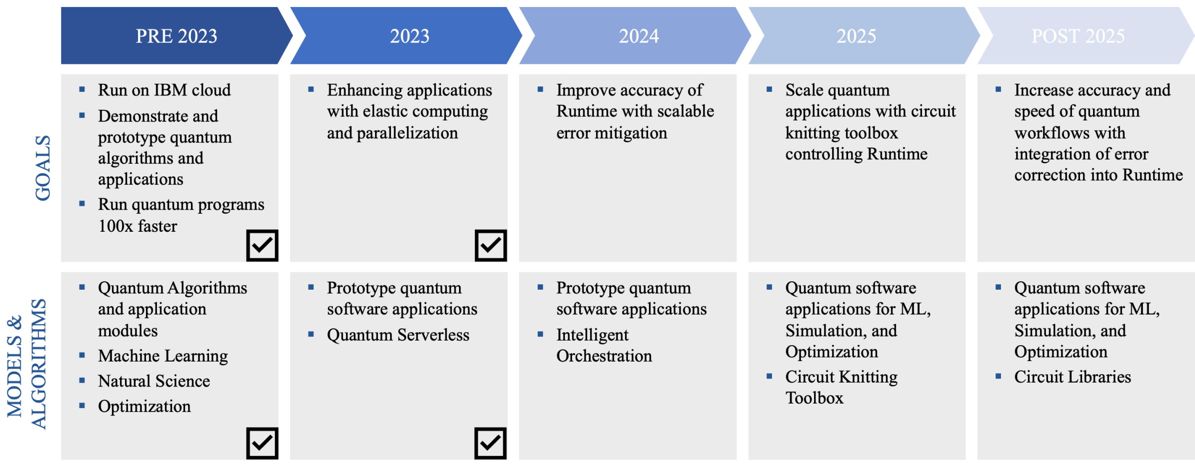

Figure 4: Quantum Roadmap

Replica of the IBM Quantum Roadmap

From this roadmap, it can be seen, that until 2026, the NISQ era is still very much in place with advances from the current 433 qubits to approximately 4,000. Afterward, the focus shifts to "increas[ing] accuracy and speed of quantum workflows with integration of error correction" (IBM 2023b) and actual quantum software applications. This aligns with the previously introduced broad quantum advantage era in which first real-life applications can be seen. Full-scale quantum capacity is not outlined within the overall roadmap, as the timeframe is too uncertain. Overall, the theoretical future outlook represents the plans and goals of the overall industry pioneer.

2.2 Potential Applications of Quantum Computing

Quantum computing can be divided into four potential application cases that are different from classical computing: (1) optimization, in which QCs solve optimization problems on a large scale; (2) quantum simulation, in which computers model physical systems to discover new materials and better understand chemical reactions; (3) artificial quantum intelligence, in which better algorithms could sustainably improve the accuracy and power of machine learning; and (4) quantum cryptography, in which encryption could be revolutionized (Streichfuss and Alexander 2021). However, it is significant that QCs are limited to solving highly specific problems; they are not designed to replace classical computers but, rather, are used alongside them (Fraunhofer Institute 2023a). According to a 2022 study, quantum computing could generate $450 billion to $850 billion in added value by 2050. Potential applications in simulation are estimated to be at the forefront, with a value of up to $330 billion (Alsop 2023).

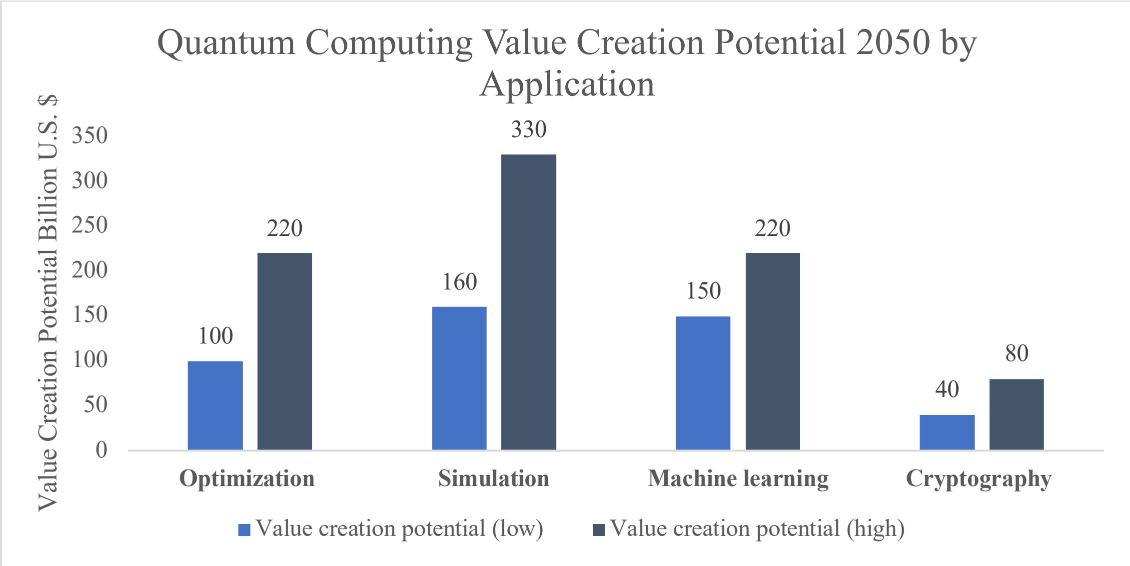

Figure 5: Quantum Computing Value Creation Potential 2050 by Applications

In replica of Alsop 2023

2.2.1 Optimization

Looking to the future, solving complex optimization problems appears to be the earliest applicable quantum computing use case (Streichfuss and Alexander 2021). Defined as the effort to optimize a key metric under specified constraints within a system, optimization occurs in various aspects of life across diverse industries (Vermaas et al. 2022). The process of formulating a mathematical equation and subsequently computing the best among many suitable solutions is not a new concept in either research or practice. However, as the complexity of the optimization problem and the amount of data involved increases, classical computers are reaching their computational limits (Biondi et al. 2021). By exploiting quantum phenomena such as superposition, entanglement, and interference, quantum computing provides a novel approach while improving computational performance in terms of both the speed at which solutions are found, and the quality of the solutions by a factor of approximately 15 (Pinto 2023). Quantum optimization algorithms aim to overcome challenges such as scalability and complexity resulting in faster and more accurate optimization (Pelofske et al. 2023, Lubinski et al. 2023).

Signs that solving optimization problems using quantum technology are becoming more tangible can be seen in recent progresses highlighting the applicability of theory in practical usage. For instance, quantum technology was already applied to a real-world problem at the 2019 WebSummit in Lisbon, where a quantum annealer improved the traffic flow of visitors (Vermaas et al. 2022). The technology was not yet so advanced that a classical computer could not have conducted out the optimization itself. However, there have been regular news articles about the increasing progress of quantum technology since then. For example, the Canadian company D-Wave, renowned for its pioneering advances in quantum computing providing the world's first quantum annealer for commercial use, recently demonstrated a milestone overcoming typical quantum constraints regarding hardware and qubit coherence, therefore approaching quantum advantage (Gururaj 2023; Fadelli 2023; Heng et al. 2022, 120106).

With a promising outlook for the practical application of quantum optimization, several use cases can already be defined that could enable businesses to make better decisions and optimize their operations in real time (Durazzo and Gilkes 2023). While there is currently a shift from an academic path toward a more industry-oriented approach, QCs are increasingly being built according to real-world problems that rely heavily on optimization algorithms to improve efficiency (Angioi 2023). Examples in this area include portfolio optimization, route optimization, airport security, patient scheduling and the optimization of renewable energy networks, creating utility along the entire value chain of organizations (Biondi et al. 2021). In all industries and business sectors, corresponding calculations are made to determine the savings potential. Despite individual variations, the overarching result of applicability is common: Even a 1% improvement in problem-solving in these areas could translate into millions of dollars in annual cost savings for an organization (Biondi et al. 2021). However, research and development investments must be considered as well, and it is still uncertain when these savings will reach their full potential. As mentioned earlier, quantum computing is still in the early stages of development and many of its potential applications, including optimization problems, have yet to be fully explored and realized.

2.2.2 Simulation

After the optimization problems that can be tackled, it appears that simulations with QCs will be the next realistic application (Streichfuss and Alexander 2021). The application is based on quantum chemistry, a branch of chemistry that uses quantum mechanical principles to calculate and predict chemical properties and reactions at the atomic and molecular levels (Vermaas et al. 2022). QCs can accurately simulate complex molecules, which could speed up development processes by a factor of approximately 200 in many industries, ultimately saving time and money (University of Waterloo 2023; Pinto 2023). In general, quantum simulation means that many different materials could be prototyped in a QC and all of their physical parameters tested, rather than physically built, and tested in a laboratory, which is a much more labor-intensive and expensive process. These simulations cover areas such as the behavior of exotic materials at low temperatures, the causes of superconductivity in certain materials, or the study of important chemical reactions to improve their efficiency (Walliman 2021). Running simulations is currently a major challenge for classical computers because each atom interacts with other atoms in a different way (McKinsey 2023). With some techniques, it is already possible to simulate 48 to 61 qubits on a classical computer (University of Chicago 2020). However, this becomes exponentially more difficult the more quantum particles are involved. In theory, a quantum simulator would be exponentially faster at solving the laws of quantum physics (Walliman 2020). Quantum simulation algorithms help to advance computational chemistry by allowing theoretically infinite combinations of materials to be simulated faster and more accurately and their physical properties to be measured in the simulator (Walliman 2020; McKinsey 2023). In this context, the accuracy of these simulations is crucial in areas such as chemical reactions and superconductivity, where even small calculation errors might have significant consequences. In this way, the challenges of today's materials could be overcome, and new technologies invented (Giani and Eldredge 2021).

One industry that could benefit from quantum simulations is the pharmaceutical industry. QCs could become so advanced that they could model molecules in humans, helping to develop new drugs (McKinsey 2023). Other known uses include designing materials for solar panels and batteries, developing aerospace materials and improving catalysts for fertilizer production. Moreover, accurate simulations could help the environment by developing chemical catalysts that reduce CO_2 from the atmosphere (University of Waterloo 2023). In addition, quantum simulations could move the chemical industry toward sustainable alternatives by developing greener plastics and biodegradable materials. This development of new materials is much faster and, therefore, cheaper, making it easier to bring the new materials to market (European Investment Bank 2023). Among all of the potential near-term real-world applications of quantum computing, many are within the scope of the simulation (University of Strathclyde 2022). However, the challenge remains as to when a QC will be good enough to solve these real-world problems using simulations (Walliman 2020).

It is important to note that most potential use cases cannot yet be simulated on a QC and are still better on classical computers. However, QCs have already demonstrated their ability to simulate complex systems such as hydrogen, lithium hydride and water using a trapped-ion system (Walliman 2021). Overall, quantum simulation could be a highly powerful technology with many real-world applications.

2.2.3 Machine Learning

Many industries have already been revolutionized by machine learning, a key area of artificial intelligence (AI). In addition, the combination of concepts from quantum computing and traditional computer science has given rise to new research directions, such as quantum machine learning (Vermaas et al. 2022), whcih could achieve approximately 30% greater accuracy using less data (Pinto 2023). There are four types of combinations of machine learning and quantum computing, distinguishing between the data set, either classical or quantum, and the type of algorithm, either classical or quantum. Classical machine learning is when both are classical. In particular, this can serve as a tool for quantum computing when it comes to quantum error correction (Phillipson 2020). The second approach, quantum-applied machine learning, aims to identify the best ways to integrate machine learning into quantum experiments, either to improve their effectiveness or to find solutions. When both the data and the processing are quantum-based, this is true quantum-generalized machine learning, but few results have been published in this direction and this scenario is too far in the future to be considered for now. The focus of this research is on quantum-enhanced machine learning, where the data is still classical but is run on a QC (Pira and Ferrie 2023). Therefore, the following part is based on quantum-enhanced machine learning, and the other types are left aside for the time being (Phillipson 2020).

With better algorithms, quantum computing could transform and further improve machine learning. These algorithms take advantage of the power of qubits to ensure that training, classification, and pattern recognition in machine learning models is much more efficient (Ezawa 2022). Unlike classical computers, QCs can be used to analyze large amounts of data and multiple variables at once and can even handel faulty data due to their greater storage and processing power (Fraunhofer Institute 2023b). All of these improvements significantly enhance the performance of machine learning models, particularly in terms of speed of development. However, the acceleration of quantum-enhanced machine learning will require several more years, as the conversion of classical data sets to quantum datasets is very time-consuming and has not yet paid off (Ménard et al. 2020).

Scientists have already begun to apply quantum machine learning in certain scenarios, such as formulating new machine learning algorithms and building quantum neural networks that could operate with greater efficiency and speed (Ménard et al. 2020). The combination of quantum computing and AI could affect many areas of daily routines in the future. For example, quantum machine learning could transform the automotive industry and accelerate the introduction of autonomous vehicles, could drive automated trading in the financial industry or improve predictive maintenance across industries. AI systems could be trained quickly by allowing QCs to perform multiple complex calculations with many different variables (Biondi et al. 2021).

2.2.4 Cryptography

As uncertain as the quantum cryptography's practicability seems, the preparations for its final breakthrough are well under way. As the final application of QC, quantum cryptography, refers to the practice of applying quantum mechanics to the encryption and transmission of data to enable secure communication (Comandar et al. 2021; Brassard and Crépeau 2005). The significance of this matter lies in the fact that quantum computing presents a serious threat to the cybersecurity systems on which nearly every business relies on today (McKinsey 2023). Modern online account passwords and secure transactions are based mainly on encryption algorithms such as the Rivest-Shamir-Adleman (RSA), ensuring that data can be shared securely among authorized users while protecting it from unauthorized access (Ménard et al. 2020). The decryption, however, requires immense computational resources to sufficiently solve the complex mathematical challenge that underlies well-structured encryption. Primarily revolving around the manipulation of large prime numbers, known as prime factorization, the core of cryptography is in danger from the computational power of QCs. According to physical scientist, Edward Parker (2023), “One of the most important quantum computing algorithms, known as Shor's algorithm, would allow a large-scale QC to quickly break essentially all of the encryption systems that are currently used to secure internet traffic against interception“. Although some experts believe that it will be at least the very late 2020s before cryptanalytically relevant QCs are developed, meaning the threat is not yet imminent, it is important to prepare for change now (National Academies of Sciences, Engineering, and Medicine 2019; Ménard et al. 2020; Comandar et al. 2021). However, it is not only the threat that needs to be prepared for, but also the opportunity, as quantum computing has the potential to have a significant influence on the cryptographic standards of the future (IBM Security 2021). According to IndustryARC (2023), the global quantum cryptography market is estimated to reach $787.88 million in 2023, increasing at a compound annual growth rate of 36.3% until 2028. An enormous part of this is dedicated to the preparation for the so-called post-quantum cryptography, also known as quantum-proof cryptography, which aims to develop encryption methods executed on classical computers that cannot be broken by algorithms, or calculations, that run on future QCs (Baumgärtner et al. 2022; SSH Academy 2023). Since this type of cryptography does not depend on special hardware, various institutes and even governments are already preparing accordingly for ensure future security (Boutin 2023). The exact type of (post-)quantum cryptography that will dominate the future remains controversial. However, it is highly expected that this issue could have an enormous impact on future society.

3 Methodology

Three types of methods were used in this research to provide well-founded information for the analysis. In accordance with the previously defined objectives, findings from the literature review were used to create industry-specific scenarios. Via interviews, the feasibility of the scenarios was critically evaluated with the help of industry and quantum computing experts. In addition, the scenarios were presented to potential end users to gather their opinions on their affectedness. Finally, the insights from both the expert interviews and the survey were used to create refined and optimized scenarios.

3.1 Scenario

A scenario-based research design was chosen to provide clear visualization and diverse perspectives of the technological context around QCs. This approach is particularly useful in research areas that are characterized by a high degree of uncertainty, which is the case for the innovation discussed (Ramirez et al. 2015, 70-87). By ensuring methodological flexibility, the initial findings can be further enriched and improved through the analysis. Two targets were addressed: On the one hand experts in the field of quantum computing and on the other hand survey participants, who assumed the role of potential end users. The creation of technology-specific scenarios stimulated a multifaceted discussion within the expert interviews. The transfer of quantum applications into everyday contexts served as a visual aid for the end users to better understand the implications, which allowed them to provide insightful feedback regarding their perceptions.

Industry Selection

The industries selected for the scenarios were healthcare, finance, mobility, energy, and cybersecurity. These were selected with regard to their economic potential. A McKinsey article exploring the quantum computing ecosystem concluded that the combined potential value of these industries is more than $700 billion (Biondi et al. 2021), therefore, exploring these industries from a business perspective is particularly interesting. Furthermore, as the scenarios were formulated from the consumer perspective, it was crucial to select industries that were close to the end users. The selected industries are constant components of most people's lives, offer many use cases, and, therefore, allow for interesting and extensive exploration. Lastly, the selected sectors corresponded well with the areas of interest of the individual team members who were writing the specific deep dives.

Scenario Design

The scenarios were developed through a process that combines literature review and critical thinking within the context of quantum computing advancements. The developed use cases span the timeframe of a single day in which various industry-related events occur. Each of the above-mentioned industries was analyzed in depth, and the key technologies were identified. Furthermore, these were transferred to everyday life in a fictitious and provocative manner for the purpose of an intensive exchange.

3.2 Survey

A survey methodology was selected for its effectiveness in capturing a large amount of quantitative data regarding perceptions and attitudes from a broad and diverse demographic. For this specific research, the method enabled the envisioned scenarios to be distributed and opinions to be obtained. More precisely, this approach allowed to gather valuable insights into how various individuals may respond to the integration of quantum-empowered applications in their daily lives. The survey aimed to understand people's status quo of comparable events as well as their emotions and willingness to adopt to the event presented.

Survey Design

The survey was built with Microsoft Forms, which is a web-based application from Microsoft that is used to create surveys, quizzes, and polls (Microsoft Forms 2023). Respondents were informed about the purpose of the survey and the use of their responses for research purposes. The survey methodology took a practical approach, presenting two to three everyday scenarios for each industry. Each scenario was framed within commonplace situations, followed by three specific questions that were designed to explore individuals' emotions, the current status of adoption, and the willingness to adapt in response to the events presented. The final survey was designed as a structured questionnaire consisting of multiple-choice and Likert-scale questions. Before the designed study was distributed, a pilot study was created to test the survey to ensure clarity and improve the relevance of questions.

Data Collection and Analysis

The survey was administered online through a secure survey platform that provided a link for forwarding. Participants were recruited through various channels, most successfully via online platforms, social media, professional networks, and various types of messengers. The questionnaire was made available to a diverse group of respondents, ensuring a broad reach across many demographic segments. Data collected from the survey was analyzed using percentages of responses to identify patterns, trends, and insights. The Likert-scale responses were quantified and relationships between variables were explored.

Participants

With a high engagement rate the survey was closed at 300 participants. This sample size was statistically significant for the research and allowed the data to be analyzed thoroughly. While 81% of respondents were from Germany, 19 different nationalities were included in the sample through inclusive recruitment efforts. Despite the resulting predominance of German participants, the diversity within the dataset was enriched. As for gender distribution, the sample nearly achieved gender parity, with 44% male and 55% female participants. The age distribution provides insights that reflect younger and middle-aged adult populations, representing Generations Y and Z. Although limited, valuable perspectives were also received from the senior age groups, representing Generation X and baby boomers (Iberdrola 2023). One important note in this context ist that the survey relied on self-reporting from respondents, and their responses may have been influenced by their individual perspectives and biases.

3.3 Expert Interviews

To substantiate the scenarios based on theoretical findings, empirical studies were conducted in the form of expert interviews. Due to the growing importance of the topic, this type of data collection was considered particularly appropriate. The expert interview is a survey method that originated in social science research and can be used to generate qualitative data. The experts' statements were collected through a non-standardized interview with a guideline provided during the interview to ensure that the research focus of the thesis was addressed.

Conception of the Interview Guide

The interview guide forms the structural basis of expert interviews, with questions based on the guide aiming to be clear and precise but largely open-ended. Structurally, the guide can be divided into seven sections. General questions about the business and the position of the experts were asked in the first section, indicating the interviewees' legitimacy as experts. The second section focused on gaining a general picture of the topic of quantum computing and the third through seventh sections concentrated on scenario- and technology-specific questions about the respective industries. These scenarios were often only asked for their content and not read out in full, so as not to interrupt the flow of speech. Due to time constraints and the experts' various levels of competence, not all sectors were covered in every interview.

Selection of Experts

The experts were chosen based on their professional background, knowledge, and experience in fields related to quantum computing, technology, and the industries mentioned above. Each interviewee had participated in their industry for at least three years, which is considered to be a benchmark for professionalism (Zippia 2022). The aim was to ensure diversity in perspectives and experiences to provide a well-rounded and balanced understanding of quantum computing and its potential impact on the identified industries. For the analysis, a total of 30 experts were interviewed, with a minimum of three industry-specific professionals consulted for each of the sectors. The remainder of the experts were generalists in the field of quantum computing. For confidentiality reasons, the names of the interviewees, their companies, and other relevant data are partially anonymized. A list of experts is provided in Appendix E.

Data Collection and Analysis

The interviews were conducted over a two month period, during October and November 2023. This timeframe is beneficial as it not only allows to capture opinions and insights from experts during a specific and relevant period but it also makes it easier to compare these opinions. Depending on availability and preference, interviews were conducted face-to-face, via video conferencing using Google Meet or Microsoft Teams, or by telephone. The meetings were recorded on a mobile device and then transcribed. For the latter step, a simple transcription tool, Transcriptor, was used, in which the conversations were transcribed verbatim and the focus was on the content. Subsequently, all of the interviews that were not conducted in English were translated verbatim with the help of DeepL, thus ensuring a standardised language for all data.

To maintain confidentiality and adhere to ethical research standards, personal or sensitive information was removed from the transcripts. To allow for extraction of the data later, the first step was to develop categories based on the theoretical principles and the structure of the interview guide. The interview transcripts were then reviewed, and relevant information was allocated to each industr. Lastly, regarding the citation format of the expert interviews, a consistent approach was established. At the end of each sentence where an expert is referenced, the interview is noted as Interview Transcript (I.T.) followed by the number of the interview. In cases where an expert has agreed to be named and is not anonymous, their name may be mentioned directly in the text. Furthermore, if multiple experts share a similar opinion, readers can refer to Appendix F for all interview transcripts.

4 Industry Analysis: Cybersecurity

This section dives into the cybersecurity industry to analyze the impact of quantum computing on this area. To ensure the accuracy and relevance of this analysis, expert interviews were conducted, providing critique and feedback of the pre-defined scenarios. Additionally, a survey explored how end users might adapt to new technologies, assessing their readiness for upcoming technological developments in the cybersecurity space.

4.1.1 General Industry Overview

At the brink of a technological revolution, the cybersecurity landscape is evolving quickly. The industry aims at protecting networks, data, and information systems from any damage or unauthorized access. The backbone of cybersecurity, called modern cryptography, involves algorithms and cryptographic methods to ensure secure data storage and transmission. Modern cryptography today, is based on two primary types of encryption algorithms that run on classical computers: symmetric and asymmetric encryption (IBM 2018). Symmetric encryption uses a single key for both the encryption and decryption processes, making it an efficient and suitable choice for larger volumes of data transfers. Conversely, asymmetric encryption uses a pair of keys to secure data. Specifically, it involves a public key, which is accessible in cyberspace, and a private key, that is known only to a specific user, such as a bank or financial services like PayPal. This method offers enhanced security for data transmission, as data encrypted with the public key can only be decrypted only with the corresponding private key. Thus, this kind of encryption is widely employed to secure sensitive information, including credit card details (Herman 2018, 96–113).

The aformentioned encryption systems rely on algorithms which are based on “hard” mathematical problems. These mathematical functions are easy to perform but difficult to reverse (IBM 2018). Therefore, the only way for a cyberhacker to access sensitive bank information would by factoring the public key back to the correct private key, a task that would require too much computational power for a classic computer to work (Herman 2018, 96–113). However, the development of quantum computing poses a significant threat. QCs, using quantum algorithms, are able to solve mathematical problems significantly faster than classical computers using classic algorithms, threatening to potentially break the current encryptions methods (IBM 2018). A prime example of a quantum algorithm is Shor's algorithm, which can factor large integers exponentially faster than the best-known algorithms running on a classical computer. The most vulnerable target to break, is the RSA algorithm as it is widely used for securing bank transfers, credit card transactions, e-mail communications, and online shopping (Herman 2018, 96–113). To be exact, breaking a 2048-bit RSA encryption would take between 10,000 and 100,000 years with a classic computer system, whereas a QC could break this key in fewer than eight hours once a machine with enough computational power becomes available (Heaven et al. 2019). This means that once QCs with sufficient processing power are developed, they could theoretically break the majority of encryption methods used. In fact, a recent study by Forrester suggests that QCs could breach all existing cryptographic systems within the next 5-30 years (Wong and Gilkes 2023). As a result, organizations and researchers worldwide, are actively working on quantum-resistant solutions to ensure data security in a post-quantum world. If these advancements are properly implemented and managed, they have the potential to elevate current safety standards to an unprecedented level (IBM 2018).

4.1.2 Scenario Analysis

The introduction of QCs in the cybersecurity space presents a so-called "double-edged" sword (IBM 2018). QCs are a serious threat due to their potential to disable current encryption methods, however with this technological advancements new opportunities might arise to improve current cybersecurity defense mechanisms. The following discussion outlines potential future scenarios in quantum computing, based on current literature research. The potential challenges and opportunities presented by QCs will be explored, and insights from industry experts and end users enrich this exploration, offering a comprehensive overview of the evolving landscape.

The scenarios created focus on two key quantum-related technologies: post-quantum algorithms implemented on existing infrastructure as illustrated in scenario 'bank account exploited' (Appendix B: Scenario 3), and quantum-secure communication in the context of national security threats, as depicted in scenario 'national security channels compromised' (Appendix B: Scenario 13). Given the constraints of length for this research paper, the focus is intentionally narrowed to an in-depth exploration of only two topics, ensuring a detailed and thorough analysis within the established scope.

Post-Quantum Cryptography

As discussed above, the need for quantum-resistant cybersecurity measures is becoming increasingly urgent. In response, ongoing research is focused on developing encryption methods that are resistant to quantum attacks. Post-quantum cryptography is centered around developing algorithms that can run on classical computers and that do not rely on “hard” mathematical problems (Kumar and Pattnaik 2020). Instead, these algorithms are based on different mathematical foundations that are currently considered difficult for QCs to understand. The goal of post-quantum cryptography is to develop secure communication methods that are unhackable and that can be implemented in today’s technology (Kumar and Pattnaik 2020). Consequently, organizations, especially financial institutions collecting sensible data, are recommended to proactively prepare for the quantum computing era in order to minimize their vulnerability to potential quantum attacks (Barker, Polk, and Soupaya 2021).

Slow implementation of quantum-resistant solutions could lead to a significant security gap and cybercriminals could exploit this vulnerability with the help of quantum computing techniques by gaining unauthorized access to sensitive data. The transition to a post-quantum secure infrastructure is not only a technological upgrade, but also a necessary evolution to protect against emerging quantum threats, as highlighted in the literature (Joseph et al. 2022, 237-243).

Even though quantum computing is a futuristic technology, there is already a threat that exists in our present called 'Harvest Now, Decrypt Later' (Guarrera and Khan, 2023). This cybercrime strategy is taking place today, where attackers collect encrypted data with the intention of decrypting it years later using quantum computing. Current encryption standards may not be resistant to quantum computing, allowing cybercriminals to wait until a large-scale QC becomes available to decrypt the data. This exposes confidential information and grants unauthorized access to systems, such as bank account information as login data can be store for years, once it is intercepted, depicted in Figure 7. (Guarrera and Khan, 2023).

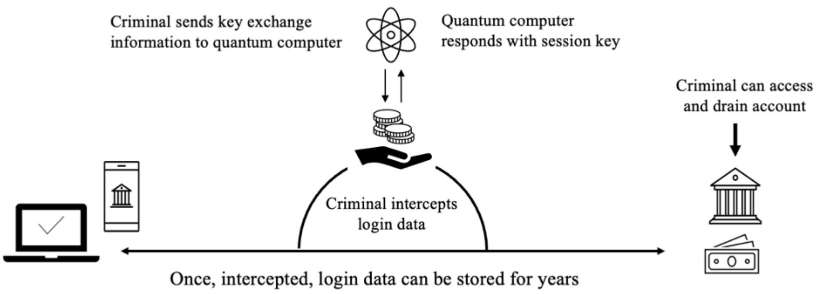

Figure 6: Harvest Now, Decrypt Later

In Replica of Guarrera and Khan 2023

Based on these findings, the first scenario involves the depletion of an individual's bank account because the financial institution has been slow to adapt quantum-resistant solutions. This scenario is predicated on the premise that quantum computing introduces significant cybersecurity challenges for current encryption methods, particularly in the banking sector, as explained above.

Many of the interviewed experts agreed that the slow implementation of post-quantum algorithms could realistically result in compromised banking accounts and vulnerabilities in banking systems. Many experts acknowledged the rapid advancements in quantum computing and their potential impact on current encryption methods (I.T. 2 and I.T. 17). Zwiehoff also agreed with the feasibility of this scenario, mentioning concerns about quantum computing's ability to crack current encryption technologies, which is vital for online banking or browsing (I.T. 13). However, some experts, such as Hellstern as well as Rodriguez Rosario, view the quantum leap more optimistically, seeing it as an opportunity for improvement. Both predicted that banks may struggle to adapt to this challenge initially, yet mature post-quantum algorithms will eventually offer enhanced security and offer a foolproof protection method (I.T. 6 and I.T. 9). Another expert disagreed with the scenario and believes that with the development of post-quantum algorithms and enhanced security features, such scenarios will not become a reality (I.T. 11). Further, continuous engagement with the subject matter was emphasized by Hartmann and another expert. They explained that these scenarios will not materialize over night. Instead, it is a process in which defense mechanisms should ideally develop at a pace equal to, or faster than the changes. This approach fosters an environment ready to accommodate these changes (I.T. 23 and I.T. 24). To adress this, such developments are already underway. Krauser, shared his companies involvement in designing Europe's first chip with post-quantum cryptographic capabilities. This innovation, a joint effort between Airbus Defence and Space and the European Commission, places them at the forefront of post-quantum cryptography (I.T. 30). Furthermore an expert emphasized an intriguing point: While it is crucial for banks to understand the quantum threat, they argued that major technology infrastructure providers, such as IBM or Microsoft, should shoulder the responsibility of implementing quantum-safe solutions (I.T. 17). This is largely because banks depend heavily on the infrastructure that these technology giants provide. Therefore, these significant players in the tech industry are the ones who should guarantee a cyber-secure future (I.T. 17).

One expert highlighted an particularly urgent concern regarding the “Harvest Now, Decrypt Later” strategy (I.T. 2). This threat is a particular high risk for data that needs to remain confidential over a long period such as banking information as depicted in the scenario. However, another expert suggested that if hackers are already capable of stealing the encrypted data today, then existing systems are vulnerable even before the widespread adoption of quantum computing (I.T. 26). This highlights the immediate need to strengthen cybersecurity measures while also preparing for future quantum threats. In terms of timeframe, Pinto stated that the quantum threat signifies the end-game for cybersecurity with the question becoming not “if” but “when”. He estimated that 2030 will be the earliest date on which encryption will fail (I.T. 29). Other experts also agreed, suggesting a similar timeframe of five to maximum ten years when this threat to current encryption methods will be present.

The survey results revealed a significant level of concern regarding cybersecurity issues among end users. Almost every respondent expressed worry about cybersecurity risks, and 87% indicated their willingness to switch to a more secure bank. This suggests a potential for customer loss in the banking sector if institutions fail to update their security measures in line with emerging quantum threats and it underscores the importance for banks to remain informed about technological advancements to retain their customer base. The survey results reflect experts’ concerns about the increasing frequency and sophistication of cyberattacks. Even individuals with limited technical knowledge fear the potential compromise of their bank accounts, regardless of the technology involved. This fear suggests a wider awareness of cybersecurity risks among the general public. Overall, these survey results indicate a growing public awareness and concern about the implications of quantum computing on personal financial security. They also highlight a critical need for banks and technology providers to address these concerns by advancing and implementing robust post-quantum cryptographic solutions (Appendix C).

Taking into consideration the expert opinions and survey results, it can be concluded that the scenario is realistic and could potentially become a real-world challenge for financial institutions. These insights collectively underscore the cirital measures to prepare for a post-quantum age. However, to make the scenario even more realistic, an alternative one could be created in which cybercriminals have no chance of ever gaining unauthorized access to data as organizations have adapted to quantum resistance in time and communication channels are now more secure than ever. Finally, it becomes evident that quantum computing as it relates to cybersecurity poses not only a threat to financial institutions, but also is a question of safety for all other sectors in which data must be secured, such as patient health data, autonomous driving, and power grids.

During the interviews, experts offered a range of recommendations for organizations, particularly those in the financial sector, to navigate the emerging threats in the quantum era (Appendix F). These suggestions have been synthesized into four main findings, providing a clear roadmap for organizations to follow:

1. Invest in Skilled Personnel: This strategy could involve upskilling existing cybersecurity experts or recruiting new staff proficient in quantum technologies and their implications for cybersecurity. These specialists will be critical in navigating the cybersecurity recommendations and keeping organizations ahead in adopting quantum-resilient practices (I.T. 17 and I.T. 22).
2. Review Existing Cybersecurity Frameworks: A thorough review of current cybersecurity measures should be conducted to potential integration points for post-

quantum solutions. This forward-looking evaluation is key to grasping any vulnerability to quantum computing risks and to strategize the incorporation of quantum-resistant measures (I.T. 22).

3. Cultivate a Learning Culture: A culture of continuous learning regarding the latest in quantum-resistant cryptography should be embraced. As developments in the field continue, an organization's understanding and practices must also advance, applying cutting-edge cryptographic defenses. This knowledge enables nimble responses to the rapidly changing cybersecurity landscape (I.T. 5 and I.T. 24).
4. Build Expert Partnerships: Collaborations should be launched with leaders in the field of encryption to explore and, when ready, implement quantum-secure solutions. Forming alliances with those at the forefront of encryption technologies can provide early insight into new protective tools and help ensure that an organization's cybersecurity infrastructure matures alongside these innovations (I.T. 2 and I.T. 24).

Overall, the experts' insights highlight a critical need for organizations to proactively prepare for the quantum computing era. This entails cultivating a deep understanding of the evolving security landscape, embracing post-quantum cryptography, and planning strategically to capitalize on opportunities while mitigating the risks posed by advancements in quantum computing. The increasing emphasis on quantum security in the finance sector reflects a broader trend across various industries.

Cyberwars and Quantum Communication Networks

Another cybersecurity threat is the risk of cyberwars. The industry has seen a steep increase in cyberattacks in recent years; in fact, cyberattack on the Internet of Things alone are expected to double by 2025 (McLean 2023). This escalation is due to the digitalization of almost every aspect of modern life which has expanded the attack surface for cybercriminals. Especially during the COVID-19 pandemic, cybercriminals were able to take advantage of misaligned networks, which has led to an alarming 600% increase in cybercrime since then (McLean 2023). Additionally, geopolitical tensions have increasingly manifested in the cyber domain, with nations using cyberattacks as a tool for espionage, sabotage, and influence (SentinelOne 2023). It has become essential to secure communication channels and create a safe environment for current cybersecurity infrastructure. Although quantum computing holds immense potential to transform the global cyber infrastructure, if it ends up in the wrong hands, it could compromise existing defenses, leaving national security systems vulnerable (Grobman 2020).

While the technology presented in the first scneario is centered on advancing computational capabilities through innovative post-quantum software algorithms, the second technology focuses on hardware and network structures, known as quantum communication. One of its most promising and well-known applications is QKD (Herman and Friedson 2018). With the help of quantum physics, the QKD technology ensures an un-hackable communication channel as information travels between two points. One of the main advantages of QKD is its inherent security feature: Any unauthorized attempt to access the communication is immediately detectable by the involved parties, cancelling out the risk of eavesdropping. In order words, an attempt to measure a quantum system actually disrupts it (Gillies 2022). However, QKD has its own physical challenges, as it only allows to creation of a key ony for the sender and recipient. To transmit the actual message data, a separate channel is needed, which is limited by the distance the network can cover. Thus far, physicists have been restricted to a distance of 200km before light absorption made the process of transmitting quantum information, via individual photons, impossible (O’Neill et al. 2018). A quantum repeater that would function as an amplifier could enhance this capability. However, it has not been invented yet (Herman and Friedson 2018). China has been at the forefront of applying quantum communication technology, and with the help of a satellite, it has built a quantum communication network construction that covers the distance 2,000 km between Beijing and Shanghai. Despite the current challenges faced by QKD, the field is experiencing rapid growth and innovation. In the short term, quantum channels can offer secure communication only over limited distances, but further experiments with satellite developments could significantly extend the reach of QKD, enabling a global network for secure data transmission. This evolution could not only enhance the scope of QKD but also pave the way for a broader application of quantum technologies in communication networks (O'Neill et al. 2018).

Given the increase in cyberwars and the emerging threats to existing communication channels as well as new technological opportunities such as QKD, a second scenario was formulated. In the scenario, the television news report states that a nation was able to gain access to sensitive foreign government information and is using it for blackmailing. This scenario takes place in a setting in which the implications of cybersecurity reach beyond safeguarding individual or corporate data and become crucial to protecting national communication channels.

Exploring the intersection of quantum computing and national cybersecurity reveals a complex and multifaceted picture of the future. Multiple experts agreed with the literature and suggested that cyberwars have a geopolitical perspective, as there is potential for a technological divide among nations due to disparities in quantum computing advancements (Appendix F). This could have significant implications in the military and national security realms. Similarly, Schulte recognized the daily threats posed by digitalization, including cybercrime, and the considerable costs that institutions bear to secure their networks. He said he considers the concept of a cyberwar to potentially already be in progress through various online manipulations and digital aggressions. He drew parallels with the transformative impact of the atomic bomb, suggesting that quantum computing might be the next major breakthrough with its own set of cyberwar implications (I.T. 10).

One expert agreeed with the theories presented and accentuated the importance of reaching quantum supremacy as a country (I.T. 2). Quantum Supremacy refers to the point at which a QC can outperform a classical computer on certain tasks (as introduced in Section 2.1.4). On a national level, the race for quantum supremacy is a matter of strategic advantage, especially in defense and cybersecurity, as the first country to achieve functional QCs could claim a major technological edge in various fields (I.T. 2 and I.T. 10). This achievement is also referred to as Q-Day and equalized by some researchers as the potential quantum Pearl Harbor. According to one expert, only a Chinese team and the US firm, Google, claimed this achievement, to date. However, the expert explained, this was specific to a particular type of problem and does not imply overall supremacy as classical computing continues to match quantum achievements in all areas of quantum computing. Despite these debates, a hybrid approach in quantum computing is demonstrating promising results, suggesting that clear superiority in certain applications could be seen within two to three years (I.T. 2). In contrast to these opinions, another expert actually questioned the ongoing conversation on quantum supremacy and its implications for national security. They noted that the fear in the market, due to the uncertainty about quantum computing and its ability to break encryption, is often fueled by consulting firms. They further observed that these firms quickly point to emerging European Union security requirements, promoting post-quantum security measures as a reason to sell their consulting services (I.T. 5). Moreover, they considered this to be just another technological advancement in time, as there also was a time when a historical encryption was once considered secure, but it can be easily decrypted with todays technological advances. Consequently, quantum computing, after all, “might just be a faster computer, but that is it” (I.T. 5).

The second scenario, acknowledged as a potential threat by numerous researchers, also opened the door to the development of innovative safeguard technologies. Zwiehoff emphasized the innovation of quantum communication as a pivotal counter-technology. This innovation aims to secure communications of a country's sensitive information (I.T. 13). Echoing Zwiehoff's concerns, another expert highlighted the significance of developing quantum-resistant algorithms and QKD (I.T. 2). These technologies are essential steps in adapting to the new quantum computing landscape, ensuring that communications remain secure even in the face of quantum advancements. However, to achieve quantum secure communication, the challenge lies in creating a completely new infrastructure - the quantum internet (I.T. 9). The quantum internet represents a shift in how one thinks about and implements secure communication. It goes beyond the limitations of classical computing to provide a more secure and quantum-resistant framework. Drösken, addressing the innovation of the Quantum Internet, voiced her skepticism regarding the outlined scenario. She said that she firmly believes that the advent of the quantum internet will revolutionize the cybersecurity landscape, making it redundant. In her view, the implementation of quantum internet technology will render cyberattacks completely obsolete, fundamentally altering the nature of cybersecurity challenges and making them a non-issue in this new environment (I.T. 18). Apart from the Quantum Internet, another challenge that was mentioned multiple times by the experts is the crucial development of quantum hardware development for achieving quantum supremacy. The invention of fully developed hardware will determine what theories will eventually become real life threats. The opinions differed about when the hardware should be fully developed, but various experts said they expect it to be within five to ten years or even farther in the future (Appendix F).

The survey showed that a significant 78% of end users expressed concern about the potential vulnerabilities of national security systems and sensitive government information to cyberattacks by foreign entities. This highlights the common fear that the era of cyber warfare is already here. It represents an increasing awareness and anxiety among the general public regarding the security of national infrastructures and confidential information in the digital era. Additionally, 90% of respondents said they believe cybersecurity will have a significant impact on their lives, which suggests that end users recognized the evolving nature of cyber threats. The considerable concern about national security and the expected personal impact of cyberwars imply that the public is keenly aware of, and worried about, the evolving cyber threat landscape (Appendix C).

Considering the insights from experts and the findings from the survey, it is clear that the scenario of national communication channels being compromised due to cyberwars is not only realistic but also poses a potential risk of being exploited for military advantages. However, there is a silver lining with the technological invention of QKD. This technology offers a significant leap in securing communications, potentially ensuring that sensitive data remains uncompromised. To improve the scenario, it could be considered that nations, capable of developing and adopting QKD in the future, will eliminate the threat to data security. This would make any cybersecurity concern irrelevant and render the scenario obsolete.

Conclusion

In conclusion, the consensus among industry experts aligned with the one highlighted in the literature and points to the significant influence of quantum computing in various sectors. Quantum computing's ability to eventually disrupt traditional encryption methods calls for a proactive shift towards quantum-resistant algorithms, a change that is particularly crucial in sectors such as banking. Moreover, the emergence of quantum-enabled cyber warfare could bring about a fundamental transformation on how national security needs to be managed and protected. While the challenges presented may seem daunting, a closer examination reveals a balanced scenario as these technological advancements will happen overnight. Discussions with industry experts confirmed that the concerns noted in the literature are indeed valid. However, these challenges can be counterbalanced by the transformative opportunities quantum computing offers. These advancements could revolutionize secure communication, fostering a safer and more resilient digital environment amidst evolving threats.

4.1.3 Additional Findings and Future Outlook

Who wins the race in computational power was a very important future oriented question experts were eger to discuss. With major players such as IBM and Google leading the pack in the United States it appears to be a competitive field. Other technology giants such as Microsoft, and Intel are also making significant strides in quantum computing. On a national level, both the United States and China are making substantial investments for development, however the US remains the leading contender with setting up startups, winning patents and higher investment amounts (Herman 2018, 96–113). Meanwhile, the EU is not far behind and also appears to be at the forefront with public investments, with these efforts explained by an expert in this sections (Candelon et al. 2022). The situation suggests an impending technological arms race, as noted by Hackländer. The emphasis is on not only on reaching quantum supremacy but also on simultaneously advancing cybersecurity measures to keep pace with the evolving capabilities of hackers. Hackländer stressed the need for investment in both quantum technology and cybersecurity, and mentioned the availability of EU funding which was also found in the literature. However, he highlighted a knowledge gap in Germany, which prevents full utilization of these resources (I.T. 20). This is attributed to unfamiliarity with the application process and reluctance to tackle highly technological issues. Hard facts, such as Shor's algorithm beating any classical algorithm, have fostered interest in governmental funding and overall research (I.T. 2). Hartmann noted that Germany only recently began investing in quantum computing, with various federal states providing funding and starting programs two years ago (2020). By contrast, Google already acquired a university research group in 2014, meaning Germany is approximately seven years behind (I.T. 23). Hartmann attributed this lag to German skepticism about quantum computing's feasibility. He acknowledged the difficulties faced by startups in this field and predicted that many may not commercialize soon. In his opinion, the race for quantum supremacy is still open, as hardware technology is yet to be fully invented. Thus, even though literature predicts otherwise, it is too early to determine a clear leader among nations or companies (I.T. 23). This suggests that Europe can still remain competitive. However, since computing was never a major industry in Germany, there is a lot to catch up on (Appendix F). Krauser expressed optimism about this matter, citing the European Quantum Communication Infrastructure (EuroQCI) initiative (I.T. 28). The EuroQCI goal is to protect Europe’s data infrastructure and encryption methods by developing a secure quantum communication network that spans over the entire EU. This development could mark a significant milestone in Europe's path toward quantum-secured communications and it might secure industry specific infrastructures against cyber threats, including healthcare facilities, traffic control, financial institutions and power grids (European Comission 2023). According to the experts, the first operational system is anticipated to be available within this decade (I.T. 28).

In conclusion, the race toward quantum supremacy is not just a competition for computational power, it is a strategic necessity that requires a global shift in encryption and cybersecurity standards. Quantum computing is likely to undergo significant changes, providing strategic benefits and possibly becoming equivalent to modern strategic weapons.

5 Ethics

As analyzed throughout this paper, QCs hold substantial potential to revolutionize various industries. However, this technology also poses significant ethical considerations. Different experts highlighted that these concerns can be viewed parallel to the ethical discussions about AI (Appendix F).

Major ethical concerns require careful evaluation. First, data privacy and security issues are paramount. The potential of QCs to break existing encryption methods introduces a significant risk to data privacy (Bucholz and Ammanath 2022). This poses ethical questions about the right to privacy, the responsibility of institutions to safeguard sensitive information, and the potential misuse of power if data privacy is violated (Appendix E).

Secondly, fair access and resource allocation are crucial concerns, as unequal access and lack of inclusion could lead to the misuse of power (I.T. 16). The resources required for this technology are accessible only to a few nations. Quantum technologies could allow nations and organizations to gain strategic advantages in military and economic aspects, raising ethical concerns. There is a moral obligation to ensure that the benefits are distributed fairly and do not exclusively serve the interests of a few. Moreover, another expert raised concerns about potential power struggles resulting from uneven investment. To prevent the misuse of this technology, the initiation of a global dialogue is crucial in forming international agreements.

In conclusion, while quantum computing represents a technological leap forward, it is important to navigate its ethical landscape with care. Balancing innovation with responsibility, ensuring equitable access, protecting privacy and security, and fostering international cooperation are crucial steps toward harnessing the potential of quantum computing for the greater good.

6 Conclusion

The following chapter concludes the presentation of the overall findings on possible future application scenarios of quantum computing in different industries. The findings are presented in the light of applicable limitations from which further research recommendations are derived.

6.1 Summary

This master's thesis analyzes what a day in the future under full-capacity quantum computing could look like. The analysis focused on five industries: healthcare, finance, mobility, energy, and cybersecurity. For each industry, representative sources were studied to identify crucial potential applications that could emerge under the influence of quantum computing. In summary, the current state of the art of the literature is more confident than the opinion of industry experts. Most of the pre-developed scenarios were declared realistic during the interviews. However, some scopes required adjustment and others were judged to be unrealistic. These use cases are mainly expected to increase the efficiency of the business activities by shortening the development timeline, enabling faster time to market and reducing costs, and increasing the quality of both existing and new applications. A survey producing end user perspectives was an additional component of the scenario evaluation, and survey respondents were positive about the potential of experiencing this new technology in their daily lives. Only some scenarios with high personal impact caused for scepticism.

Within the healthcare sector, the use of quantum computing for personalized medicine and advanced diagnostics, including precise disease detection and targeted treatment strategies, is widely considered to be realistic. However, the concept of fully autonomous or AI-based patient care without human supervision is generally considered less realistic, with a preference for hybrid models in which quantum computing assists human practitioners.

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The scenarios developed for the financial industry were generally confirmed by the experts. Improvements in Monte Carlo simulation and fraud detection are considered very realistic. Additionally many experts see an increase in portfolio optimization to be likely, although opinions here are more varied.

Among the experts for mobility all had a sound understanding of the presented scenarios. The scenarios for route optimization and autonomous driving are seen as realistic, but the drone taxi scenario was declared unrealistic, with delivery drones being considered a more feasible alternative.

The energy scenarios were partly well received by the experts. Overall, the optimization of the power grid using quantum optimization algorithms and the potential of quantum simulations to develop materials for more efficient batteries are realistic. However, increasing the efficiency of solar panels using quantum simulation was believed to be rather unrealistic, while a general approach to climate change using quantum computing considered to be more likely.

Lastly, the impact of quantum computing on the current state of cybersecurity was acknowledged to be a dual-edged sword by industry experts The scenarios created based on the literature are considered very realistic, especially since it has been proved that QCs can break current encryption methods. However, new opportunities for improved security levels will also emerge. While the initial threats of quantum computing may seem overwhelming, a closer look suggests a more balanced situation, as these technological advancements will not happen over night but rather unfold gradually over time.

Given the current technological state of NISQ due to bottlenecks such as qubit decoherence, most of the mentioned use cases will not be fully or even partially implementable in the short term. Ultimately, the realization of the industry use cases depends on the development and future roadmap of the QC and the point at which full-scale fault tolerance is achieved.

6.2 Limitations and Future Research

Limitations

The contribution of this thesis consists of a systematic, realistic, and comprehensive assessment of the various industrial use cases through a literature review, extensive expert interviews, and survey participants. However, there are many limitations that need to be considered.

The selection of industries is where the limitation of this work begins, there is space only for five selected industries, one industry per group member. However, quantum computing is predicted to have a significant potential impact on many industries (Biondi et al. 2021), which had to be omitted here regardless of their importance. Moreover, the comparability of the selected industries presents a limitation. Not only did the literature search within the selected industries reveal that the various fields of investigation tend to have a different number of suitable and reliable sources, the sources found are not always comparable in quality and elaboration. Furthermore, the different applications of quantum computing in the various industries led to analysis results that are not entirely comparable.

Continuing the aspect of literature research with fundamental reference to the topic of quantum computing, the following limitations must be mentioned. Due to the novelty and futuristic nature of the chosen topic, it is important to note that not only books and academic articles are used as literature but also business press releases based on expert opinions and best practices. It is also worth mentioning the battle for a pioneering position in research and execution, known as the quantum race, whereby many companies choose not to disclose specific information about their processes, such as the particular algorithms or hardware they use. In addition, potentially relevant literature was sometimes unavailable due to lack of access to databases. For example, the university's access to Springer is limited to articles and books with the keywords:

“business”, “economics”, “management”, and similar words. However, as quantum computing is a technology-related topic and the keywords are related accordingly, access there was limited.

One of the main problems is that the timeframe for the potential use cases cannot be defined with certainty, making it difficult to predict exactly when the futuristic day might become reality. Most possible applications are based on future predictions and research progress that may be realized at different speeds, a time span that can be determined only based on expert opinions, literature, and best practices. Moreover, spontaneous technological breakthroughs cannot be predicted, and it should be recognized that the field of quantum computing is advancing rapidly and in unpredictable ways (Ménard et al. 2020).

Apart from the timeframe, another clear limitation is that only theoretical scenarios are considered, which are based on present research findings and potential future achievements. This is a general limitation of using a scenario-based approach; the scenarios are highly uncertain as they are subject to change with the actual development of quantum computing. A certain degree of fictionality, weakening the degree of realism, must be noted accordingly. There is no guarantee that the predictions will play a role in the short or medium term or that they will become reality at all, because they may be overtaken by other technologies. Furthermore, QCs that are powerful enough and have a sufficient number of qubits to make these use cases a reality have not yet been developed. Finally, the scenarios and their potential also depend on external factors such as investment in technology and research or societal hurdles such as those seen during the COVID-19 pandemic.

Furthermore, it should be mentioned that the topic area of quantum computing is based on physics, computer science, and mathematics, therefore it is outside the authors’ field of study. For the most part, the detailed physical and computational configurations are not presented in the use cases, and the omission of this data makes it difficult for companies or researchers to replicate the use cases in this paper. It is also challenging to quantify the impact of the selected scenarios. In other words, it is currently almost impossible to weigh up whether the benefits and gains will outweigh the costs of applying quantum computing and, as a result, create value. In conclusion, the scenarios are not a guide for companies in various industries to integrate quantum computing into their business but, rather, an inspiration for researchers and businesses to consider where quantum computing might make sense and to prepare for it. According to Ménard et al. (2020) "Every business leader should have a basic understanding of how the technology works, the kinds of problems it can help solve, and how she or he should prepare to harness its potential."

The chosen methodology of interviewing experts can also be seen as a limitation of this work, as personal opinions instead of facts were often offered. Therefore, the representativeness must also be questioned critically, because the experts were able to respond based only on their own particular knowledge, which might include biases. Furthermore, there were limitations in conducting the interviews, as most of the interviewees occupied important positions in corporations or were founders of startups; therefore, they often had no more than 30 minutes available and could not respond to everything in the interview guide. In addition, they were sometimes restricted in what they could share because they were not allowed to talk about their company's current research and development. Finally, the number of experts interviewed is limited because at some point it was necessary to consider whether an additional expert would bring major new insights. Additionally, although the origin of the interviewees varies, the majority are from Germany.

Regarding the other methodology method, the survey, several limitations must be mentioned as well. First, many of the respondents do not know or have never heard of quantum computing, which may lead to misunderstandings within the scenarios. Also critical for the evaluation of the survey is the individuality of the different industries which required non-comparable questions around the scenarios. In addition, the demographics of the 300 respondents are highly similar; for example 81% were Germans which limits the representativeness. Lastly, no background questions on the participants were asked in the survey which could have added perspective to their views.

Future Research

As the topic of quantum computing is highly present and only selected aspects and industries were investigated in the context of this master's thesis, there is a need for further research to broaden the viewpoint and to counteract the limitations of this study. To ensure more complete findings, it would be crucial to explore additional industries as others such as aerospace, defense, or chemical, which indicate great promise for new applications fostered by quantum technologies (Biondi et al. 2021). Overall, increasing the scope of this thesis with more scenarios, interview partners, and survey participants would offer highly interesting findings that cannot be included in this thesis due to space and time limitations. One main recommendation of this thesis is for policymakers and industry leaders to act now to be quantum-ready when the hardware reaches the fault-tolerant era. Insights from regulatory decision makers on what is currently being done to foster or regulate the advance of quantum technologies would provide a different perspective and help with understanding a potential timeline. Additionally, opinions from industry leaders who decided against investigating the potential of quantum computing could add another angle that would complement the findings of this master's thesis. The science and technology behind quantum computing is another area in which further research could add value. The complex background of QCs is briefly explained in the literature review, however, the scope of this thesis allows only for the introduction of the most important aspects. Therefore, a deep understanding of the technology behind the scenarios would be a valuable addition. Lastly, other quantum technologies such as quantum sensing, quantum networks, quantum communication, and quantum internet were only briefly touched upon in this thesis (Acín et at. 2018, 2). These could have interesting real-life applications on their own and lead to completely new scenarios. Investigating these other technologies could provide a more complete overview of what a truly quantum world could look like.

6.3 So What? – Personal Implications

In the final section of this master's thesis, we integrate our personal perspective on the implications of quantum computing. First, in our view, in order to fully realize the potential of QCs, policymakers have a crucial role to play in creating an innovation-friendly environment with incentives for further investments. We believe that if the development of QC hardware is successful, the potential for industries could be enormous. As the experts are sometimes highly cautious and withhold some information, we could imagine that the breakthrough will come even sooner than expected. However, we can also understand why companies might be reluctant to become involved in quantum computing. The entire setting is very uncertain; in fact, many highly touted quantum applications are expected to be realized to some extent without quantum computing, however, not unleashing their full potential. We believe it is worthwhile to address this fear and continuously build a healthy ecosystem. Not only physicists and technology specialists should feel included, but also business people, policy makers, and students, as it is already important to consider potential use cases and implementations. From our personal perspective as students who believe in the potential of quantum computing, one of the most striking points is the need for universities to include the topic of quantum computing and its applications in their curricula. Although several master's degree programmes in quantum science and technology are offered, the potential of quantum computing at bachelor's level should be highlighted. Furthermore, the focus should be not only on the theoretical technology but also on real-life applications. However, from a business student's point of view, we are concerned about what the reliable development of QCs could mean for the economy as a whole. Large companies could use this technology, which might be inaccessible to small companies, thereby creating threats to competition. Finally, we would like to emphasize the need for increased collaboration, highlighting the transformative power of people from different backgrounds, including those not specialized in quantum computing, working together.

Despite the technology being in early stages, we believe that industries must begin their quantum journey today of they are to be quantum-ready in the future. We are sure that we will have more certainty about all of this in the next century.

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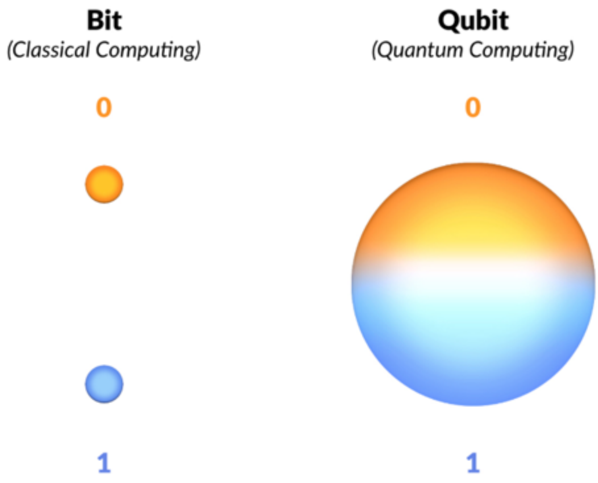
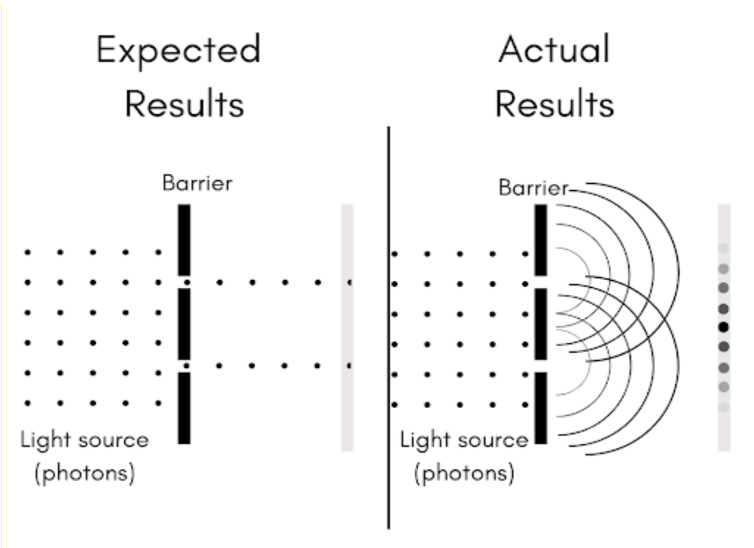
8 Appendix

A. Illustrations



Source: Dumon 2019



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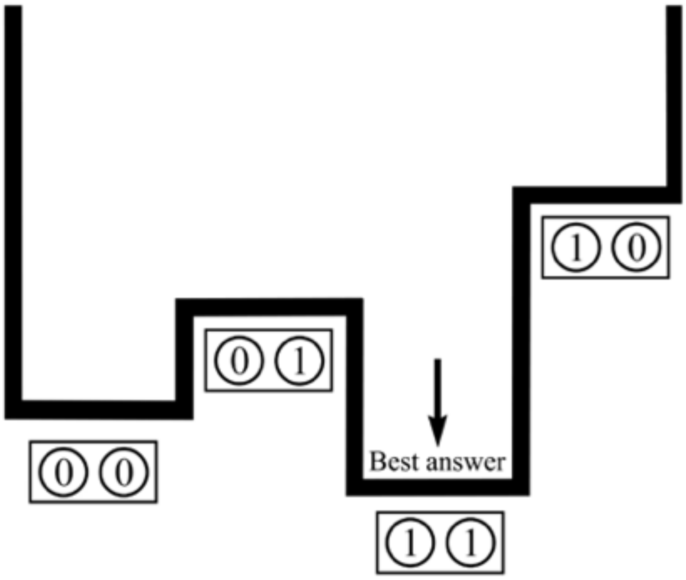
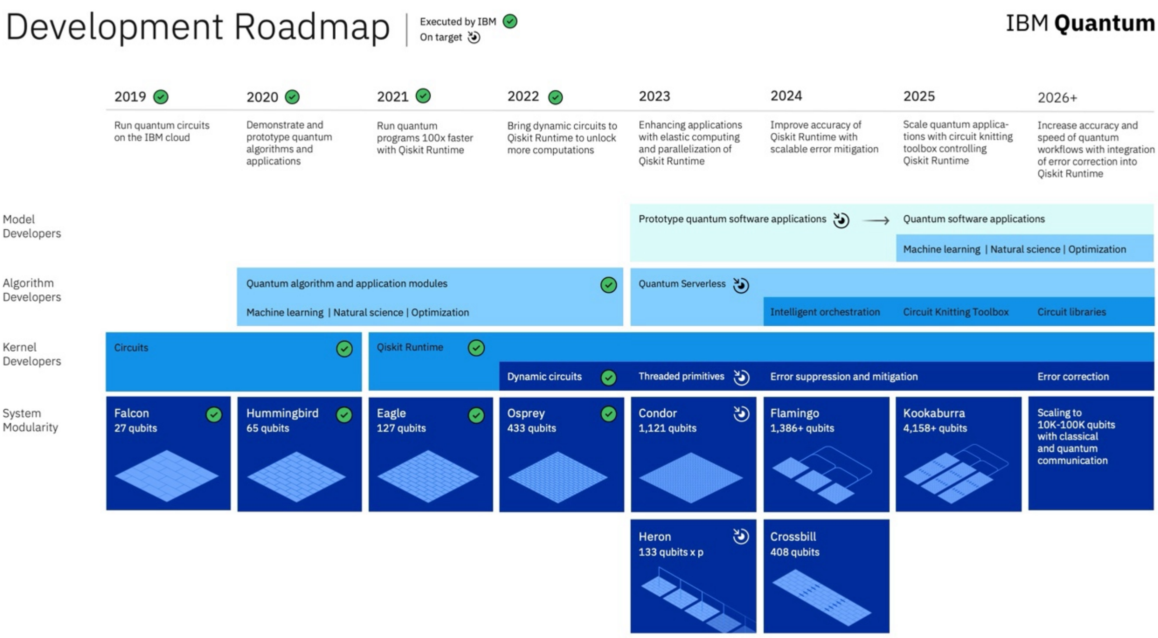
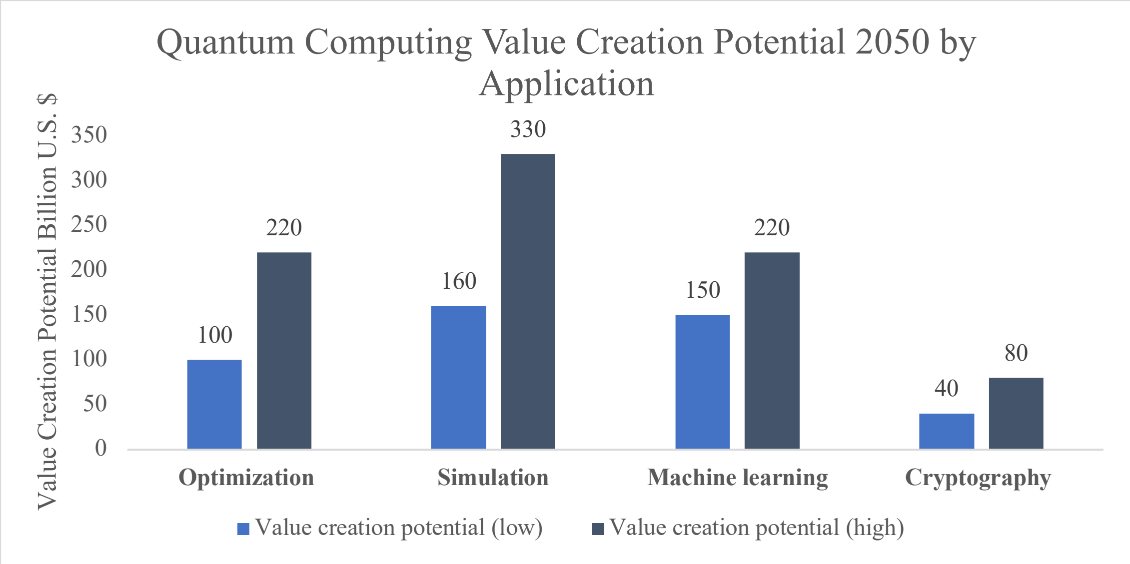


Source: IBM 2023f



Source: IBM 2023b

Group Part



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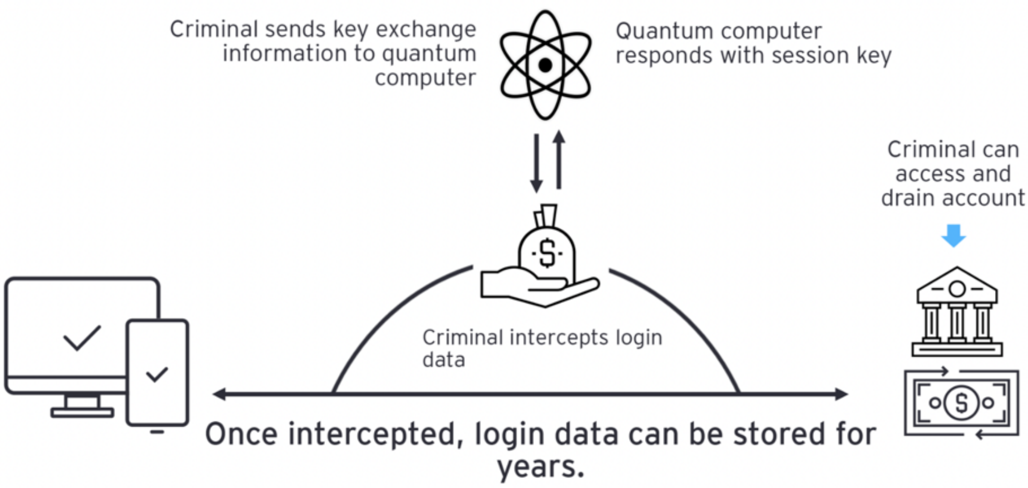


Source: Guarrera and Khan 2023

B. Scenario

The scenarios are intended to describe an example of a day in the future with the full capacity of quantum computing in the different industries. That is the reason why they are described in "you" form.

Numbering	Scenario	Industry
1	You wake up and your personalized medical app shows you your current health status and future predictions – you then get the most precise recommendations for a perfectly suited day regarding nutrition and movement. Based on a quantum steered sensor in your body, your mobile phone shows you your current life expectancy of 93 years and 4 months and the perfect ration of multivitamins is already flowing from your drink dispenser.	Healthcare
2	You realize that you forgot to charge your mobile phone over night. You last charged your phone five days ago and used it all the time. The same goes for your empty Electric vehicle, but you can quickly charge both within 5 minutes while having breakfast.	Energy
3	Your bank had a cyberattack last night and your entire account was emptied. There have been multiple attacks all over Europe in the past year as banks have been slow to adopt to the new technological advancements. All these quantum computing cybercriminals are causing many financial markets to plunge.	Cybersecurtiy
4	Because of the cyberattack you decided to look for alternative banks and have come across tomorrow bank, which is supposed to be a pioneer in banking secured with quantum computing. After 15 minutes you are verified by your bank and can log into your new bank account.	Finance
5	Your bus always comes at exactly 9:07 every morning. Inside the fully electric, autonomous bus you enjoy the noise free, swift ride to your office.	Mobility
6	As the route is always optimized you are always perfectly on time for your first meeting.	Mobility

7	You got a notification that new solar panels will be installed at your home next week. These panels have been optimized by design and new material developments such that their efficiency has increased enormously. This morning for one hour, the sun was shining, which is already enough for two days of energy use in your household.	Energy
8	You check your emails and received personalized information from your new bank including recommendations to invest in new stocks. It takes a few minutes for the website to provide you with a portfolio tailored to your needs with all your interests considered and great return rates.	Finance
9	Later in the day, you receive a push notification which tells you that your portfolio has already made a plus.	Finance
10.1	As your family has previously shown some case of lung cancer, you scheduled a screening appointment for today. And indeed: the tiniest first cancerous cells can be seen on the brand-new high-resolution screen in your doctor's office.	Healthcare
10.2	The computer starts generating: Your DNA-individualized radiation plan will be available shortly.	Healthcare
11.1	Your Grandma has once again forgotten her Alzheimers medication pill. Thankfully you have a spare at home. However, for maximum effect, granting cure of the disease, she needs to take the pill at exactly 7pm every evening. If she doesn't get her pill in time it will have strong implications for the effectiveness.	Healthcare
11.2	*implemented in the question*: Imagine this pill was tested on your grandma's digital clone.	Healthcare
12	You decide to call a dronetaxi so you can make it in time to your grandma. Within 2 minutes the Taxi has arrived at your doorstep and you listen to the instructions before the drone taxi autonomously takes off to the predefined destination. The entire trip is 5x times faster than if you had taken ground transportation.	Mobility

13	After an exhaustful day, you turn on your TV, the news are on. Apparently the Chinese government was able to hack the US for sensitive information and is using this as a form of blackmail. In Europe our national security and its communications are by now safeguarded by quantum-secure channels.	Cybersecurity
14	You still have to pay the electricity bill. Luckily you switched the energy provider last year because of the reputation for very smart energy distribution. For example, this allows ensuring that your excess energy is efficiently stored and distributed to other homes and industrial productions. Then you realize that you even got moneyback due to your energy supply.	Energy

C. Survey

Introduction

A day in a life of Quantum Computing

Dear participants,

In the course of our master thesis, we are investigating the impact of quantum computing on people's everyday life in the future. 🚀 For this purpose, we created a hypothetical simulation with different use cases. We are interested in hearing your opinions on this topic. We would be very pleased if you would take 7 minutes of your time to do so. ⏱

Thank you and have fun 😊 - Ameli, Elena, Emelie, Hanna & Victoria

🤠 Disclaimer: This is a fictional scenario. Nevertheless, please answer the questions in such a way as if it were yourself in the situations.

Demographic Questions

1. Your age group

Under 25 years	94
25 - 40 years	100
41 - 56 years	37
57 -75 years	66
76 years and older	3

2. Your gender

Male	133
Female	166
Non-binary	0
Prefer not to say	1

3. Your country of residence?

300
Antworten

Neueste Antworten
"Germany"
"Portugal "
"Deutschland"

Aktualisieren

199 Befragten (**66%**) antworteten **Deutschland** für diese Frage.

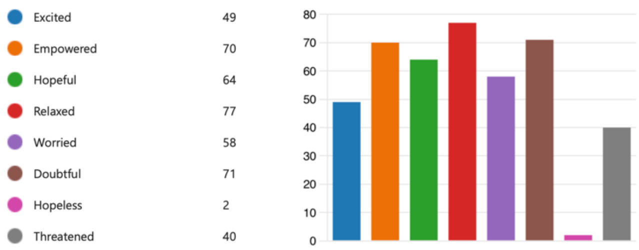
Group Part

Scenario Questions

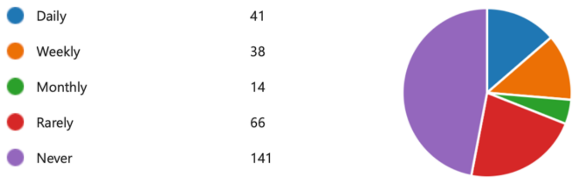
Wake up

You wake up and your personalized medical app shows you your current health status and future predictions – you then get the **most precise recommendations** for a perfectly suited day regarding nutrition and movement. Based on a **quantum steered sensor** in your body, your mobile phone shows you your current life expectancy of 93 years and 4 months and the perfect ration of multivitamins is already flowing from your drink dispenser.

4. Given the scenario, how do you feel?



5. How often do you already use personalized medical apps for health monitoring and predictions?

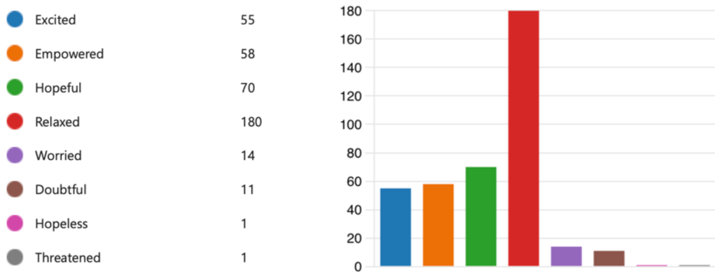


6. Would you believe that the technology described has the ability to show your correct health status?

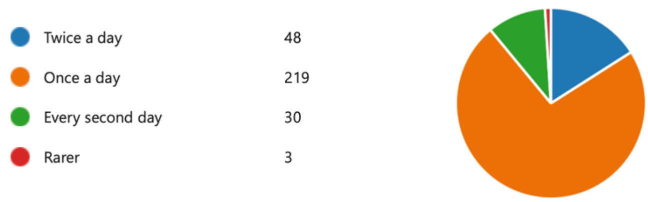
Get ready

You realize that you forgot to charge your **mobile phone** over night. You last charged your phone five days ago and used it all the time. The same goes for your empty **Electric vehicle (EV)**, but you can quickly charge both within **5 minutes** while having breakfast.

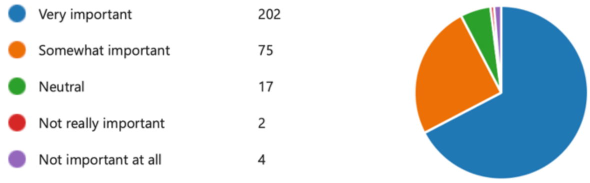
7. Given the scenario, how do you feel?



8. How often do you charge your mobile phone on average?



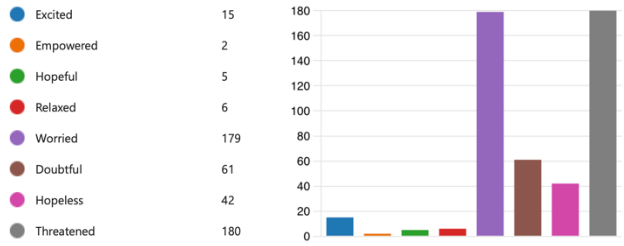
9. How important is the EV's battery duration as well as the charging time when buying an EV?



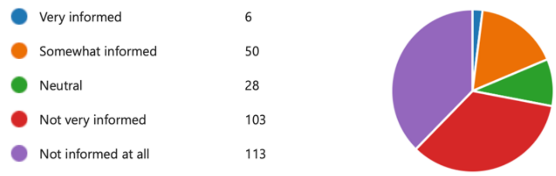
Later in the Morning

Your **bank had a cyberattack** last night and your entire account was emptied. There have been multiple attacks all over Europe in the past year as **banks** have been **slow to adopt to the new technological advancements**. All these quantum computing cybercriminals are causing many financial markets to plunge.

10. Given the scenario, how do you feel?



11. How informed are you about the security measures taken by your current bank to protect against cyber attacks and data breaches?



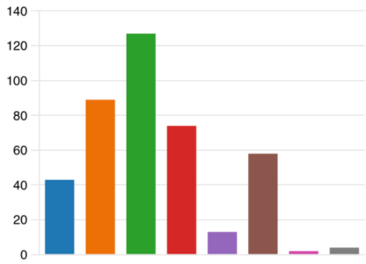
12. If this scenario was real, would you be willing to make the effort to switch to a more secure bank?

Still at home

Because of the cyberattack you decided to **look for alternative banks** and have come across *tomorrow bank*, which is suppo-sed to be a pioneer in **banking secured with quantum computing**. After **15 minutes** you are verified by your bank and **can log into your new bank account**.

13. Given the scenario, how do you feel?

Excited	43
Empowered	89
Hopeful	127
Relaxed	74
Worried	13
Doubtful	58
Hopeless	2
Threatened	4



14. How long did it take on average for you to be able to create a new bank account (credit) in the past?

15 minutes	41
1 hour	116
A day	65
A week	76
Rejected	2

15. Is a faster and more precise verification process a deciding factor for you when opening a new account?

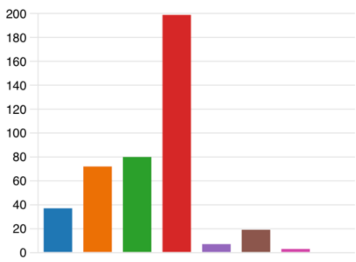
Yes	183
No	117

Leave home

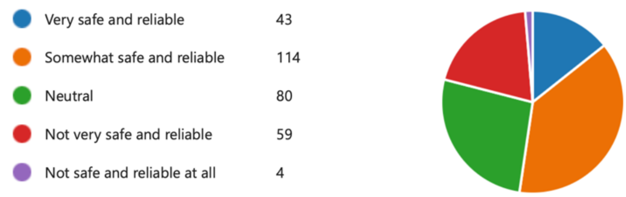
Your bus **always** comes at exactly 9:07 every morning. Inside the fully electric, **autonomous** bus you enjoy the noise free, swift ride to your office. As the route is always optimized you are always perfectly on time for your first meeting.

16. Given the scenario, how do you feel?

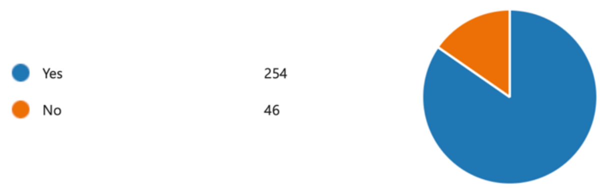
Excited	37
Empowered	72
Hopeful	80
Relaxed	199
Worried	7
Doubtful	19
Hopeless	3
Threatened	0



17. How do you feel about the safety and reliability of autonomous vehicles compared to traditional human-driven vehicles?



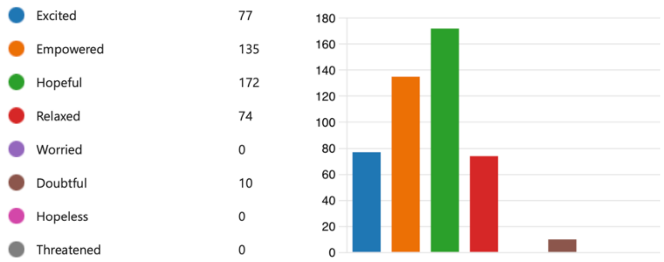
18. If it were 100% safe to travel in an autonomous vehicle, would you be more inclined to use it for your daily commute or travel?



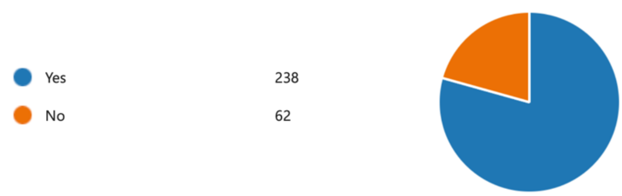
Moving on

You got a notification that new solar panels will be installed at your home next week. These panels have been optimized by design and **new material developments** such that their efficiency has increased enormously. This morning for one hour, the sun was shining, which is already enough for two days of energy use in your household.

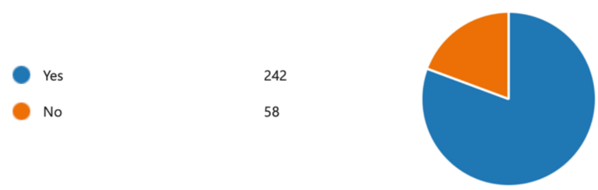
19. Given the scenario, how do you feel?



20. Have you considered transitioning to renewable energy sources for your electricity needs, either in your home or at your workplace?



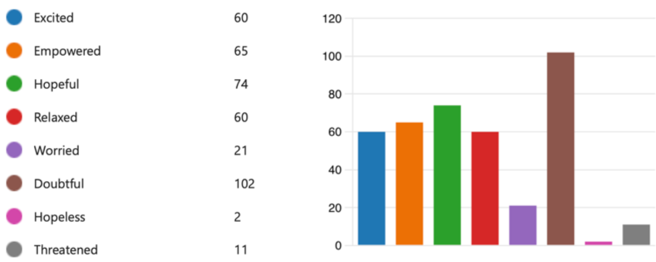
21. Would you invest in these solar panels even without government subsidies?



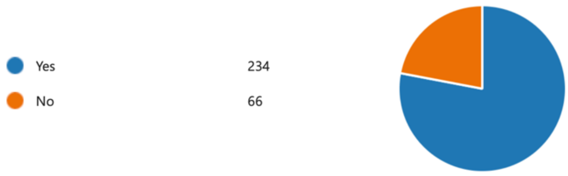
Before lunch

You check your emails and received personalized information from your new bank including recommendations to invest in new stocks. It takes a **few minutes for the website to provide you with a portfolio tailored to your needs** with all your interests considered and great return rates.

22. Given the scenario, how do you feel?



23. Are you considering your personal interest when deciding where to invest your money to?



24. Would you rather invest in an automatically perfectly personalized portfolio than the portfolio your personal bank advisor proposed?

25. **Later in the day,** you receive a push notification which tells you that **your portfolio has already made a plus**.

    Have you personally been affected by a stock collapse?

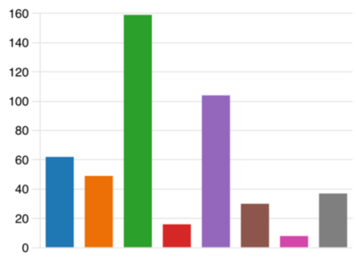
26. Do you believe in portfolios without an investment risk in the future?

Lunchtime

As your family has previously showed some case of lung cancer, you scheduled a screening appointment for today. And indeed: the tiniest first cancerous cells can be seen on the brand-new **high-resolution screen** in your doctor's office. The computer starts generating: **Your DNA-individualized** radiation plan will be available shortly.

27. Given the scenario, how do you feel?

Excited	62
Empowered	49
Hopeful	159
Relaxed	16
Worried	104
Doubtful	30
Hopeless	8
Threatened	37



28. How involved are you in your current health status regarding difficult-to-cure diseases?

Very involved	30
Somewhat involved	98
Neutral	55
Not very involved	85
Not involved at all	32

29. Are you confident in leaving decisions about your health to computerized calculations?

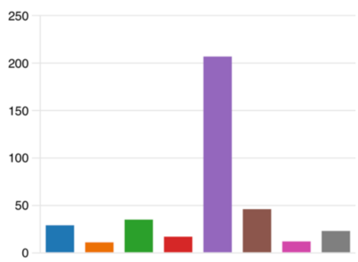
Very confident	42
Somewhat confident	146
Neutral	50
Not very confident	51
Not confident at all	11

Afternoon

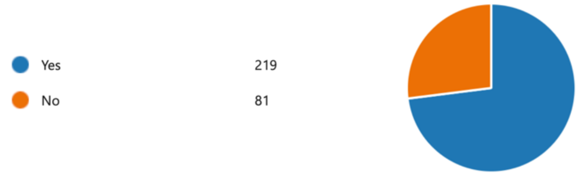
Your Grandma has once again forgotten her **Alzheimers medication pill**. Thankfully you have a spare at home. However, for maximum effect, granting cure of the disease, she needs to take the pill at exactly 7pm every evening. If she doesn't get her pill in time it will have strong implications for the effectiveness.

30. Given the scenario, how do you feel?

Excited	29
Empowered	11
Hopeful	35
Relaxed	17
Worried	207
Doubtful	46
Hopeless	12
Threatened	23



31. Would you support your family members in participating in a clinical trial for a drug that could cure a disease like Alzheimer's?

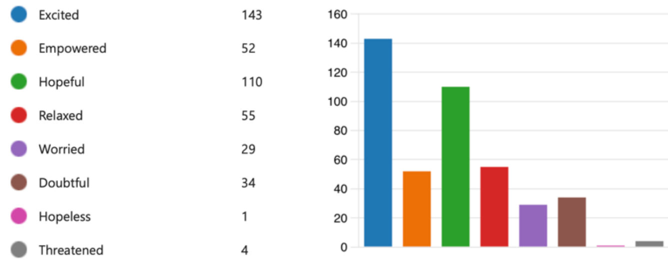


32. Imagine this pill was tested on your grandma's digital clone, would you then be convinced that the drug is able to heal your grandma?

Later in the day

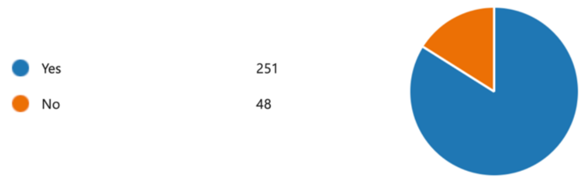
You decide to call a **drone taxi** so you can make it in time to your grandma. **Within 2 minutes** the Taxi has arrived at your doorstep and you listen to the instructions before the drone taxi autonomously takes off to the predefined destination. The entire trip is 5x times faster than if you had taken ground transportation.

33. Given the scenario, how do you feel?



34. Would you consider using drone taxis as a convenient and time-saving mode of transportation for situations where time is crucial?

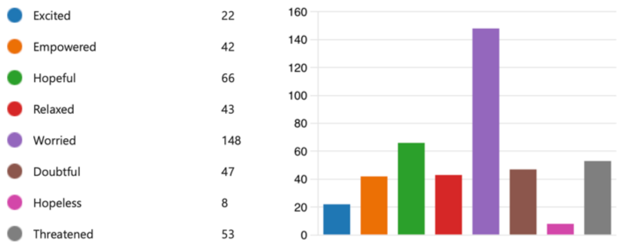
35. Would you use drone taxis over traditional ground transportation if they were competitively priced?



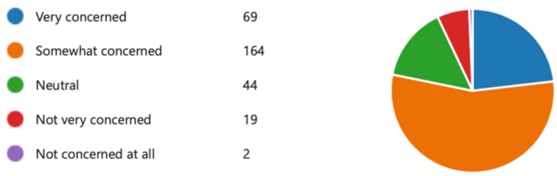
Evening

After an exhaustful day, you turn on your TV, the news are on. Apparently the Chinese government was able to **hack** the US for **sensitive information**. In Europe our national security and its communications are by now safeguarded by **quantum-secure channels**.

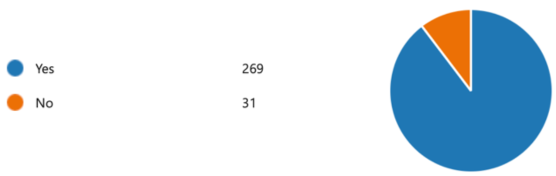
36. Given the scenario, how do you feel?



37. How concerned are you about the potential vulnerability of national security and sensitive government information to cyber attacks by foreign entities?



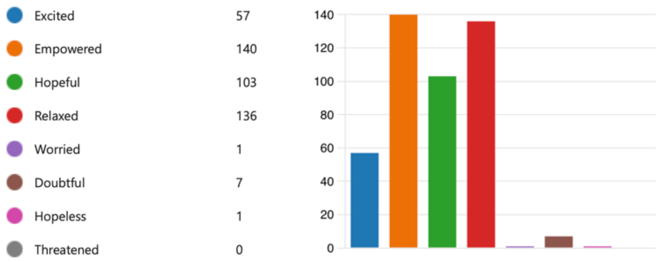
38. Do you believe that in the future cybersecurity-wars will have a bigger impact on your life?



Before going to bed

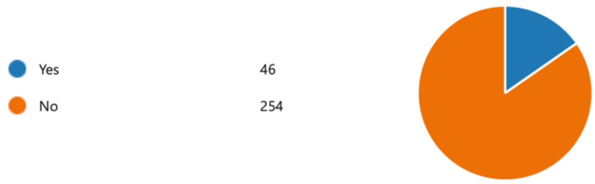
You still have to pay the electricity bill. Luckily you switched the energy provider last year because of the reputation for **very smart energy distribution**. For example, this allows ensuring that your excess energy is efficiently stored and distributed to other homes and industrial productions. Then you realize that you even got **money back** due to your energy supply. Good night, sleep well! 😴

39. Given the scenario, how do you feel?



Group Part

40. Do you have a smart energy integration grid (which allows for more energy efficiency in general) at home?



41. Would you consider switching your current energy provider if it led to more efficient energy distribution and potential savings?

Group Part

D. Interview Guideline

Introduction:

- Thank you for your willingness to participate
- Introduction: Name, name of the university, topic of the work
- Implementation: Approximate duration (around 30 min.), structure of the interview, reports of assessments and experiences
- Data protection: Present recording device, offer anonymization of data, Transcription consent
- Clarify open questions from the interviewee
- Start recording

Topic: Scenario analysis: A futuristic day with full scale quantum

We have created a scenario representing a possible day in the future touching upon different industries which might be affected by quantum computing. As part of the thesis, we are conducting an empirical study in which we interview experts on our futuristic day and evaluate the scenarios based on their opinions later.

Part 1: Self introduction (Due to privacy reasons this part is deleted in the tanscripts):

- Please introduce yourself briefly and describe your current position and the associated industry.
- When was the first time you were introduced to the topic of quantum Computing and in which context?

Part 2: General Questions:

Group Part

- Which area of our daily lives do you think will be impacted by quantum computing the soonest and why?
- What sort of time frame do you think we're looking at for fully applying quantum computing in the industries?
- Are there any other factors that impact the timeline of quantum computing applications?
- In what technologies or industries do you see the biggest challenges right now and what are they?
- What are the potential ethical considerations associated with quantum computing, and how can they be mitigated?
- Where and who is the pioneer in quantum computing research at the moment?
- Are you collaborating with any insitutions/ companys/ non-quantum specific insitutions for real life applications?

Part 3-7: Industry specific questions (In this parts our scenarios will be introduced):

- In general how realistic would you view the presented scenario on a scale from 1-10?
- Is there any part in the presented scenario which you believe is unrealistic / far fetched?
- What is still necessary for the presented scenario to become real life?
- Do you think the respective technology will be possible without quantum Computing?
- What do you foresee as the most significant developments in quantum computing and the respective industry in the next 5-10 years?
- What advice would you give to companies and decision-makers in the respective industry considering incorporating Quantum Computing into their projects?
- Do the technologies advance at the same pace in the underlying industry?
- Is there any other aspect that you want to add, which we didn't considered in our scenarios for the discussed industry?

E. Expert List

The experts were contacted mostly through LinkedIn search and through referals of members of the quantum computing exosystem. They all have extensive knowledge of quantum computing with some having a specific industry focus.

Nr.	Cite In-Text	First and Last Name	Expert Information	Interview Date
1	Schulz	Dr. Otto Schulz	Phd in Physics and 25 years work experience at consultancies such as A.T. Kearney and EY Parthenon	18.10.2023
2	Anonymous	Anonymous	Quantum Venture Builder at a quantum computing hard and software start-up	20.10.2023
3	Anonymous	Anonymous	Quantum Computing Specialist and a Bank with a PhD in Quantum Physics	20.10.2023
4	Paudel	Hari Paudel	Senior Researcher at Leidos Research and Development with a PhD in Quantum Information Processing	20.10.2023
5	Anonymous	Anonymous	COO and Co-founder of a Quantum Software Company	23.10.2023
6	Hellstern	Prof. Dr. Gerhard Hellstern	Professor at Duale Hochschule Baden-Württemberg with Data Science and Quantum Computing Focus	24.10.2023
7	Anonymous	Anonymous	Quantum Computational Chemistry Lead at an OEM with PhD in Computational and Theoretical Chemistry	24.10.2023
8	Anonymous	Anonymous	Senior Vice President Healthcare Vertical at a Technology Company with PhD in Medicine	25.10.2023
9	Rodriguez Rosario	Cesar Rodriguez Rosario	CEO and Co-founder at Commutator Studios a	27.10.2023

			Quantum Software Company with a PhD in Physics	
10	Schulte	Prof. Dr.-Ing. Thomas Schulte	Dean at OWL University of Applied Sciences and Arts with Focus on Control Engineering and Simulation	30.10.2023
11	Anonymous	Anonymous	Research Scientist Quantum Computing at a Technology Company with PhD in Physics	30.10.2023
12	Ajallooiean	Hoss Ajallooiean	Technical Product Lead for Quantum Computing at IBM	30.10.2023
13	Zwiehoff	Fabian Zwiehoff	Quantum Engineer at ParTec AG	31.10.2023
14	Anonymous	Anonymous	Director of Energy Systems Engineering at RWTH Aachen University	31.10.2023
15	Ruefenacht	Martin Ruefenacht	Researcher for High-Performance & Quantum Computing Integration at the Bavarian Academy of Sciences and Humanities Leibniz Supercomputing Centre	02.11.2023
16	Anonymous	Anonymous	Head of Marketing and Sales at a quantum computing start-up with PhD in Computational Chemistry	03.11.2023
17	Anonymous	Anonymous	Quantum Algorithms Researcher at a Quatum Computing Research Center with PhD in Applied Physics	03.11.2023
18	Drösken	Helene Drösken	Chairwoman at Institute for Industrial Information Technology at OWL University of Applied Sciences and Arts	06.11.2023
19	Rotermund	Natalie Rotermund	Scientific Officer at Artificial Intelligence Center Hamburg with a PhD in Neuroscience	31.10.2023

20	Hackländer	Stefan Hackländer	Innovation Manager Digitalization at WKW.automotive	07.11.2023
21	Wick	Oliver Wick	Techonology Scout at BMW	07.11.2023
22	Dlugosch	Dr. Julian Dlugosch	Senior Consulatant with Project Management for Quantum Climate Challenges	08.11.2023
23	Hartmann	Michael Hartmann	Professor at Friedrich-Alexander University Erlangen-Nürnberg with PhD in Theoretical Mathematics and Physics	10.11.2023
24	Anonymous	Anonymous	Professor at a University of Applied Sciences and Arts and Industrial Security Consultant	15.11.2023
25	Stadler	Dr. Daniel Stadler	Business Development Lead at NMWP Management GmbH with PhD in Chemistry	16.11.2023
26	Anonymous	Anonymous	Quantum Computing PhD Candidate at a Technology Company	27.11.2023
27	Valcarce	Carmen Valcarce	Quantum Computing Engineer at Moody's a financial intelligence and analytical tools provider	17.11.2023
28	Krauser	Jasper Krauser, Emanuele Marselli	Quantum Technology Central Coordinators at Airbus. “Quantum Computers vs. Super Computer: What’s the big deal“ Talk at Web Summit 2023	16.11.2023
29	Pinto	Karan Pinto	Global Director of Growth Terra Quantum AG	24.11.2023
30	Strohm	Thomas Strohm	Chief Expert for Quantum Technologies at Bosch	27.11.2023

F. Interview Transcripts

Interviews that were conducted in german were translated with the help of *deepl.com*

Interview Telephone Notes 1

But he doesn't believe that there will ever be a portfolio with no risk because there are too many human components involved
Crypto he very much believes in
He also believes in energy, but thinks that the progress will not be that great because the systems are already quite efficient and he doesn't know if the financial outlay is worth it
What he doesn't believe in:
Supply chain and demand
Too many human factors such as fashion trends
Too many different suppliers where you have little insight
Example: You throw a stone into a calm lake and you see the waves... aka you see all influences can include everything and therefore quantum computing effectively
You throw a stone into a wavy sea and you only see very little effect... aka if you can't see all the influences, quantum computing can't work properly either... Garbage in Garbage out
Autonomous driving:
He finds it super difficult even if he thinks it will work with QC
Either the QC has to be in the car and then be small, mobile and very robust (and inexpensive) which he doesn't think is possible for a long time
Or the car is controlled centrally by a giant QC, but then connectivity must always be guaranteed. This raises a huge question regarding cyber security. What happens if the connection is broken for just a few seconds + what happens if the system is hacked.
Ethics:
If you have autonomous driving then you also have to program the quantum computer to make decisions. Aka... you can no longer brake, you run over a granny or a family with children. If you do that, it's clearly the fault of the programmer, i.e. the car manufacturer.
His example: autonomous driving will reduce car accident deaths from 3000 to 1000 a year but then you can say exactly 250 deaths are directly attributable to VW
Generally:

He thinks QC is great for things that are already understood in principle but can't be done fast enough yet. For example, medicine or chemical research. Otherwise, if you don't understand things, you end up with the question do I understand the result and if the answer is no, you have to ask yourself: do I believe the result without being able to check it somehow?
Social science topics (everything where a person has an opinion) are difficult

Interview Dialogue 2

Interviewee	Yeah, sure not. Thanks for the introduction. That's pretty much the only professional picture I have. I'm Mexican, I'm living in Berlin. Did computer science, engineering and then management as well, as you probably read. My background's in the innovation venture space. So I had a start up a long time ago. I also worked in XX, little bit in consulting and now of course at XX. So at XX, it's been a year almost since I've joined back into the tech game. And yeah, we are quantum computing as a service company. What that basically means is we offer the whole quantum computing stack. So starting with the hardware part where we have a simulator, so not a native CPU, but simulators, we have a quantum computing cloud. We also then have libraries that have well bunch of code already prewritten to speed up the coding process and then on top of that we do applications. So what basically my role is as a venture builder is a combination of business development, project management, customer delivery and then trying to marry the let's say the deep tech IP that we have. So the algorithms that we develop for example and then customer problems, so whatever kind of customers there in the market, let's say a bank or you know CPG Company, what could be use cases where quantum computing plays a role and has the potential to enhance their existing methodologies. And, it's been really good. Happy to jump into your questions or like any particular point that might be interesting for you.
Interviewer	Yes, I might actually already have a question in back of my hand because of the company that sounds super interesting because I'm wondering because quantum computing is still such a theoretical thing when you think about the future and what impact it could have and like my question is also how does Terra Quantum in a business, business wise function already with like real customers, because I saw that you have different industries listed from healthcare to finance to do everything. And do you work with like the big corporations in those industries already or because we were thinking how does those corporations already prepare for the quantum life that's about to come?
Interviewee	Yeah, no good question. So, we do work with clients in industry. So we work with XX. We've worked with Devlani, with Uniper, like these are some German big companies, for example, HSBC, you probably know we worked with Honda already. So we do have customers. So quantum computing as theoretical has is both true and not true. So there's already a lot of advancements in quantum computing that have

	occurred over the past couple of years where using quantum methodologies you get the same or sometimes even better performance for certain very specific use cases. So I mean, you have to also understand that quantum computing at its core is just computation. So what that means is that it's just like you can think of Intel coming up with a new chip. That chip itself empowers a lot of different technical capabilities that didn't exist before, but buying it itself, it's not really impactful to you and I. So Apple coming out for the a 16 chip basically means we get, you know, tiny bit faster things on our iPhone for example, right. But what we don't know is the background processes that enable that to happen. And quantum computing is not a oh, the world's going to change on its own. There's a lot of layers that will have to be built on top of that in order to impact the end application which will then be many different things that come up. So that being said, what we specifically do and this goes to your point of it's theoretical is and that the hardware right now is a little bit theoretical in the sense, sorry, not theoretical but not mature. So we call it MISK, which is noisy intermediate scale quantum computers and right now they're basically what computers were in the 1970s like regular computers, right. So they were these huge mainframes and like computation power of, you know, very limited computation power mostly used by very few industries or military for, you know, complex number crunching. So right now they're like that like you you've seen the IBM or whatever, like these big, you know, cyrogenic chips, fridges and then you have these chips, they're not scalable, they're not industrially usable even at this point because it's very hard at either the quantum error correction, right or coherence right, or number of qubits like there's a whole. So what we do specifically is we try to bridge the gap between when quantum computers actually come up to a point where they're outperforming classical ones right now aren't. So organizations could try to focus on partnership like we provide and collaborate to bridge the gap. And the fact that quantum computing, it essentially is a sort of rethink on how we do computation, right. So fundamentally it's operating at a different kind of frame, not just zeros and ones. And what that means is the algorithms or the software that's going to go in will have to be different to actually exploit that kind of computation. And what we do is we have this thing called hybrid approach where we try and combine certain elements of quantum computing with the best of the class in classical computing to offer performance enhancements to end customers. So I know it was a long way to the answer, but I just wanted to share some insights on that and then some examples. I mean if you Google XX, you can probably see a few of the press releases that we have done with. For example, I worked on Honda with use case on emergency evacuation. What that basically means is we model an earthquake scenario and then we try to find the shortest path to escape in a changing dynamic environment. And in that paper we tried to prove that our method of combining supervised learning with the quantum layer actually enhances the performance of a regular

	classical algorithm. So these are like many different examples of what we do with clients and then with clients. The major thing that we try to do is firstly get them quantum ready like start thinking about quantum even if the performance increases is limited. We do like PO CS where we try to prove that are discovered together and then we even do applied research which is where we work their R&D teams to try and come up with the next thing. And, it's a little bit like, you know, it's deep tech. So it's a little bit like what AI was let's say in 2017, you know, before now it's like. It can do everything. In 2017 it could do very limited things and most was in research. So think of it in that way.
Interviewer	Thanks so much for these nice insights already. Do you already have a time frame in mind when, like the end user will be influenced as well?
Interviewee	Really use or get used of quantum computing depends on the use that you want. So what we are seeing is in certain cases already that now there's this term called quantum supremacy, right? Which basically means the point where quantum computing just outperforms classical computing at a given task. Only two companies have actually claimed this. One is the Chinese team, one is the Google team. However, each time that was claimed there was immediate you know push back because classical people found a way to do Quan was doing in the way and this is because the ecosystem, so the hardware that's developed, the middleware that's developed, the tools that have developed in classical are 20-30 years old in development but trillions of tons of dollars gone into them versus quantum which is very nascent. So it's very hard to outperform on a theoretical level. That being said, we're already with our hybrid approach. We're seeing in certain instances that with the what the client has is already you're outperforming it. So we're not saying that, OK, this is you know we have quantum supremacy. What we're saying is we can help you get performance today which is better than what you have and at the same time get ready for the future. And just in terms of the timeline for like very useful applications which are clearly outperforming, I would say like maybe, 2-3 years even. Like we could probably start seeing that because the thing is the computation starts growing exponentially. So the moment you get past a certain point, it's going to be very different. That being said, it's very dependent on quantum hardware. So like the true quantum supremacy probably like five years or five to 10 years somewhere because I think it might depend on the hardware actually developing and then truly unimaginable use cases that, you know, we couldn't think of right now because for example, when people came up with the computer, they couldn't think of us having a video call on a computer like this. Right. So we're, I don't know how much distance. So that would probably be

	like the roughly the 10 year to 20 year range, I would say when things start get developing
Interviewer	Ok. That sounds super interesting. Maybe also to link to that is the things that will first come into practice because I mean you said you will work with companies also in the R&D developments. Do you have specific industries in mind where you would say this is the first where quantum computing will take place and and where it will actually have the biggest impact in the next few years?
Interviewee	So I think I mean the thing is computing is broad and therefore quantum computing is broad. So it's applicable to most industries. That being said, what it's truly applicable to for now is problems that are computationally hard and complex, so where we were not able to model systems. So a couple of industries have that and are pretty advanced in terms of computational usage already. Finance is 1 where you do all sorts of things which are extremely complex. A lot of data, a lot of competition goes into it such as well forecasting financial markets, like portfolio optimization, like Monte Carlo simulations, like risk analysis where you have thousands of, you know, assets, thousands of parameters, thousands of things and trying to come up with the next thing for example. So that's one. The second thing is the world itself is at the smallest level quantum right. So the the principles of quantum physics and quantum mechanics operate at the atomic level on a on a molecular stage. So wherever we are trying to simulate our model processes that have interactions at that level, the discretization of the zeros and ones makes it harder. Whereas if you use a computational paradigm that reflects that reality, which is quantum computing, that makes it a lot better to model these complex systems. So molecular chemistry and drug design for example is 1, which is extremely powerful where we can come up with new materials, we can come up with new processes, chemicals, but also we can shorten the drug design and discovery process because we could simulate instead of having to go through a 10 year time frame of finding it out. And then the third one is I would say is more in the machine learning side. So where we have basically what GPU sort of did to AI in some ways like with the parallelization that they offered the ability enhanced. I think QP us will offer that will be the next wave in AI that happens. I think like I mean there's many industries and for all of them it's applicable. But for me these would be like very good starting points.
Interviewer	And we also focused actually on all the industries you just mentioned example given in the healthcare sector we were also going with the idea of cancer or Alzheimer being able to build, do you see quantum computing there being the the big solution that will make this happen? Or do you think that without this technology at one point we could also get to the solution?

Interviewee	That's a good question. I mean Quantum will definitely help. I think those are clear use cases where it helps. The only question is could AI get there anyway without it. So that's why the intersection of quantum AI is so important because it's not quantum or AI, it is AI enhanced with quantum computing, right. So that's how I would see it. And yeah, in that frame of reference, definitely it's a big game changer.
Interviewer	Also one application we had, because you mentioned you had this cooperation with Honda is that we thought about and made further research on flying taxis which could be in one way possible with quantum computing. What do you think of this?
Interviewee	I mean, the whole autonomous tracking paradigm is also computationally expensive and complex. And then when you start scaling it towards not one car, but like a whole plethora of cars coming through, there's an explosion of data and decision making that would happen. So potentially, yeah, even if you were doing autonomous driving, I would say quantum computing starts playing a role because the other side of the computational paradigm is like Moore's law is going to stop very soon because we're already at a nine nanometre size for transistors, which is basically a little bigger than photons. And when we get to 3, we'll be at photon level already in terms of the nano sizing. So there's a physical limit to how small and how many transistors we can put in a chip. So that means like the regular classical computing which has always doubled every two years, and computational power will probably start not being able to do that. So how do we then solve super complex challenges? And there I think, yeah, it's not autonomous driving, definitely. And then flying cars is just more complexity added because of motion. So there's also the complexity of the landscape changes and therefore I think, probably it's a good one, but that's still I think pretty far off.
Interviewer	I also saw on the website that you offer or I don't know if you if it's included in the whole package of collaborating with you guys, but the whole cybersecurity side of it because you also mentioned. The Chinese government does the whole thing on trying to reach supremacy and it's kind of like what I always read is that it's kind of a race of who gets to be quantum boss and then the whole thing of security, it plays a really big role in the future. What are your thoughts on that?
Interviewee	So I mean I think quantum like chips and like AI is sort of now modern strategic. I don't want to call them weapons, but sort of yeah advantages or even weapons to an extent for governments that which is why you're seeing a lot of national quantum programs coming in. And one of the core elements there is, A, the technological advantage that would give that nation which has its own quantum computer and then B is the ability to decrypt and encrypt information and maintain that versus others, which is a big strategic advantage, right, Information. So I mean yeah, you've probably read about Shor's algorithm which proves that the modern encryption basis which is SHA hash functions can be broken in a linear manner versus the exponential rise that was happening currently with quantum techniques. And which is one of the, to be honest, the

	one of the only very clear exponential advantage that we've seen from software side. And given that information, a lot of companies, governments, etc. are funding quantum computing for that security, a security as defense and AB security as you know, being able to read other people's information. And there's also this paradigm of store now, decrypt later, which is basically you can well just intercept encrypted information now and let's say in three years you get something that can break that encryption. You could still read information from two years ago which might or might not be relevant, but there might be a lot of things that are still relevant and you can get a lot of insight. So yeah, 100%.
Interviewer	It seems like that's going to be one of the like biggest threats when quantum computing comes in. You can also work with governments or like the national institutions or with any other non-technical institutions together for this to like to not happen or to protect themselves from this happening.
Interviewee	Yes, you know the other side is then the security side of quantum, right? So it's how do you change from encryption that's based on SHA hash functions to There's something called post quantum cryptography which is basically quantum resistant algorithms or encryption which tried to create algorithms that even if you had a quantum computer will not exist, will not be breakable. Then there's things called QKD, which is quantum key distribution, which makes even the encryption part really hard. There's QR and G which is quantum random number generators, which are basically as an input into the encryption, which make it harder. So, nothing is ever bulletproof, unhackable. But then, alongside the breaking, there's also the, you know, the development of. Resistance or defense? That's happening, which is why, yeah, quantum security is extremely important.
Interviewer	Thank you. I also have one last application questions, A question because you're also focusing on the energy industry and I also saw that you had this on your website. And how important do you see quantum computing for sustainability in the energy industry?
Interviewee	Yeah, definitely. I mean so it's extremely important I think for a few things which cannot be done in regular ways or can be enhanced in with quantum rays. And I mean some of them are the materials that we the energy transition that's happening and the materials that we need. For example, the carbon capture don't exist yet, so the material science element is very important, which I think quantum can play a role at then the modelling of physical systems. So physical systems also at in this essence are a highly complex and B essentially at its core quantum as well. And I think like for example whether modelling, which is an unsolved problem could potentially be solved by quantum computing. I think then in terms of sustainability, there's all sorts of like quantum machine learning elements that you could put in with the, for example, we've done work in renewable energy forecasting in you know, time series for predictive maintenance etcetera, which are more in terms of KKK, can we predict how renewable energy happens and then one very cool one which is potentially going to happen. Yeah, I don't know how soon, but is the intersection of nuclear fission and fusion with quantum because those are again processes that are very

	quantum based and very complex. And if we can use either quantum to to enhance nuclear, then that's our answer to humanity's energy problems.
Interviewer	So, yeah, lots of potential. And also, maybe going back to the job that you have in the customers or yeah, companies you work with. Has there ever come up the question of the role of the end consumer's acceptance towards all of this? Because same as with AI, everyone was kind of scared or still has their doubts for it. And then do you think that with quantum computing coming into this race as well and our technology side developing so much that we have all these new opportunities, do you think that there's going to be some sort of like acceptance obstacle?
Interviewee	I mean I don't think so to be honest because like I said AI is different versus quantum. Quantum is just the think of it as just the based on which other things are built, right. Yeah, it's not self intelligent or you know doing anything that's completely game changing from a from an itself point of view. What it enhances is for example AI itself that is the potential. So that I think the question is not that customers will not want to use it or people will be against it. I think it's more. Will it further the divide between the global South and the and the developed North? Will access to this competition itself be a strategic barrier for people to even compete or even have you know services? Because if for example the world gets more divided and you know the US or China have the only quantum computers, they could develop AI application that are way more advanced than. What the other side of the world can, and that would be like a very big strategic priority. So buying itself, it's just computation possibilities. I think what you can build on top of it is the part like the AI part for example, which could be potentially, but then again then it's an AI problem not a quantum problem to know.
Interviewer	Thank you. Maybe looking at the time, I don't know if you have time for one more last question or not.
Interviewee	Maybe one last question.
Interviewer	No, I mean maybe just the final question maybe more general, but what do you think will be the next big milestone in in quantum computing? Is there anything like for suitable future that you can say like in the next five years this will happen and this will push everything even further?
Interviewee	I think like the hardware needs to develop, so if someone comes up with the next innovation in well, fault resistant quantum computing for example. Where people have access to that exponential power, that would be a game changer because that would start exploding the potential possibilities. I think that is a possibility. The other one is the cryptography angle, if someone does manage to do it, but that's I don't think in the next five years that really happens. Yeah, I think, I mean we need the hardware for it to be very, very significant. The other thing that can help is quantum supremacy in one element or the other where we see, yeah, a clear out performance of a quantum

	algorithm. And I think that would be a game taming moment as well where people start really taking it seriously.
Interviewer	And what exactly did you mean with the an encryption method of that this being the next big step, the whole the that this develops further or that someone is not able to hack quantum computer that exists so far?
Interviewee	So that's not, I don't think it's going to happen in the next five years, but it's more like someone takes your algorithm and breaks the encryption. So when that happens, people everywhere will have to switch. If they haven't already into the new paradigm.

Interview Dialogue 3

Interviewer	how did you get started and how did you first get introduced to quantum computing?
Interviewee	I did my undergraduate degree at the University of Manchester in Physics and in the final year there was a course, a master's course called quantum computing. I was like, oh, what's that? And I took the course, really enjoyed it. And then after university, I already had a job lined up in software development. So I did that for a year and didn't enjoy it too much. And then I decided to do a PhD in quantum computing & quantum technologies. Then phd I found was just outside London in the UK and I did that for about four years. And that was developing technologies using superconductors or quantum technologies using superconductors. And from there I joined a startup that was spun out from the University of Oxford and they were building quantum computers. So for a while I was actually building the hardware, which is quite exciting. And then just over a year ago I moved to where I am now, XX. So I was sort of doing the flip side, rather than the hardware, I'm doing the software now and starting programming quantum computers. So that's how I sort of got involved, how I got started my varied career so far. So, yeah, that's my story.
Interviewer	Where do you think quantum computing will have major impact on our personal lives
Interviewee	Yes. So when I was doing my research for my PhD. You’ve almost got sort of tunnel vision and stuff working on your projects and trying to think of solutions to your projects. And at that stage I sort of just assumed it was, you know, a researchers curiosity as mostly in the lab. I'd heard that big companies had quantum computers and stuff, but I didn't know if they're doing anything useful with it. And then sort of as I was finished with my PhD, I just sort of realized as I started going to a couple of conferences, how big the industry was getting and how many other businesses who are not traditionally quantum companies were interested in this and doing work on this and starting projects on this, which was quite interesting. So I sort of started to realize that it was the end of my PhD, which was 2019. Yeah. And there's all sorts of companies, such as pharmaceutical companies, who are interested because they want to simulate a certain drug. Simulate the molecules that they're trying to synthesize. And those

	molecules themselves are quantum systems, right? So to understand fully those systems, you want to use something that is quantum to simulate it. So that's the one sort of application of quantum computers. How they're going to get used. And then this whole boom of AI and machine learning has come about as well and it's been around for a while that quantum computer could help with some of these sort of problems or have similar solutions but in a quantum way to doing some of the machine learning algorithms as well. And then you can think wherever you apply those technologies, you can in theory also apply quantum technology. So yeah, it's quite exciting to figure out how. This could impact everyday lives and how it could explode very soon once the engineering challenge of the current state of hardware is solved. And yeah, it's a very exciting time to be to be looking into concept.
Interviewer	Whats your opinion on the time frame?
Interviewee	That's a very good question. There's lots of different time frames based on sort of like subjects and sector. So the typical thing you hear when you go to conferences is they are over 5 to 10 years. So that's like the easy answer. But the general ideas are that machine learning will probably get better at first and then probably pharmaceuticals not too long after and perhaps optimization problems as well. Some problems that are much larger will obviously be much later because they tend to be more complex. But it's likely, I think maybe I'm biased because that's my area, that the machine learning areas will be first to sort of benefit from quantum release.
Interviewer	And as of right now, what do you reckon is the biggest challenge which has to be overcome for this to become reality.
Interviewee	I think some of the biggest challenges are definitely an engineering challenge. Quantum computers, they consist of these, these devices called qubits. These are like the sort of zeros and ones. They can exhibit noise, so in measuring them you can see noise in the response. And right now measuring 1 qubit is fine. You can sort of get it to what's called a high enough fidelity. This is a measure of how you expect the qubit to behave. But as you start scaling up and connecting normal qubits together, the fidelity rate that's measured as a percentage tends to drop and more noise is introduced to the system. So coming up with noise mitigation technologies in terms of the physical hardware and there's also what are called quantum error correction. So this is for correcting for errors in sort of quantum software as well and also hardware. So I think those challenges need to be addressed to sort of really Start to get sort of true quantum advantage in what's called fault tolerant quantum computing as well, and at that point we can start doing some real cool stuff with it.
Interviewer	So one of the biggest effects that quantum computing has or can have on the finance industry is on the Monte Carlo simulation and we read that it can optimize the simulation and through that minimize the overall risk of an investor's portfolio. What do you think about that and do you think that it can really take into account the human behaviour when simulating?
Interviewee	I've not worked on Monte Carlo simulations directly myself, but I have sort of had discussions with colleagues and other people in the industry. It's the sort of

	same argument as with classical simulations as well. The idea of the quantum advantage for whether it's Monte Carlo or some other quantum machine learning algorithm is that it can provide some advantage in some way, typically either in some sort of speed up so it can do a problem faster, or learn a certain algorithm faster. Or secondly some sort of data benefit whereby you can use less data to achieve similar levels of results as well, which is always helpful because it's hard to get good data these days. So I hope that answers your question. I think that's how the benefit will come to those sorts of problems. In finance we're constantly looking at problems to apply quantum technology to and one thing that I can talk about that my organization is doing because it's public and you can Google the article, is that we at XX have an agreement or a partnership I should say with an organization called the USRA. It's the University Space Research Association and they're sort of academic arm of NASA. And we're working together to look at quantum inspired predictive methods for forecasting rainfall. And the reason that is, is that Standard Charter is keen on its own green credentials and if we can start including climate risk factor into various risk models that the bank takes when supplying a loan to for example a warehouse in an area that's particularly prone. We can add that risk factor into the calculation for handing out that line of credit or that loan or whatever financial products being on offer to whatever client. So that's just one example that we're doing. A lot of people obviously do the classic things that you've heard of using optimization methods for portfolio optimization. Or similarly using quantum machine learning for sort of fraud detection as well. So this is using a normally detection, which you can do with normal classical machine learning. And the hope is to get some sort of advantage with this sort of exponential increase in certain problem solving capabilities using quantum features.
Interviewer	Do you think that quantum computing really could predict the financial crisis?
Interviewee	That is a very good question. I think it would be tough for any model, regardless if its quantum or not to predict some sort of financial crisis. There tend to be shocks to the market. So what's really interesting to look at is if you look at certain foreign exchange rates which is something I've been working on recently. You can see during COVID there was a big dip in currencies, but also say for dollar, pound like when Brexit happened there was a dip or when the recent Prime Minister changes, there's a dip or whatever way it goes. You can sort of see that there's shocks to the market that would be hard to predict in any other way. So because they happen so suddenly they are just a difficult problem to predict regardless of whether it's with quantum or not. If there is a way to do that, typically people use other sort of financial indicators to try and predict whether there'll be some sort of financial shock or keep a close eye on the news and things like that. That has to be the biggest strategies. But I would be skeptical of models that could predict sort of shocks like that because they tend to be sudden, of course.
Interviewer	And so the literature also indicates that customers from banks often complain about the lack of personalized and individual offerings. Do you think that can

	be solved throughout quantum computing in terms like even if you think of AI, machine learning?
Interviewee	Yeah, it goes again about that sort of advantage you want to see from machine learning. If you can get some sort of increased data advantage so you can find out more information from your client with less information about them, that's great. So if you can have better recommender systems based on the little information you've got and that's always a positive, if quantum computing can provide that sort of boost, that would be great. I don't know if it could yet, but we'll see. But that is a sort of a general sort of AI machine learning conundrum as well, not just specific to quantum computing.
Interviewer	Is there any other finance related technology which we haven't discussed yet?
Interviewee	Let me have a think. I'm trying to think of sort of projects that we've spoken about that that are interesting. There's sort of two things I thought recently is that if you look on HSBC website, they have used quantum technology to create a quantum secure link. So between their head office in London and a data center in the country side, they're using to just sort of improve their security as well. And JP Morgan have a list of patterns that they've taken out with regards to quantum technology as well from their website. So if you're interested in what it is they're doing and the problem statements that they're sort of trying to tackle using quantum technologies, that would be a good source as well. They produce a lot of academic papers, quite dry reads, quite difficult reads, I'm not going to lie, but you can get the gist just from reading the abstracts, what problems they're trying to solve and what methods they're trying to do it with. So that might be a good source for the two of you as well.
Interviewer	How worried would you say you are about potential impacts of cyber wars or cyber criminalities when looking at banks and generally finances?
Interviewee	Yeah, so the things that people often talk about particularly sort of like quantum decryption I guess on current encrypted files is sort of like harvest now hack later or harvest now decrypt later. So you can have some sort of nefarious creature taking your data and storing in some way, knowing that they can't access now because it's too well encrypted. But the idea being that they're hedging their bets that in the future there'll be a sufficiently powerful quantum computer to decrypt that data and then find out what it says. So that's sort of 1 fear that the industry tends to have as well that that I can think of as well anymore. And then again, it's the usual stuff that's sort of like the regulatory standards around not just quantum computing, but AI as well can be sort of similar the data protection laws and also making sure that, you know, this technology is accessible. So it's not just in the hands of a few large corporations or a few large institutions or governments that it becomes accessible and usable by and beneficial to most people in society, not just not just a few.

Interview Dialogue 4

Interviewer	That's nice that you have some time for me. Me and some colleagues are writing our master thesis in. Quantum computing and we are simulating a day in the future which could be possible with full quantum computing and build a scenario and therefore we want to talk with some experts to validate it and get some opinions on our scenario and all the quantum computing landscape right now. And yeah, me personally, I'm building this scenario in the energy industry. And maybe you can get me some nice insights about quantum computing in general, Some challenges, could I also ask you? Maybe you want to say what you're doing right now or I could also ask you some specific questions and also introduce our scenario we build. Nice to meet you and thank you for your time. So what What do you actually do?
Interviewee	Right now, my background is physics so and I worked several years in that area, in the area of physics, you know chemistry, some research on the chemistry as well material sciences and so and so forth. So, this is the moment, the place where I work, it's government facility, the US government facility and so it's a national lab and here the lab it's basically focus on the the carbon management and all that in my area, my area of expertise is on the more like computational material sciences and quantum information processing. So you know, we work in many different areas. So at the moment we do sensing development, quantum sensing development and the quantum computing in order to benchmark the currently available state of the hardware. As always the software that's what we do benchmarking them and benchmarking in this meaning here basically take them as a test bed and and evaluate their capability. It's like how is what is the strength of the the current hardware quantum hardware and what is the strength of the current quantum software like algorithms and all that in terms of solving problems from chemistry, mostly chemistry and then optimization. Peeled optimization means like you can take a problem from electrical grid to power supply rate and then there is they're trying to make a a grid those electrical grids smart grids and then control over the the power probe and the problem is pretty complex there. So people can, you know, simulate that problem using quantum simulator or quantum computer. So there are a couple of different areas where we currently work on in the area Quantum Information processing.
Interviewer	And and can I ask you some questions, so some general questions. So first maybe some general questions before I want to introduce my scenario I created. So what challenges do you face right now with Quantum and what are the main challenges which exist there right now?
Interviewee	Quantum computing, it's development of the hardware, limitation in the hardware, the hardware is still in its infancy, you know. So the problem is the noise there hardware. So if you have a noise then you get a lot of error in the results. So that is where the limitation challenge we need to come up with that hardware development so that we can tackle bigger problems as well.
Interviewer	Do you also collaborate right now with Other companies to also already face the end users and try application?

Interviewee	This is government lab. The setting is very different than the university and company here what we have. So we we are ourselves like this lab itself it's sort of type of the not the company but we develop technology so means our problems are highly applied. So we work with the company directly as well some companies like a QC Ware, let's say one company from California QC Ware, we worked with them in the past and then General Electric and few couple of like yes all of them are now we are going to start to work together but more focus for us is we select the problems with our applied and test against the hardware capabilities.
Interviewer	Maybe I can I can introduce you to the three scenarios. I thought in the energy industry after reading all the literature and papers which are already published. So first like I put a scenario in the energy storage thing that the battery will be optimized due to new materials which could created and that it would be possible to charge due to better battery duration and last to charge EV and also a mobile phone in 5 minutes in 10-15 years. What do you think of this thought?
Interviewee	Do you believe you mean like using quantum computing?
Interviewer	Due to better material development, due to quantum computing, because I read everywhere that it could help in the material development.
Interviewee	Sure. You know and this is one of the let me put this in this way. This is one of the areas of applications where quantum computing can find the opportunity to provide better solution for materials; usually lithium ions batteries these sort of materials or finding a new materials through the you know optimization process combining different elements together which would provide better you know charge storage capacity and which we still don't know about those material or it to explore they're in the space but maybe with the quantum computing that's going to be helpful. Yes, I can definitely see that in maybe next 10 years time that I think they did put this whole thing in a way short term, mid term and long term. Short term is like at the moment current quantum computer what they call the NISC. I think you know that like a noise NISC computer, that NISC computer may be able to solve small molecular systems for chemistry applications like a very, very material small so very small molecular systems within this five years maybe in that it's a kind of short term and the midterm maybe 5 to 10 years. I'd say not full solution for the matrix battery materials, but it's kind of going on that direction. So next 5 to 10 years and long term means after 10 years maybe you could be able to solve more complex problems related to battery. More complex in the sense that it would provide most likely more complete solution where we can have you know opportunity to explore many more battery materials which would be able to restore more charges for a long time. And then also another problem is degradation of the battery over the time, right? Maybe they are more sustainable for a long time. So and and this problem goes along with the many other problems. Again, the fundamental limitation is the hardware.
Interviewer	When do you think will be the first quantum applications in real life?
Interviewee	It known for me I was in the Quantum for Sustainable Climate and Sustainability, a workshop two weeks ago in the General Electric headquarter in

	Newyork, General GE Global Research in Newyork. We had a lot of discussion there on this about the quantum computing and still all these big companies did they are so reluctant about to to benchmark their hardware, solving chemistry problem, e.g. battery materials and so on and so forth. They don't want to say that means like there are those hardwares that are not benchmarked yet. Where we don't know how big problems they can solve and in fact they are very weak at the moment. It's compared to classical computing system. They cannot even in A5 qubit system it's you know still maybe you cannot go more than 10 qubits even though they, you know, IBM said they have like 400 / 400 qubit system hardware there. But just to use less, because if you just take a problem that needs just 15 qubits. It finds so difficult to solve that meaning we don't know yet where it will find the applications in the near future. Maybe there would be Ice Age, quantum Ice Age. You know, Ice Age means there may be. When you do all this work and then after a few years, quantum will just like slowly a little bit and then stay there for a long time and then just come up later on after many, many years I see so or like maybe quantum winter. That would be quantum winter where not much activities are. So we don't know, but the current level of the effort people are putting. It's really appreciated, a lot of work has been done. So I think first application would be definitely in some of the areas chemistry applications. That's what I see. Chemistry applications mean it could be for material optimization because chemistry is very very close friend of quantum Computer. All the quantum chemistry problems that you can write immediately in the quantum code, the quantum computing code very easily. It's easy to quote, easy to translate those chemistry problem but they did you Let's say if you people have used the quantum computer business or economics too but there is a little bit tedious you need it doesn't understand the quantum. It doesn't understand that economics language and you translate that into science language and math. On top of the quantum math so that is where the problem. So but yeah, quantum chemistry like a battery and some other you know or maybe like ammonia, you know like a fertilizer where they use ammonia molecule to produce fertilizer. So they maybe could be immediate.
Interviewer	Thank you. Also from the other two scenarios for the energy industry I came up with a very smart energy distribution. It could optimize the supply and demand of energy so much that money could even be refunded to people.
Interviewee	Yeah, you can. You can see that's what I talked earlier here that was about the power line, you know power line industry where they have these grids, they tried to convert those grids into smart grids.
Interviewer	I mean it's already in place in some households. I mean, there are already households which have Smart Energy distribution, but it could be more and more specific and optimized.
Interviewee	Yeah, yeah, rather, I think. Here you just saw you just talk about the quantum computing. But smart grid could define the quantum information processing more close, close application where the security is a problem. And I don't know in Germany, but in the US, grids are frequently hacked by the Russell and some other, I don't know who were there. So security is a big threat here, right? So then quantum like QKD quantum key distribution, which is sort of like

	intermediation processing, quantum information processing, they could find such application could find immediate Use in the smart grid. Now quantum computing for a smart grid is basically simulation to find the optimal solution for power balancing. You know you have many grids and then you don't know how many, how at given time, how much power you need in a particular direction, particular community, particular house, particular. But it's a very big mess there, right? So people think that quantum computing would find the easy solution for that but it's still don't know how that go just to be optimistic on that.
Interviewer	And and then I have a third one that solar panels. I read that really often.
Interviewee	Again, that's sometimes the Problems in the quantum computing could find whole application. Just take two. Maybe you can mark down there. One is optimization, the other one is minimization. The optimization is for the one you talk about, electrical grid, smart grid, solar. Solar panels and all that, not material side optimization again where there are many, many parameters just like in economics, I think you have the economics rates, so you took economics rate, so you have insulated if you see the supply and demand curves, how many parameters there that impact us that seek the supply curves up or down, right, so maybe income. Of the people maybe I didn't know there were some other circumstances. There are many many more right that seek the supply and demand current by the. So that means you have a lot of parameters there. So kind of problems where there are many parameters, you define this optimization problem and then exactly the smart grid problem is optimization. So there are there is there are many things, many parameters that you need to optimize to certain levels. The other one quantum computer see it's a minimization that's a chemistry problem where we always try to see the problem goes to the minimum level where it's a more stable. So these are two areas that quantum computer can solve. So again if you solar panel again if this optimization again the power. Balance here and there flow all that. If the minimization and the materials solar panel materials to find the best solar panel materials yeah that could be another applications. I could give you a number of applications, you just. You know solar panels. You can talk about ammonia fertilizer or power grid or belly materials Or nuclear physics where nuclear you know waste management and all that are fine. Try to find the better materials for that you know sustain the high energy or high temperature in the nuclear reactor, right, nuclear reactors or or machine you know, or toxic. Gas simulation like that effect the you know increasing the temperature or carbon capture material where you need to find good materials. Carbon management where you need to manage how to manage carbon processing. This is the post processing. How It's going to be more like a techno economic analysis that you know, quantum computer could find a solution good Area there too. So what else And wind power. You can still use that in wind power or semiconducting industry where you need to find a better materials that can really that. That is basically, let's say Can generate more power, more current, but less heat. These computers, they heats up nowadays, right? So maybe we can save some energy low power semiconductor materials, right?
Interviewer	But which application do you see most realistic?

Interviewee	I think minimization. You know when you talk about the quantum computer, there is one gate based quantum computer, other ones like AD web where it's a little different. So D web is more relevant to optimization, gate base is more relevant to minimization but people use all one per other. It's OK but. I don't know how these different technologies will come along and down the road in future, but I think quantum chemistry or barrier material would be the most likely. But then also the optimization for example the power grid problem would be realistic. But what I want to give you on your way. In addition to quantum computing, other technologies are also having a significant impact on the energy industry. Renewable energies play a central role in sustainable power generation and are helping to accelerate the transition to environmentally friendly energy sources. Smart grids optimise energy distribution, enable flexible integration of decentralised energy producers and improve the efficiency of the overall system. AI in particular plays a role in controlling energy flows, forecasting consumption patterns and optimising energy efficiency measures. The combination of quantum computing, AI and these advanced technologies opens up these horizons for innovation and transformative developments in the entire energy sector.
Interviewer	And I don't know if you have more time, I mean you already gave me a nice insights for. Do you have any more to talk or not really for energy and I mean you already said the main challenges also the future outlook it's what we are most interested in.
Interviewee	Just let me know if you have anything more to talk since you are already here.
Interviewer	Yeah, I mean let me check if I already prepared some questions I wanna ask maybe maybe one last question. Have you already thought about the end user and if there will come ethical considerations to apply quantum computing in the future? Or don't you see any considerations? I mean also what with AI? There are already some ethics concerns and security concerns, also with cyber security. You mean like whether you could provide a better solution for that or yeah, or whether it will be a challenge for the cyber security or like ethical more if you think that there will be problems in coming for the end user to to use applications based on quantum computing or is it too much in the future?
Interviewee	Really, I don't know how this technology will affect later on, right? So I'm just be. I'm optimistic that it will make the society better rather than worse, right?
Interviewer	Yes. As you know, yeah, I mean after reading all the papers about quantum computing, the applications and everything, it sounds really promising on many aspects like climate change, the society.
Interviewee	It's optimistic just to when we be optimistic but it's again it comes with the challenges that it will result and you know not all the people In this world they have, they see positiveness you know of let's say technology we have or people that try to use that into negative way too and no one can stop them, right. And that has been going on now bright. So that is happening. Both in a good way or bad way, but most likely it's a better impact will come from come to in in a good direction rather than in bad direction. So that means quantum

	computing will definitely open up many avenues to make the society better rather than making worse. That's what I think, yeah. And along with that, I don't know what other new avenues will open up in the future which is still yet to explore. We don't know, right? The whole last space is out there. If you have this technology on hand, just like this classical computer in nine, even though there was a computer in this in 2000. This computer, But we didn't know this would be the world would be something like this on those days, right? Now because of the computer everything's, it's completely changed in the same way in a quantum computer. Once everything in the full scale quantum computer is here, we don't know what would be the new avenues, what the new space and what are the challenges with that. It's. I don't think anyone can tell or predict that. True. Even even with this computer technology we don't know how let's say things after 10 years will go right and he had never realized that even before COVID situation the current it is all these you know what we have now new way of working using these technologies and ITS and all that would be something like this. So now after COVID, things have changed a lot.

Interview Dialogue 5

Interviewer	Tell us briefly about yourself and your background.
Interviewee	I'm a business economist and also studied business administration. I previously interned at a few banks and then realised that I prefer to work independently. I also met my current partner during my first semester.
Interviewee	At our company, we want to solve big planning problems because we are coming to the end of Mor's Law and have huge optimisation problems. For example, a German timetable takes weeks to calculate. We spoke to a large transport company in Germany and they said it would take 21 days to simulate their entire network. But what we would like, as a customer, is for you to stand somewhere and say I want to get from A to B and then in future there will be more autonomous buses driving around and they will know exactly where these people want to go - we have to send a bus there and pick them up at the corner and then it will take them exactly to the station where the S-Bahn will take them further. That would be music for the future. Also the railway timetable; the current situation is when a train is cancelled, for example between Frankfurt and Stuttgart (an important route in Germany). Then there is someone in the control centre who then tries to switch the trains manually and says, all right, the route is not working now because there is a train on the route that can no longer run.
Interviewer	Yes definitely, thank you very much. That sounds super exciting. We saw on your website that you work with different industries. We also picked out 5 industries for the simulation (pharma, energy, mobility, cyber, finance). Where do you see the greatest opportunities/potential when it comes to quantum computing?
Interviewee	We see optimisation as the first thing to come. We also do optimisation AI and simulation, but we also have a very good partnership with IBM, which is now

	also focusing on optimisation. But it's not industry-specific at all and an insurance company does it just like a manufacturing company.
Interviewer	Okay, you talked a lot about optimisation in the mobility sector before. We also considered two topics: route optimisation and the fact that autonomous driving is being driven forward. Do you also see opportunities there?
Interviewee	Exactly, first and foremost you have to say that QC is simply an accelerator for all things, whether we're talking about autonomous driving or something like that. It's actually more of a machine learning topic, which is also extremely favoured by QC because everything is faster and better and therefore cheaper (training run and what it costs). I think there's always a bit of envy that the topic of ML wasn't as hyped back then as AI is today because it's less accessible. *shortly internet cancelled*
Interviewer	Let's jump into the next topic, we'd like to ask you a few more questions about our other industries.
Interviewee	Yes, of course, you're incredibly lucky because I just wrote something down for Energy a few days ago. I'll just look it up and send it to you. The main point is that the biggest problem in energy is "unit commitment". Because in the EU or in Germany, I think energy is traded every 15 minutes. These are issues where you always have to optimise quickly to get the right mix. I can also send you something on finance, but it's just a compilation. What you can see is that companies always want things that can be used in the coming months and we are simply not there yet and are still dependent on hardware optimisation. We are also currently working with a lot more US companies because they are preparing a lot more to be Quantum-ready. And that's actually quite funny because people have been saying all along that Germany has missed the AI train and now we're back to the same topic. There are also many banks in the financial world that are doing research in this area or working with start-ups, and the Americans are doing a lot, but so are EU banks. They all have case studies out there of what they have done. It's about portfolio optimisation, Monte Carlo simulation and becoming quantum-ready
Interviewer	Another topic is healthcare and pharma. When you think about it, what ideas do you have?
Interviewee	mh Well, there's a lot happening and we're the furthest away. But there is a lot going on in drug discovery, with many new possibilities and with the various combinations of how what works, we are in areas that are too high for conventional computers and QC will make a big difference here. We are still relatively far away from this due to the current hardware capacities. However, the process will be much faster and cheaper than it is today. You can also see how the chemical and pharmaceutical companies are way ahead of the game. Ah, a topic that I left out before, but which is very important. It's the topic of the different hardware architectures in the field of QC, i.e. whether they are superconducting or devices,... That's another thing you have to prepare for. Which QC architecture do I actually build on? That's an advantage for us because we don't care because we can work with anything. You also mentioned security, which we don't really deal with either, although other companies

	advertise it heavily. I'm a bit critical of the topic because I realise that there's a lot of fear in the market with this story. And if you look at who is selling it, it's often companies in the consulting sector that are already announcing that Macron wants to create a new security requirement in the EU and everything has to be Post-Q Secure and that's why they're buying consulting services to switch everything over. Encryption has also developed in the past if I were to pull up information from 80 years ago, I could easily decrypt it with today's technology. It's always funny to see that on the one hand there are always people who say "Yes, the age of data is still a long way off and it will be a while before we have an advantage" and on the other hand you find consultancies that say there will soon be a QC and it will hack everything if you don't come to us.
Interviewer	Yes, our scenarios are also about which nationality will be in the lead and China is already doing a lot in this area and therefore the threat of cyber warfare is becoming more apparent. Are you also positioning your customers in this direction?
Interviewee	It's not currently a focus, but could develop into one. We are a quantum as a solution provider, but you never know.
Interviewer	Would you say that companies should prepare for this quantum era?
Interviewee	Yes, so I think they definitely have to deal with it and get ready. The security aspect is just as much a part of it as everything on the pro side. It's important to look both ways. And I know it is a highly technical problem but being open to this challenge is essential. Organizations should have an open learning culture to be open to developments and continuous learning in this regard. If you can’t speak up or develop ideas or discuss threats with your team then you’re doomed
Interviewer	Is there a clear roadmap or steps that a company can take?
Interviewee	One step is definitely to approach us. We offer a kind of counselling service and investigate their quantum readiness. Some people understand this straight away, others are sometimes slower. There are industries where every day counts where you are preparing to not load behind your competitor, especially in the energy market.
Interviewer	Very exciting, our final question. We are also analysing our end consumers, so is it an issue to think about these customers? Are you already thinking about how people can/should deal with QC?
Interviewee	What I'm hearing is actually a lot of enthusiasm. Many people say that this will be a bigger leap than traditional computing has ever been. When the first iPhone was introduced, many people thought - cool, now I can go online and text, but nobody could have imagined what it would lead to and everything we use and do every day has nothing to do with that time. And that's where I always see a bit of a mental block, that you only think, okay, what do I have today and does that really make it better. For example, there are already trains today and timetables are being created and what do we need them for? There is simply a lack of awareness of what is possible. Imagine all the traffic lights in a city

	becoming connected and being able to see where there is congestion and traffic to minimise exhaust fumes. But once you understand it, there is enthusiasm. The reason why we exist is also to democratise quantum computing and make it accessible to everyone. And if it works like this, then I hope it will develop into something good and work as well as we already imagine it will. It also helps us to make it more understandable to the end user, because we connect business and tech and not many people can do that yet.

Interview Dialogue 6

Interviewer	I can go on for a moment, right, we're writing our Master's thesis about a simulation in the future. What exactly our lives could look like with quantum computing and we have set up a scenario in various industries. We are in 5 industries in energy finance, healthcare, automotive and cyber security. Exactly, and perhaps you can also briefly introduce yourself.
Interviewee	Right. I studied physics many years ago, did my doctorate and then stopped doing physics after my doctorate, then worked in the banking sector for 20 years, at various institutions, for a long time at the Bundesbank and actually always worked at the interface between technology, IT, yes, and also quantitative things, i.e. risk calculations, derivatives valuation and stuff like that, and then went back to university five years ago. I actually discovered the topic of quantum computing there and have now been working on the potential applications of quantum computing in finance for 5-6 years. I'm also involved in a small research project myself, where we're simply exploring what can be done, what's worth doing, what's not worth doing, what needs to be done.
Interviewer	Sounds very cool.
Interviewee	I could go on and on, but when I start talking, I usually don't stop. And then I'm quiet and wait for them.
Interviewer	No, we're also very happy when they just talk, but we have a few general questions and then we'd like to go into the finance area specifically?
Interviewee	Yes, okay.
Interviewer	Very well, first of all, in general, what do you see as the biggest challenges in the next 5 to 10 years in the field of quantum computing and the development that we really feel in everyday life?
Interviewee	In my opinion, the biggest challenge is for the hardware to get better, to get big enough, to have more qubits, to get the error problem under control, to have lots of error-free qubits. In my view, that is the big challenge, what we have at the moment are small-scale game systems which, to be honest, do not yet offer any advantage for practical applications. In other words, if you look at the road maps from IBM, Google and other hardware manufacturers, we're looking at 5 to 10 years. Hopefully, in 10 years' time, we will have hardware that is really ready or capable of being used. That

	is one issue. The second topic that I am also very concerned about and where there is still a lot to do is the question of algorithms, to be honest we still have too few. Quantum algorithms or algorithms that can be applied to this hardware and really bring an advantage. A lot still needs to be done in this area too, these are the two big issues that will occupy the community for the next 5 to 10 years.
Interviewer	So, you also see the time frame of 5 to 10 years as realistic, or 10 years? I say, until we somehow have the first applications in our everyday lives.
Interviewee	Exactly.
Interviewer	Mhm OK and overall, when you think about it, which industry do you think will be affected first, whether it will really be in the financial industry or will it be healthcare or mobility? Where do you really see the first effect or is it difficult to say?
Interviewee	I definitely don't think it's finance. I don't think mobility either. What is being done a lot is optimization with quantum algorithms. And I'm very pessimistic about that, also based on my own experience in my own research, where I see great potential and where I think it will become established is in the field of materials research, chemistry and pharmaceuticals. So the question that is already playing out in the quantum world anyway, i.e. how can I construct molecules? What can I solve with the quantum computer? Optimization, the quantum machine is more likely to happen later, if at all.
Interviewer	Who do you generally see as the pioneer right now? In the development of computers?
Interviewee	Well, whoever is doing a lot and talking a lot about it is IBM. They're also doing a lot for distribution and outreach and publicity. They're certainly, they're certainly ahead in terms of reach at the moment. Personally, I think Google is underestimated. They're a bit quieter, a bit quiet, but the work that they do and the research that they do is a bit more serious and a bit more honest from my perspective, they don't do as much.
Interviewer	What is the level of education in quantum computing?
Interviewee	Unfortunately not good, especially in Germany, the topic is still very much dominated by physics. In other words, we have some universities in Germany that are also very strong in physics, which is OK, such as Jülich, of course, or TU Munich or Aachen. Physicists, hardware... But if we think in terms of applications, the transition is to computer science. The transition into areas that are foreign to physics and that is something that drives me. Although I'm a physicist, I'm not actually interested in the subject, it's not my subject, I'm interested in algorithms, the application, how can I bring a problem to the quantum computer and there's still a lot to do. I also notice at my university that classical computer scientists are struggling with the topic. There is still a lot of, yes, reticence. And it's also the case at other universities. There's a bit of a gap in that, on the one hand, there's a demand from the government and the federal

	states that we want to do something about this and it's a big issue, important. But in terms of the broad impact of education, there's still quite a lot missing.
Interviewer	Do you see any ethical considerations in relation to the application?
Interviewee	Sounds stupid now, but not really here. Nothing that goes beyond normal technology. From my point of view, quantum computing is a tool that fits into existing applications, i.e. in terms of optimization, AI and security: the same prerequisites apply, the same ethical issues that need to be considered, but I don't see anything fundamentally new being added. So I don't think I personally see that, nor do I see quantum computing as the great savior. Sometimes you read articles saying that quantum computing will solve all the world's problems, from sustainability to diversity and whatnot, but I honestly don't think so either.
Interviewer	I have another general question. Quantum computing could tackle various problems such as simulations, optimizations and AI, i.e. machine learning, what do you see as the most important part?
Interviewee	Simulation. Simulation, of course, because in the other 2 areas it is still not clear whether there is any advantage at all.
Interviewer	Thank you. The first question, I'll say now in relation to finance. We have already read in the literature that there is a problem with banks in particular, that this whole thing, this whole service is not personalized enough and that quantum computing can be a solution for this. When it comes to personalized portfolio offers or somehow personalized chatbots, do you think that quantum computing can help banks in this area?
Interviewee	To be honest, no. So I know that the topic of portfolio optimization is always played and is always presented because it's a topic that you can sell well. If I'm looking for someone to give money for it, who understands portfolio optimization, many people know it from business studies, so marcowitz, you can explain it and then sell it nicely in use cases. I'm extremely cautious as to whether this really works in practice. I don't think so, because there are already very, very, very good classic methods for doing this in this area, including from the field of AI. I don't really see where the big advantage is supposed to come from. Theoretically, it's absolutely unclear at the moment. From a theoretical point of view, there is no argument why quantum computing should really bring an advantage in portfolio optimization. Portfolio optimization is MP completely, exponentially difficult. Quantum computing is not able to linearize MP complete problems, so theoretically it is not at all clear where the advantage can come from. And then the other one has very good classical algorithms. That's why. I know it's always played and always said that this is now the use case, but I don't actually believe that this really helps. And in the field of AI, quantum personalization, the topic of generative AI brings much more.
Interviewer	Mhm OK, and do you then believe that quantum computing cannot predict financial crises or similar crises, slumps, etc.?

Interviewee	I would differentiate here. So this portfolio optimization thing or personalized services are optimization problems. Another topic in this finance world, where we are also dealing with financial crises or stress scenarios, would all be simulations. If you look at Monte Carlo simulations, which is used for derivative calculations, but also for risk calculations. You can at least show that there is a speed advantage. A quadratic speed up, that is, instead of 100 sim
Interviewer	Mhm OK, very cool, thank you. And then another issue that I've also read about, which could perhaps be solved by quantum computing, is this whole fraud detection, i.e. ultimately that banks are losing sales by rejecting the wrong people and or rejecting the right people and accepting the wrong people. Do you think computing will help there?
Interviewee	I'm also a bit reserved. I mean, fraud detection action is ultimately just machine learning on special data and there are actually already extremely good classic algorithms for this, right up to neural networks. This means that the benchmark is relatively high against the quantum computer. If there is to be an advantage, then it will be in the area of quantum computing. I say better and faster data can be generated. That you can generate artificial cases of fraud, so to speak, and use them to improve my algorithms. That is one possibility where it might be conceivable. However, I wouldn't see it as necessarily obvious. It's not low-hanging fruit, but there's still a lot to be done.
Interviewer	Mhm, OK.
Interviewee	I know the use case sounds good and you can explain it to anyone and of course it will. But honestly, from what I've seen in my own work in this area, it hasn't convinced me yet.
Interviewer	It's good to get a critical opinion on this, because the literature says that theoretically anything is possible. That's why we are happy about such opinions. Then there's the last finance topic, all related to cyber security and blockchain. Does that make you more confident that you think somehow? Wow, with quantum computers we'll be able to encrypt our accounts etc. in the future or rather that you say that this will definitely be a big issue again and that many banks and many accounts will be hacked in the future and get into trouble.
Interviewee	Mhm, I have to say, I'm not an expert when it comes to this quantum cryptography and this whole topic, not really mine. My impression is that it's more of an opportunity, the assumption is that sooner or later today's algorithms, i.e. the RSA? algorithm will be cracked by Shor's algorithm. That quantum computing will make it possible to override today's encryption mechanisms. It will be a problem for some banks to deal with this, but in the longer term there will be other encryption algorithms, perhaps also quantum-based algorithms, that will make it more secure, including on the blockchain technology. In other words, I am optimistic about this coordination, i.e. security, encryption, blockchain. I think quantum computing can really help here and really bring an advantage.

Interviewer	Mhm, very cool and if you think about it, which country is currently a pioneer in the field of quantum computing? So where is the best level of education and research?
Interviewee	Well, certainly not Europe. The USA is very far ahead. They also invest a lot of money, even if education is generally a problem in the USA, also in terms of dissemination. China is a big unknown, nobody really knows what is happening there. Although the publications that come out of China in this area are pretty good and you can see that they are technically very far ahead and in case of doubt they will not publish everything that is known. China is the great unknown. I would say that China and the USA are the dominant players in this area, both in terms of hardware and software.
Interviewer	I think that will also be the questions about the finance sector, is there anything, any technology, anything that you say, we haven't even talked about it yet, we should.
Interviewee	No, no, that's actually all. Yes, I said Monte Carlo simulations, that's the area that interests me in finance. And from my observations, the other things are being pushed forward a bit. People are actually interested in simulation, Monte Carlo, risk calculation and that will be the killer application, so to speak, and then to bring that into finance and perhaps just as a supplement: I don't believe that quantum computing technology will change the world in the way that AI might do. In my opinion, quantum computing will be a tool that takes place somewhere in the machine room. So we will use some things today and somehow AI algorithms will be working in the background. Later on, some quantum computing calculations will run in the background, but we won't even notice them directly. So my expectation is not that quantum computing will become part of everyday life.
Interviewer	Very cool. Those were definitely very exciting insights and helped us a lot to validate our simulation. Can we quote you in our Master's thesis?
Interviewee	Yes, I will be interested!
Interviewer	So you're definitely more of a specialist in the financial sector, but do you have any exciting insights into energy, automotive, healthcare or cybersecurity in addition to the industries I've listed?
Interviewee	In transport and logistics, I would say that it's mainly about optimization problems and the same applies here as in finance. So optimization is still very overhyped, there won't be much to it, I'm sceptical. Automotive, which I know what BMW and VW are also doing, is very much about simulation, materials, simulation, car batteries, which again means almost chemistry in this area.

Interview Dialogue 7

Interviewee	Thanks for contacting so myself. I'm Chandan and currently working at BMW and R&D and one of the research tasks that we focus within quantum quantum

	computing is quantum chemistry. And so I'm responsible for quantum chemistry applications together with quantum computing in BMW.
Interviewer	So my first question would be, how did you first get in touch with quantum computing?
Interviewee	OK, so my background is in quantum chemistry. So I did my PhD and post doctoral research in the field of quantum chemistry especially for method development like DfT methods and wave function based methods. And I would say that in early 2016/17 there was lots of initiative from IBM and many others who explored quantum computing quite early. And then in terms of opportunity to work here I met Elvira from another department. You might know her and there was opening And since there's a large overlap between quantum computing and quantum chemistry applications together. So that was a start. So my own experience directly working on computing topic would be last year. Before that I would say 10 years of quantum chemistry.
Interviewer	And which area of our daily lives do you think will be impacted by quantum computing the soonest?
Interviewee	So like if you mean in terms of industry, that would be something like process development. I mean direct examples are certainly discovery of new materials. I mean that is what everyone talks about. I mean of course it could be like a decade away and so but you would see that there is potential that if we are able to scale the algorithmic race, like algorithmic applications put together with hardware, you would see some direct results that we wouldn't be able to solve that easily at the moment. And it will offer some alternative methods to look into some, I would say complex systems. I mean even within classical framework, there are means and tools, but that is also challenging. So even the classical calculation for difficult systems are not really easy. I mean you can see this way and with quantum computing that would be something that you might be able to do. I mean with lots of constraint for sure. Looking at other automotive applications, we have the use case of optimization and that is something like. It's also at the level what we call it research so far.We don't use let's say quantum optimizer to solve the last problem yet. And what most of the researchers do is, you solve the model problem and see when the capacity grows, one might be able to do at the larger scale. So these are the direct benefits for some of the industry. And as you say like in very future if you want to have generative design, generative scenarios or AI research with Quantum. This is something I do not have much experience to be honest. I only hear as much possible from my colleagues or LinkedIn and so I wouldn't comment much, but one could see that like there might be some benefits coming out of those use cases, but this is something to expect. So really, I mean at least you have to have classical AI guide to talk about something going on. So I wouldn't say myself.
Interviewer	Do you also see a time frame for what you said?
Interviewee	So for the materials or even some other use cases where a resource requirement is the number of qubits and the other parameters that produce like good quality of quantum computing. So it will be progress step by step. I would say like 10

	years is not too optimistic. Saying 5-7 years would be optimistic.So you can say it like this, OK. This would be a time frame and being optimistic would mean to people and for researcher being optimistic is different than for a business. I mean business might want to have and in seven years might not be optimistic, could be optimistic depending on which company or industry we are looking into. Like pharma, for example. I mean, they already spent 20 years doing 1 drug. I mean, so I don't know, but that is the difference. Yeah.
Interviewer	Thank you. And one last general question, What and what technologies do you see the biggest challenges right now?
Interviewee	I mean I do only algorithmic resource, not so much into hardware, but following resource and collaborating with hardware and companies and people. I would say the development of good hardware. And 2ndly would be also like low level of algorithm research that reduces the resource requirement. And the last would be people like us looking into algorithms that are actually efficiently implemented. So the third part, something that could be easily implemented, would be also that people like us are looking into quantum. And the use case together and to say that we have some problems from the domain expertise that needs to be solved on whatever comes in next few years on quantum hardware and that is also lots of work. So these three aspects are like main challenge, but I think definitely the hardware side will be the most critical. I mean as you know, like it require much longer development periods like going from 24 qubit to 48 qubit is something quite time taking. And for algorithm that OK, maybe in the next six months you already have 30% better algorithm to solve the same problem. So for time it will be hardware for the requirement of skilled people that will be also be in algorithms because we need people who actually are able to do the most recent work that is available in the tracer switch is sometimes not that easy because it takes time to follow up through all the current research.
Interviewer	Thank you. I have one more question actually. So as the quantum computing benefits could be divided into simulation, optimization and machine learning, which one has the most potential for you and which one is the most important?
Interviewee	So I think for the machine learning, I cannot really comment. One of the aspects is like the true potential, even from the current standpoint, like the current classical state of art, it will still grow a lot. I mean, there's no limitation into that. For the materials there is definitely some promise and I also really would give equal or almost similar credit to optimization. So the way within BMW or people who are working on supply chain and so I think their use case, their applications might also benefit equally and depending on the volume of the businesses I mean. Supply chain volume is also quite big like all the big companies and global trade. So I would say both and the machine learning side is really hard. I mean people are like they're good experts, they do have some good ideas. But to me it's really like something that doesn't even splash the Surface, even though I'm like in autonomous driving team.And just looking at the potential of what what can be done with the machine learning, that's amazing.

Interviewer	Thank you so much. Thank you. I think that leads quite nicely over to my part which focuses a little bit more on the automotive industry because I actually wanted to talk about the route optimization. And from the industry, from the literature, we know that it's already something which is really hoped upon. How big do you think these improvements can actually be compared to the technologies we already have which are not conducted by quantum computers?
Interviewee	So I do have some like overview from colleagues from different departments and I think there's lots of plenty of scope to improve even for the classical optimizers. Meaning that like how to formulate the problem well, what kind of constraint you want to optimize. There's lots of scope. So it's like first people from the domain expert like who is actually working in supply chain, They might not be really doing the state of art optimization, I mean since they already have built lots of expertise in doing the task really well and it might not necessarily become very optimized. But it might already be very good for the process and I would say due to quantum there's a push also for classical part, and the classical part will offer the benchmark. Let's say that if I want to see any quantum algorithm, how it performs, we also have to employ a set of classical as much as possible and that is also pushing the like use case development quite a lot and within BMW, I would say there's a nice parallel development. One is route optimization, but different optimization also like one of the very famous BMW case was to optimization of sensor positioning in the car, I mean so like any constraint optimization as you say for our businesses. I think classical it is still used to go quite further from now, meaning that everything is really well understood, which is not the case. And then the second part would be like if we really understand the classical part, like what we want to optimize, what would be the best parameters to look into? And then one could apply the quantum matrix. And I mean you might have heard like in optimization and annealer and other two or three algorithms, they're quite popular. And I think they are like subject of ongoing resource. So I would really hope to see some development from the optimization side as well. But I think the domain experts, they still have to play a big role because since all the industry has been doing optimization for supply chain, any process, So meaning that they already know the bottlenecks of the problem and expertise from the optimization side and engineers or scientists. I mean, I think there's lots of scope from the classical as well and the quantum part is just like beginning I think. I mean we still have to have all the algorithms tested, tested for the hardware, the scaling and to really see that whether it performs advantage with the current state of art, classical methods and so and so
Interviewer	and do you think the time frame for that is similar to the one you previously outlined?
Interviewee	Yeah it could be faster, it could be same and So what would be like slightly different is their hardware requirement. So since optimization problem are also well suited for the neutral atoms, so some more hardware where the gate connectivity and other things might be different for the chemistry problems. So that might benefit hardly, or it could be the same timeline. OK, I mean, they're a little bit more flexible. But they might also face the problem that some of the

	classical problems might not be able to translate it into a quantum way. So there are pro and cons to the optimization.
Interviewer	So now I want to move on a bit to our scenario for autonomous driving. We have a scenario in our day where she takes a completely autonomously driven bus. So there's no driver, there's no one staring at and no one has to be alert. What's your take on that? Do you think that is actually a possibility?
Interviewee	So I mean, I should not really speak anything about that. I mean, so for our first quantum is purely research. But you know, like autonomous driving is like really a hard industry thing right now. And first of all, I mean I do not really have any expertise just like you know, knowing things about it, talking with people. And I wouldn't really consider myself as someone who really grasps potential of different machine learning methods, different perception technique. So I think it's, I wouldn't comment on autonomous driving potentially. I think even from the classical side, as you know, like all the German automotives, they're moving ahead every year. So you can always see some more and more development. And I think one of the R&D is in automotive is the autonomous driving. I mean, yeah, which you see in Germany, like even in the US for example.
Interviewer	So it's definitely being worked on. It's just a question of when it will come into action and whether it's actually powered by quantum computing or not.
Interviewee	Yeah, exactly. So I think the role of quantum computing in a technology that's already being developed with lots of it will be some place of any like future computing. I mean not just quantum computing, I mean as you know like in autonomous driving lots of requirement of. Computing is there like fast process of data and so and so. So any form of future computing will definitely help it. But autonomous driving in itself is like a big topic.
Interviewer	And I don't know if you don't feel comfortable commenting on it, but do you have any concerns about cyber security when thinking about this topic?
Interviewee	Hey, so cybersecurity is one of the topic that like quantum key distributions and cryptography. And for us in BMW I mean as you know, our product and our business maybe for banks, maybe for other institutions is quite important. And overall cybersecurity, this is just for us a research topic that we follow. I mean, I think out of 10 people, I wouldn't say if it's a focus for someone, but there were like some POC done in BMW. But it's really far away, I would say, from our day-to-day activity.
Interviewer	OK. And in general, within the research, how much do you take the human component into account like? All most decisions in the future will still somewhat be objective, objective to like. What the human behind that says is that, is that something you look into?
Interviewee	I think it will be lastly humans. I mean if I understood it right. I mean you see like these are like very deep research. I mean I expect it to be even 10 years later very much research oriented thing. Even though we have more application day-to-day and so far in research, this is still very much like led by engineers,

	scientists in every organization or even in Academy. I mean you see for most of the basic research, it's just driven by people who have expertise and like even in physics for example, lots of physics is taught by teachers, but a last part of physics is only restricted to like, you know, cities where people are actually able to do something. So in that sense this is still, yeah, I mean it's a regular research I would say even few years later.
Interviewer	OK. Thank you. Now one last like area within our simulation is also we're looking at EV batteries and maybe so from a quantum chemistry perspective. What sort of capacities do you think? How quick could phones be charged?
Interviewee	How quick could batteries be charged if that is backed by quantum computing so I think so the in quantum chemistry research is slightly different. So there are many components. So what you see as battery like commercial battery and so there's so many things goes inside to optimize the power density and so and so and quantum chemistry is like if you if you think of like multi scale kind of system it only offers like insights at the very beginning that what is the like intrinsic property of something for some materials and how to employ these materials to make a product that's like a whole lots of process that goes into like from the engineering side, from the electrical engineering high voltage and so and so and coming to the quotient of fast charging. And so I still think I mean battery resets powered by quantum chemistry would mean like you have better materials like you know some of the properties for certain combination of systems would be better. But overall battery itself is somewhat like still I would say Anzac (don't know) topic but how do we make it efficient for certain system. So even in autonomy like electric vehicles or for even for phone mobile phones like keeping the energy density, how long it has, how long battery is supposed to last, how many years. These are still lots of interesting questions. So for us I can give you an example like it's a good method to look into if silicon carbide is working like this what will if I change some components there what are the some of the electronic properties will change and this you can calculate. So it's really further below than the battery system and the topic of charging, discharging, this is something we, I mean I'm myself and we don't really look into it. The engineers, I mean you might see from the job advertisement or the activities we do have battery users. So I might say in the press release for any automotive they really look into battery as a whole battery back and improve it.
Interviewer	Thank you so much for that. Is there any technology which powered by quantum computing possibly which we haven't spoken about yet, which you find really interesting, which will really affect our daily lives.
Interviewee	I think you have covered most of it like optimization and materials related research. I couldn't comment on 2 topics like machine learning itself and the cryptography. I mean they're very specialized area itself saying something wouldn't like from my side wouldn't make sense. So those two are like already very specialized topic for the expert working on them. And I only have let's say interacts and meaning that I would hear something. But for the optimization, I'm in close touch with some of our colleagues. So our peers to see their topic and I think that's very exciting. Same for the materials, we might have seen

	some numerical simulations, what does. And so these are the topic I think we are closely working on and so we keep some insights. The other two there are huge potential I see, I mean I mean smart people saying good things about something. It might make sense even though I don't get fully believe in it, but I think this goal would be quite like big industry for the applications.
Interviewer	OK. Maybe you can hand over back Ameli. Yes, maybe I have one final question. Do we have and take-ons on the other industries?
Interviewee	I mean I do, I mean you might have also seen that people applying on finance algorithms like Quantum Monte Carlo and so. So that's one of the unique, single use case that I know, I mean there there are many but especially like in finance they have been using Monte Carlo for decades and Quantum Monte Carlo would be definitely one would like to see how much benefit it offers. So that would be one topic I think I know of.

Interview Dialogue 8

Interviewer	Okay, thank you very much for taking the time, that's really super nice and we'll try to keep it short, we know that your time is very limited at the moment. Exactly, we are currently writing our master's thesis in the field of quantum computing and are investigating a day in the future and what it could look like with full quantum computing capacity. We are looking at a total of 5 different industries & one of them is the healthcare sector, which we would like to ask you as an expert about. We have considered various scenarios, which we would like to validate or refute with the help of your opinion. However, we would like to ask you 2-3 general questions about the technology before we enter the industry. Does that suit you or do you have any questions in advance?
Interviewee	All right, no, that's fine. I think my questions will come during the interview. Just to start with, I'm actually a doctor by training but quantum computing is my field of interest and integrated in my profession. I'm happy to help.
Interviewer	I'd say let's just get started. When did you first get involved with quantum computing?
Interviewee	More intensively, that was 2 years ago
Interviewer	Ok, and how did you come into contact with the topic?
Interviewee	Well, I teach at the research institute traditionally Healthcare and it's through teaching and also through my interest in the subject, reading a lot of literature and talking to people
Interviewer	Do you have an approximate timeframe in mind for the developments leading up to full quantum computing capacity?
Interviewee	I can probably only give you what the general opinion is. I don't believe that quantum computing is now, but I do believe that it is close. It also depends on

	the use case, the healthcare and life science market, for example, is a very regulated market, so it could possibly take a little longer. I think that if the industry really starts to look into it and build up domain expertise by 2025 at the latest, then by 2030 there will probably be some real momentum again, so that we can be well positioned.
Interviewer	And where exactly do you currently see the biggest challenges in the development and implementation of QC?
Interviewee	Yes, it's simply stability. We're currently in the Nisk era, you know all about that, so how much noise is there, how much noise, and in the healthcare sector in particular, how reliable is the data that is produced?
Interviewer	Okay, thank you very much! The areas in which quantum computing can primarily create added value can be divided into these 3 areas: Simulation, Optimization & Machine Learning. Where do you see the greatest potential here? Also with regard to the healthcare industry.
Interviewee	I wouldn't even want to decide where the greatest potential is. I believe that all three can have an incredible impact depending on the use case. When it comes to simulation, of course, I think first of all of life science, when it comes to the behavior of molecules and therefore really the production of new innovative drugs. Of course, if you think about it further, it can also simply be the course of a disease in a patient, for example, when it comes to simulation. When it comes to optimization, if I now come from my job at X, then you could certainly optimize in the context of image reconstruction, you could give the clinician a kind of part way companion that is quantum powered, what the next important steps in a therapy would be, for example; especially interesting in cardiology, neurology... and they you have to say if I talk too fast
Interviewer	All good, that works for us!
Interviewee	So what did I say, cardiology, neurology and oncology are the big areas where I think quantum can bring an advantage and if you simply look at optimization, then it's certainly in scheduling, so really in workflow optimization in the hospital. I think in the USA alone, there are studies, 10.5 billion costs are incurred every year due to mismatch and scaling or no shows. And I think that if you, we're getting into quantum machine learning now, if you take the algorithms that are currently used for scheduling and either optimize them with quantum machine learning or maybe even go in the direction of quantum annealing to solve the optimization problems in the scheduling area, that you could certainly do a lot there. Quantum machine learning in general, if we now think further from the AI side, from the IOT, from the metaverse, then I believe it is incredibly helpful if we can make these algorithms even better faster with the help of quantum machine learning. I believe this is also justified and there are of course an incredible number of use cases when it comes to implementing digital twins of patients, hospitals and production facilities in the metaverse.
Interviewer	Very exciting. I think we can even jump straight into our scenarios, because they contain a lot of what you have already mentioned.

	Exactly, the very first question would be the following: In my research, I primarily identified the following 4 areas that will be particularly affected by quantum computing, or that could have a particular impact on everyday human life, and that was precision medicine, diagnostic assistance, radiotherapy and drug discovery. Do you agree with that?
Interviewee	Yes, that really goes in the direction that I said, where we have to differentiate between the life science market, i.e. the pharmaceutical market and the healthcare market, and these are really two different markets, if you look at it from the industry side but also if you look at it from the B2B side and I don't know how much importance you attach to making the distinction there, because in the end it's also about developing the use cases there and you have very different players. In the pharmaceutical market, for example, you don't have any healthcare providers, i.e. hospitals that you work with, and you don't necessarily have the same relationship with the players, i.e. the insurers, that you have in the healthcare market, for example. Yes, there's a different dynamic and that's the exciting thing, because you have to assume that it's not just the technology that has to reach a certain level of maturity, the market also has to be there and the business cases, otherwise the industry won't reinvest. Then it's great what you can already do academically in basic research, but we're also seeing that in the quantum area right now. There are so many start-ups that either offer this as software as a service or actually produce hardware. And sorry, I'm digressing for a moment, but I think that's important to ultimately answer this question: Which of the quantum technologies will then actually prevail: superconducting, photonic, IO trapping? But it's also important to look at the various indications, what is suitable and with which partner would you approach which use case, so to speak? At the moment, many are focusing on superconducting, where you simply have to say that photonic, for example, definitely has its advantages, especially when it comes to even more complex problems. The topics from Heathcare, which you mentioned, I really think in these three major areas oncology, cardiology and neurology. Quantum can be used in the field of precision medicine (important to note: What exactly is precision medicine? Is it about the clinical outcome? What are the KPIs? There is already a lot of research in this area. In the field of oncology, i.e. tumor and radiation therapy, optimization. When it really comes to radiation, i.e. identifying the tumor volume even more precisely, but also really in patient path planning, using the optimization capacity of Quantum. And the same applies, of course, to other diseases that are being caused by demographic change.
Interviewer	That was a lot of really great insights, thank you very much! I would now like to present the 3 different scenarios that we have considered as examples for a day in the future. The first is a digital app on a cell phone that uses a quantum-controlled sensor in a person's body to provide precise information about the person's current state of health and also forecasts for the future. Examples here would be the exact representation of life expectancy in 93 years and 4 months, or that the perfect ration of vitamins is already flowing from the dispenser. Can you imagine such things in a future with quantum computing?
Interviewee	Well, for me, it's really moving in the direction of quantum sensing and I wouldn't say I would implant it now, if we really look at what manufacturers are

	already formulating for quantum sensor technology, such as Bosch, for example, who are also active in the field of healthcare, then it will be more wearables, so a kind of t_shirt or maybe a new watch or something that I put on in the morning, yes, and my heartbeat and everything, my sweat or my health status is checked via my sweat or other physiological information. Plus the dose of a drug in my blood is determined or in prevention: radicals, which can simply increase in my body in extremely early tumor stages, could be detected by quantum science. Or if we go into neurology, early forms of Alzheimer's or Parkinson's can be diagnosed, can be monitored and could then be optimized in conjunction with devices, for example with drug pumps. So I think that's definitely conceivable. But in my opinion, it will probably be some time before the size of the quantum sensors is small enough for this to work. Where that might come sooner, and they could look into it again and also a large field, and that is much sooner in my opinion, is the whole field of amputation surgery, for example, i.e. how can you mount sensors in arm or leg stumps or on them, not inject them, in order to be able to operate prostheses even more precisely. In prosthetics, I think this can be done relatively quickly, even minimally invasively, and of course there are also highly interesting business cases, so if you could increase the precision of a hand prosthesis from 90% to 95/98%, for example, you could of course also imagine incredibly good scenarios with insurers when it comes to cost avoidance business cases.
Interviewer	Very cool. I'll definitely look into this again in my further research. I would start straight into the next scenario, which is very much linked to what you said at the beginning. Here we imagine a particularly high-resolution screen that can detect even the smallest cancer cells in the lungs, for example, and can then be used to create a DNA-specific chemotherapy plan. It would be great if you could also give us your opinion on this.
Interviewee	So all of this would not really be visible to humans anyway, but it would have to be made visible to the human eye using software. I have just taken part in a study by the X, with this help for reading certain image information for a younger oncologist or radiologist in this case. To be honest, I'm not quite sure yet. So there are studies, there is research, at the moment I would rather say to optimize image reconstruction and probably even accelerate it. I could imagine, if we're talking about quantum, then I'd rather be back in the life science area of gene analysis, how can we identify our genome even faster, read it out and reduce the risk factors accordingly.
Interviewer	OK, all right, and then I have the third scenario and that would be a pill against Alzheimer's, i.e. a drug that could actually cure Alzheimer's disease. I've already read a few studies on this and that work is being done on it, but of course it's not ready yet, but do you have any opinions on this?
Interviewee	Yes, it would be great if there were. That will take time, so I think that's probably one of the scenarios that really lies furthest in the future. If it really is about pharma. There are so many factors that play a role in Alzheimer's disease. The environment, for example, genetics, as we've already said. Yes, I don't know whether there will be an all-encompassing pill.

Interviewer	OK, that means it will start with being able to detect Alzheimer's earlier, but not necessarily in the near future, so that we can talk about an actual cure?
Interviewee	There are already these, yes, these kinds of caps that you put over your head and can measure the changes in brain waves at a subatomic level, which is much more accurate and precise than NEG can do today. If you had something like that or could miniaturize something like that in order to simply monitor the progress of the disease very closely and accordingly give the drugs that are on the market or perhaps also make behavioral recommendations. That would probably be the first step. I would just estimate that, because the approval of such drugs would take longer, I guess. And quite honestly, I would guess that yes, Alzheimer's is common, but if we think in terms of medication, probably this longevity, which is now attracting an incredible amount of attention in America, yes, how can you prolong life with certain medications? So I could imagine that there is more money and the research follows the money. As sad as that often is. Yes, but I could imagine that something could probably happen in that direction. But maybe that's simply because I've just had conversations about it and I find it incredibly interesting. Alzheimer's is one thing, diabetes is the next, it's been researched for decades and we haven't really found anything yet, and that's something that goes broadly, that scales again, yes, you always have to see where you can get your research money back, so diabetes would be interesting there, obesity can be done something about it, which influences the fat metabolism, the household. So I would think more broadly and I know that it helps if you have a bit of an idea of the industry, where are the real business cases, where are the use cases, scenarios where you can either reach a very rich target group or a very, very broad target group, and that you would also invest in that.
Interviewer	OK, great, your statements really help us enormously! Apart from these scenarios, I have one last question about the healthcare sector. This relates to the ethical aspect, because we also conducted a survey to find out how people would react today if, ultimately, diagnoses - and quantum computing will probably get that far - were to be left to a computer somewhere. How do you feel about this? Will this somehow still come up against obstacles, challenges, that people will ultimately have to participate or trust?
Interviewee	The ethical aspect is always a big part of my seminar. Yes, I even devoted an entire block to it. We have the discussion with AI and we will also have to have the discussion with quantum, then the question is politics, government, payers, healthcare players, so where do you find a common denominator, shouldn't it actually be almost global? Because for me, quantum and AI can no longer be reduced to one country. That's one thing and the other is actually the end user, i.e. us patients, we probably won't be sitting at the discussion table during the ethics debate, and then the question is who is prepared to put their life in the hands of a computer and, above all, when. Once this has been standardized and it has been shown that life can be prolonged with a high level of quality, then surely everyone will want it. In the beginning, however, I believe that, just like with AI and all the influencers, there will of course also be people who will stir up primal fears and say no way and medicine is something so personal that putting it in the hands of computers is unacceptable. So I think these are two

	different tracks, and I believe that they will also develop along different timelines. Finally it is also important to say that ethically there could be concering questions and fears but on the other side this technology will bring new job opportunities and change the job market in a positive way.

Interview Dialogue 9

Interviewee	Right, Yeah. I am the Chief Executive Officer of Commutator Studios. I'm the founder of this Quantum Company. I'm originally from Puerto Rico, but I live in Dusseldorf, Germany. And I have over 20 years of experience in quantum computing. I studied engineering in Puerto Rico, but I wanted to do like the next thing in computing. That was really it. I was very passionate about the limits of computation. And I said back a long time ago, I'm going to go now after I finish my degree, I'm going to go study quantum computing. And everybody told me you're crazy, they don't exist. What are you talking about? I'm like, I know, I know, but somebody has to help build them. So I'm going to do that. So I've moved to the United States and did my doctorate there in quantum information. Then I worked at the Harvard University in one of my top teams in quantum computing and algorithms there. And that was a really great times because I used to, I was the organizer of Quantum beer, which was, you know in the Boston area, you have a lot of fantastic universities in quantum computing like MIT, Harvard, but also Boston College, Boston University, Tufts, all have very, like, they're very well known for very famous people in the field. And so basically, I mean like every day we have to go to a different university for a different seminar, like we were always like crisscrossing the city because there were so many good seminars, so many good invited speakers, and like at some point we decided like, we should all just meet somewhere also. So I started spamming the e-mail list with quantum Beer. So they're like, hey, if you want to meet up on Tuesday, this Tuesday at this bar, we go and have beers. And then all this famous quantum physicist, one of them won the Nobel Prize last year, will come. And we'll have beers. It was like 40 of us. It's terrible for the bar. They hated us because quite the physicists like we just we just talk about equations on napkins and like everybody hates us. But I would go on a slow day, you know, like a Tuesday or something. That's what I would do. And and of course, back then we're dreaming like, you know, maybe the future's going to be an industry and now there's an industry. And basically almost everybody that was drinking beers with me now is like a tough person in one of the top quantum companies. In the world. And after that I moved to Germany, I worked in Max Plank Institute and other places. I traveled to Lisbon too, by the way, because there's a colleague of mine working there in climate information. And then after some time, like the industry started to appear to happen. I was taken out of industry by a company called Strangeworks. I was just Chief Scientific Officer there. And then finally, about a year ago, I started to take the risk and take the leap and start my own company, which is both extremely fun and terrifying at the same time.
Interviewer	So cool, thank you for sharing! So, what is your company actually doing?

Interviewee	Yeah, so Commutator Studios. So just so you get a little background for the name the commutator in quantum physics. It's what's used to evolve the quantum state. So it's kind of like we're pushing forward the state of the industry. And what we're doing is we're using some of my scientific discoveries to build tools such that the quantum hardware performs better for specific applications. So it's like a software boost on the performance of the hardware. So for example we were able to show that a specific application that on real hardware maybe will perform only with 50% success ratio. We were able to boost it to like 80% and this is with very basic stuff. We think we can get much, much further with more advanced techniques that we're working on.
Interviewer	Ok great! So, maybe before heading to our simulation, maybe we could begin with some general questions regarding Quantum Computing. So, as you are kind of responsible for quantum software. One issue that always comes into our mind is like the difference between hardware and software. And as we have you right now, could you please explain us like briefly the main differences between software and hardware for quantum computing?
Interviewee	That's a really profound question because when you think of a classical computer, when you think hardware, you think of a silicon chip with transistors, right, and cables and then the software is the series that you sent through that, right? Like that's roughly but it's not quite true because actually some of the software is embedded in chips for controlling the hardware itself. So usually you say you have a section of hardware and software that way, but it's not quite true.There's something called middleware and it's really like there's software embedded in the chips, for example, like the software to control the chip controls all the chips. So we have to have some software to do it. And and you can see that there's actually many layers of hardware stuff that's like more roof control very still hardware. And then you have like at the at the top you have a browser with applications running at the browser like this. It's a continuum. And in quantum computing the same thing happens. But because it's only so different, we control very differently. The lines are not quite the same and it causes a lot of confusion. This is because it's too early to know. We haven't, figured out what are the proper terminology for this. So for quantum computing hardware, there's many ways to do it. We don't know which is going to be the winner. You have superconducting qubits. You have atoms or ions too. You have photonics, you have silicone, and there's a lot more. This is really how do you actually build the thing? What is the physics that you use to do it? However, unlike a classical computer, when you build this, when you build a quantum computer you don't end up with a transistor. There's no transistors in quantum computers, it's not based on that. You end up with some ways to control some bits, but this bit, this is not scalable like bits. The same stuff that makes quantum computing extremely powerful makes it also very fragile to noise from the outside destroying the information that you have. It works both ways and so although you might have some qubits they might not be so useful for computing. I mean a qubit is really a 2 level quantum system. So, you guys and me were made of atoms with electrons and so on. So we have many qubits too, right? But we're not quite computers. So to use them you have to have three main criteria, and it's more than that. But I like to simplify a bit. It's like why you want a lot of Qubits, right? That makes sense. The more cubits you have,

	the light approach you can tackle, they only have to be very good quality. Like if like you have to be protected. You have to live long enough that you can do your computation before they they like dissipate. You want to make sure that when you give them some operations to do, they can follow them properly. So if you think of it kind of like a dance, you want a lot of dancers. And you want when you give them a signal like they perform dance moves properly. And then the last one is you need a lot of connectivity. Connectivity means that one qubit can can dance with the other, communicate with the other. For example us humans we have a lot of qubits but our quality is bad and our connectivity is really really bad. So that's why we're not we're not quantum computers. You need to perform all three very, very well to how what we call a scalable quantum computer. And nobody has figured that out. Nobody, IBM, nobody has figured out how to do that. We think it's an engineering problem.We have and the all these different modalities of the atoms and the ions and the superconducting and the photons, they set different paths towards that because each one of those is better at different things. Some have more qubits, some are better connected. And you can do trade-offs between them, like if this qubit. Next to this one and they can connect and this one is connected to that one, you can suffice the one in the middle. So one and three talk to each other for example. And you can do a lot of things like that. Also if some qubits are very fragile, you can have many qubits kind of give IT support and help them out. So you sacrifice many qubits for one better qubit essentially. So that's that's how you do the hardware. Some of these techniques that I'm describing about how to coordinate this if you can picture it like it's a big dance with a lot of people and you want to very complicated choreography like the software is what tells them what is a choreography essentially that's what the software does somewhere it's very low level like like really really low level like like at this point you need to send this electrical pulse and this and that some is more advanced high level like for a specific application like you will think and you have everything between all that I would call that software. Some of that of course is middleware right in the same ways as before. So, I will say there's, there's there's people that really focus on control and error correction for example. This is very low software level to protect the information and there's some people that focus on specific applications that go on top of that like they will benefit from that. I will say I'm probably a commentator studios, or probably a little bit of both. It's kind of our secret sauce. We have a secret sauce for good control that's specific for applications. And then of course, in the end, a customer, the application that we'll see for finance, for logistics, for pharma, for all these things, they don't care if it's a quantum computer or not. What they want is to submit a problem in a format that's standardize a window and get a solution that's better than before, better or cheaper, faster, something like that, right? And that's all they care for. They don't care about the physics at all. They don't care about all the story I told you and I will say right now those are we have not reached the part, we have not reached the part with hardware or that that the performance of the of the applications is good enough. That a customer will use them because it saves them time or money and gives them a better result. That's not they do it because they want to explore the technology. That's the reason why they're using it.

Interviewer	Thank you so much for that. When you say that we are not at the point yet, do you see a time frame when this might all like, really work together?
Interviewee	Yeah, soo we don't know. Nobody knows. A lot of people like I would say people are now saying between three years and seven years. That's the number of people are saying, I don't know, I think it's the kind of thing that once you have a breakthrough, everything will be like it just happened, but you don't know when it's going to happen. So it's going to be like a singular event that somebody cracks something. Of course our position in is that we want to be in a good place to achieve that exactly right. Like we want to be part of the solution, make it happen, bring it closer and so on. It could be like I would say and also it depends what do you mean of of being valuable for the computer. There's like a little terms people use. One is quantum supremacy, and quantum supremacy is the term of when you have a quantum computer that can outperform every supercomputer that we can imagine in the world in the future too. That kind of performer is specific problem. The problem is not a useful problem. It could be ridiculous problem that has no applications to reality. So usually what it is you try to define a problem that classical computers are really bad at. And quantum computers are really good at and so it's kind of like like good and raw right like but that's like that that makes sense right. Now you want to see can they outperform some way what is the lowest line you can do it. So that was called quantum supremacy. There has been experiments already that claim quantum supremacy for this, but immediately, and this is very commonly so science works, then you people come up with better ways to use supercomputers to solve those problems and so we're still we're dancing around the line of of when it's going to happen. You're going to keep seeing it on the newspaper. Oh, another quantum supremacy experiment. There's going to be some pushback. That's not how science works. Until then it starts to be convincing. Then the other stage for usability is what I call quantum value, which is when people use quantum computers because of the same time or money. That's it, right? And that one is going to be probably after supremacy is going to be maybe, depends on what kind of supremacy stuff is achieved. Maybe starts a year or two after supremacy is achieved. And it's going to be for some very specific problems. It's going to be useful for very niche stuff. And then little by little, as the hardware and software improves, then it becomes more and more valuable for more and more people. And eventually you have the point where where my mom's cell phone is going to go up on a computer but and she doesn't know it. But that's definitely not in seven years. It's going to happen way, way in the future.
Interviewer	Alright! Thank you so much for that. Maybe one last general question: Which area of our daily lives do you think will be impacted the soonest?
Interviewee	Yeah, so, and this is a personal bias because the group I was at, Harvard, was the one that discovered the quantum chemistry algorithms. I have for quantum computers. I do think quantum computers are uniquely well positioned to solve quantum problems very easily and chemistry happens to be one of them. So that means like for example, right now when you think of a chemist, you think of somebody with like protective glasses that are lab coat.That really means they're basically a person with a doctor that has mixed cocktails basically, right? It's

	like it's a dull try and error. This is because although we know the fundamentals of how molecules work, which is quantum physics. Actually calculating it to predict and design molecules, it's very hard. We cannot do it. But for a QC it would be very easy to do that because it just it just fits the problem directly. So this is called quantum simulation. And we think that this is going to be very important because with that you can start designing bare materials for solar energy, for batteries, for medicines, for such. I think this is the one that's going to have a big impact. But the impact is going to be through the pharma companies. Like it's not going to be like that's not like my mom's cell phone calls to solve a chemistry problem. It's a song in the market. So, chemistry problems, I think they're going to have the biggest impact. They're going to transform pharma and chemistry. Chemistry, chemical company, So buyer or something, we'll have more people like me as opposed to be with the glasses and that's going to make it more efficient and they're going to be able to come up with better solutions for things. So in terms of once you have a rich scalability and such, I think there's going to a lot of the computational stuff in pharma, logistics and finance. A lot of it will use quantum computers and algorithms and so suddenly they're going to have more savings for better optimizations for for the problems.
Interviewer	Because you mentioned simulation and optimization, how would you divide the quantum computing applications in simulation, optimization, Machine learning? We also read Prime factorization.
Interviewee	So, there's many ways to do it because there's always optimization problems in everything, you can frame every problem as an optimization problem, like can you come up with the best one for this thing? That's always a very, very big thing. Quantum computers are OK at that. They're not great. They're, but they're better than classical. Like quantum computers are better at every problem than than supercomputers. But maybe you don't want to use them because supercomputers are good enough, right. That's that's that's one of the reason. But they're always better. They're always better, which could see they're like reasonable. And we think optimization problems in general are, we think beyond that they're pretty good, but not amazing. Chemistry problems, on the other hand, they're like amazing. They're like exponentially better. They can do things we think are impossible ever. For computers, like it's like very dramatic. So it's a huge, huge impact. So now it's just optimization. So some of the most popular optimization problems people are doing now is for example logistics. So logistics problems like the ones that our companies care for and such, they could be find the optimal route to my destination or like I have the high end delivery guy here find the best route to deliver all these packages in like the shortest time and and gasoline and then economics, right. This is a very difficult problem because you basically have to try every possibility. We don't know in a better way. So it's too many, too many possibilities. So one of the computers are a little better at that. But the same problem, the same problem you can have for scheduling, for logistics and scheduling is how do you make sure that the trucks are available at the right time in the right place. How do you make sure people are available? You have, you know, scheduling problem is when you have a big e-mail and you try to find a good time to have a video conference and it's a nightmare, right, 'cause you have all these parameters and they keep changing

	and it's like that's a scheduling problem. Scheduling problems of course work for logistics, but you can picture that also works for nurses in a hospital, right, for pilots in an airplane in airports, which is also logistics, right? Like, like you can see like this applies to many, many, many technologies. This is for scheduling. Other ones will be risk optimization of risk management. So this will be for example for finance, right? Like finance is like you're investing in many different shares, like many different industries. Let's say you want to have a very safe investment. You wanna lower the risk, increase the profit. But even if you can predict each, you have to kind of predict all possibilities together, because it could be that if one industry goes down, the other one goes with too because they were connected in some weird way. And figuring this out, it's also an optimization problem. So this is the one that's very used for finance and so on. So those are the main ones that we know for optimization. Factorization problem. It's also exceedingly powerful, almost like chemistry. Powerful like that's good but the use case for that is to break encryption so that one is of interest for the military side if a bad government hasn't they can steal everybody's credit cards in the world. So that's a big problem. We don't think it's going to happen before the other because that's very hard to do like the technology like I see mature and we have a hope that with quantum encryption which is quantum security that might be easier might happen earlier. So we will have a foolproof way to to protect ourselves from those attacks. Machine learning. There's two kinds of quantum machine learning. One is using quantum computers to solve standard machine learning problems, and we think those gives you a little bit of an upgrade. But then what I'm more excited is using quantum computers to solve quantum machine learning problems. So that is really you have a machine learning about a quantum problem, not bits about qubic site, but you have complicated materials and molecules and such and you're trying to really do something with that. We think quantum computers, just like chemistry, is going to be exceedingly good at that, and that's going to be about YouTube time. And just like you always said to optimization simulation, but just so you understand what even the pharma company I worked with, they were setting, they had some problems about designing proteins, which is important for medicines and stuff. And we were able to formatize the optimization problem because it was about lowering the energy of a protein it's like optimization is so broad that it can you can put it anywhere basically.
Interviewer	And how would you range these applications in a time frame? Because we also have seen like first optimization will take place then simulation, machine learning and factorization.
Interviewee	Yes, that seems somewhat reasonable but it it's quite nuanced like there's a lot of details because there's many ways to do each and such. But that's the first order that's correct that's what I would say too. But I will add a lot of more details that we don't have time in this call for. But it's tricky to predict the future right. I'm not in our business but that does seem like a Safeway to be imagined as scenario.
Interviewer	And maybe because we only have 5 minutes left, we could shortly introduce like 2 to 3 scenarios we both in. The industries maybe you run scenario from energy so so there's a very very smart energy distribution and. Due to this, it's

	already possible that due to the excess excess energy you got even money back from your energy distributor.
Interviewee	Yeah this is scenario is very similar to the finance use case and so on in some way because it's like you want to take the risk of selling when the price is high, risk is low, but the mathematics works the same. But that one is a common one and I think it's of a lot of interest for car companies because it's a way to justify electric cars as part of the big energy grid.
Interviewer	So you see it as optimistic that you can even get money back because it's so smart distributed.
Interviewee	Yeah. Although I will say that right now the reason what we don't have this, it's not so much a computational thing. That part is going to come, but it's because our electrical grids are not smart enough already because you want them to like first I need the infrastructure, right? And then you can take advantage of that. But when that happens, yes, absolutely.
Interviewer	So do you want to like introduce one of them Healthcare. Yeah, maybe I can. I can introduce one of mine that was that there's like a quantum steered sensor in your body that works together with an app to predict your current health status and future predictions on like your health status like life expectancy really accurate or. Your multi vitamins are already flowing from your drink dispenser because of that. How realistic do you see that?
Interviewee	I I don't know. I'm very familiar with the working quantum sensors. The quantities are great for some things I don't know any that are good at detecting like some of those things I could I could foresee people use getting more data out of it then the quantum sensors. I know that this is quite natural technology. Like they're really good at detecting life better. And so you can have like better radars and cameras and stuff, but you need a quantum entangled life for example. They're very good at that. They're very good at measuring time. That's the most. That's the way we use them. More like when you have atomic clothes. That's basically what they do. And that's how GPS works. Like GPS already uses quantum sensors in some way. And those are like the big ones, they're really going to detect in gravity and there's so much good at detecting the magnetic field of the Earth, so you can make better compasses basically. So I know that's very of interest for the military because they need it for submarines and there's some people who would say think birds birds use them like same kind of sensor but it hasn't been proven. I know the guys that do it and they're like yeah it's too hard to experiment to show it. So I would say I'm not familiar with specific sensors that would that we know of that are fine-tuned for some of the important vital characters is that you might care for. But I'm I'm hoping that will change in the future, but that when I would say some more future looking.
Interviewer	And maybe one last regarding mobility. So do you believe that autonomous driving will take faster in place and due to quantum computing, do you have some insights there?
Interviewee	Yeah. I'm actually working with a trucking company on this. So they have a lot of problems about route optimization and and so that will save them a lot of

	money and time of course. And the same of course like if you have autonomous vehicles then it's even better because it's you lower the cost of the driver and the certainties that go with the driver. So in terms of quantum machine learning for driving, I think that's a little far in the future. I would say logistics, scheduling, all that is going to have a huge impact in the short term and and then in the in the long term machine learning techniques for that. I think it's a bit more future looking mostly because I know the problems are really hard to to make them perform well in computers. So you need them for more maturity technology.
Interviewer	Alright. Maybe we have time for even one last example in the area of cybersecurity: We had a scenario that our bank had a cyber attack last night and this happens all over Europe in the past years because banks have been slow to adopt to the new technological advancement. Do you see this realistic?
Interviewee	So that one is a bit harder like I think it's probably one of the most important ones, but it's much harder and let me explain. So banks, as you say, they're really slow at adopting new technology and right now all they need to do is do a software upgrade. To be honest, that's it. That's easy. I think I don't even do that, right. That's like a problem, right. That's a problem with them being backwards and the way quantum cyber security, that quantum encryption works, which is it actually requires a completely new Internet, that's it's got quantum Internet. And this is being led by teams in the Netherlands, by a friend of mine, and also in Japan by another friend of mine and also with some private companies in the United States. They're trying to build a different Internet that says entangled photons through the fiber optics. So you need different fiber optic completely. You have to like take more pipes like I'm in do some of I'm begging for getting fiber optics to my house. It's not going to happen in several years. So you can imagine what the bitter is going to be like way more in the future if they can't really do that. Like I'm from Puerto Rico, we had like fiber optics for like 25 years now. Like I started, I can understand why doesn't want to get it so, and this is an infrastructure issue, right? You need this quantum Internet. You cannot do quantum encryption through a normal Internet. You need quantum. You need quantum Internet. You need a special Internet that uses completely different ways to communicate to have this better technology that ensures encryption.Now what does how does encryption work? So encryption is I want to encode some things such as the bad guys cannot read it right and the current encryption schemes that we use for credit cards, for Internet privacy, for transactions. This one's this one's the way they work is people came up with algorithms so mathematical processes to to to agree on how to do this encryption that we believe that nobody in the world will have a computer powerful enough to break it. So it's based on the belief that no government has that so you're gonna imagine some evil government has an incidentally more powerful computer than we could imagine it could be built. And the problem is quantum computers actually are that one. Quantum computers will be able to break that specific ways of encryption. It's still very, very much in the future but we know this very well absolutely like and and so so this is an issue especially for the military because for me, as long as they update every few years my credit card security, I'm OK from bad guys.But the militaries of the government, like usually they want to keep their secrets needed for 50 years, right. Like they need. Like they need they don't worry about not

	not somebody's think tomorrow is somebody breaking it in 50 years and so that's like that's like a real scenario and and then quantum encryption provides a solution to that. So quantum encryption is this idea of using the quantum Internet to use the entanglement properties of photons to do a better encryption. And the reason why this is better is that quantum encryption instead of being based that you assume that a bad guy cannot, doesn't have a powerful a computer powerful enough, right. That's like the current 1 quantum encryption assumes the bad guy cannot break the laws of realities as we know it which is much higher bar right.Like you know I could be wrong about guessing the computer they have in the house or in the building but breaking loose in reality that's like a tougher call.So so it's much more secure but it's the intention for sure is very long term security like that's that's really it. And I will say that one's that one's probably the one that's more future looking but the one we understand the best too that's going to be extremely valuable and it's why there's a feel because not then you told me you have like all major governments are interested in this right.They wanted this technology It's it's good because this is this could be a game changer right. Like suddenly the world could change if somebody just happened to have that computer and it would like the power will change. So I will say that one's the one definitely that is by far the most important for governments for, for, and in some way because of that they have led to a lot of investment in the field.

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Interviewee	That there is something inside the body that is constantly monitoring you. For me personally at the moment, it's still an idea that takes some getting used to. Perhaps future generations will be able to deal with these things more easily or differently. It's hard to say when you think about what the whole thing actually has to do with quantum computing, because we're a bit on the technological side where I say I can't really give any valid answers. Because I know that quantum computing is a different kind of technology in terms of how data is represented and processed on an elementary level in the computer. And now, without going into the details, it is relatively certain that quantum computers are also in, it is not yet entirely clear what form all this can take. There are also different technological approaches, but quantum computers can be simulated with normal computers and, conversely, quantum computers can also simulate normal computers. From the point of view of theoretical computer science, this means that the computability of problems, i.e. what can basically be calculated using technology, does not change with quantum computers. In other words, what changes, or what one assumes could happen with a computer. So first of all, it is hoped that this will naturally lead to an increase in computing power. And along with this, it is assumed that complexity classes could possibly shift from the perspective of theoretical computer science. And there is the assumption that this could possibly corrupt a large number of encryption algorithms that are used today. And that's where my knowledge ends. To map this onto your question. When you talk about something like this. Computers are very close to us, also from a medical point of view. Then, of course, the question of the safety of such systems is of fundamental importance. Nobody

	wants to have something in their body, a pacemaker, that anyone can access, switch on and off. If it really is the case that quantum computing shifts the complexity classes with regard to encryption algorithms. Then you either have to come up with completely new encryption algorithms, especially for asymmetric encryption. And if you don't find one, then we have a very big problem that quantum computing can even turn out to be an obstacle to further development because security can no longer be averted. We are seeing this today, also in the overall development of digitalization. More and more is possible, but we also have to invest more and more in the issue of security, and this is perhaps just the tip of the iceberg for now, and nobody knows how it will develop in the future, but we must not ignore it and it could be. It's always like that, we have a bit of a feeling that digitalization, as if it's a development that's increasing exponentially and nobody knows where it's going to go and so on and so forth, but it's also the development of our time, so it feels very progressive and that's quite normal. But it's not entirely out of the question that somewhere in this development, obstacles will also emerge, i.e. things that will slow down development again, so to speak, because problems such as data security will arise and will then no longer be manageable. I know this is very vague, but it should actually be included in such considerations. So if you think about it from the side, we can imagine all sorts of things, including, for example, medical technology, the scenario you outlined, and if you interrupt that now and say that this is really going to happen and, as I said, it's a difficult idea for me anyway, if I were constantly connected to the network somewhere and I could be completely monitored, I wouldn't like that for me personally at first. But perhaps other generations will be able to deal with it better, but of course we still have to ask the question, well, what are the requirements in terms of data security, for example, and also questions like who is even allowed to access it, who is even allowed to view such data and things like that. That would have to be looked at.
Interviewer	Mhm, very good. I think that ultimately alludes a bit to the next question. In Eva's next point of the day, when she opens her emails, she realizes that her bank has been hacked and her account has been emptied, which ultimately has everything to do with cyber security, which you have already mentioned a little. Do you think that something like this could happen, that we could have problems with our security in terms of banking and cybersecurity?
Interviewee	Denitiv, I said we are alluding to that. So you can now say with regard to quantum computing, OK, this is the next technological step in digitization, just as there were earlier developments in microelectronics, which is not the quality today that we had 30 or 60 years ago, no, it hasn't simply become smaller, it has also changed in other respects, so it could be that this is simply the next step. And then not much actually happens, except that performance increases. But if this occurs with the shift in complexity classes, then we really do have a game changer in the area of data security and then this may actually be a major problem, where at least a relatively large amount of catching up will have to be done. For example, all the cryptocurrencies and even blockchain, which actually have asymmetric encryption, asymmetric cryptography, underneath them. And that could possibly be copied by quantum computers, which is

	precisely the exciting question, and then that basically means that cryptocurrencies could possibly dissolve.
Interviewer	OK, yes, very good. Then the next point is also based on the fact that Eva's bank was hacked and now she's using cybersecurity to open a new account and that's perhaps a bit about what can ultimately be made more secure by quantum computers and that's this whole fraud detection thing, that banks currently still have the problem of rejecting potential customers based on their calculations, that they somehow don't fit into the customer base or ultimately admit the wrong customers who are ultimately not creditworthy and banks lose money as a result. And the literature says that this can ultimately be solved by quantum computers. Do you believe that? So do you believe that fraud detection and distinguishing fake customers from real ones can work better?
Interviewee	I have to admit that I'm not entirely clear about the connections. I haven't read this publication, so you are certainly better informed. It's not entirely clear to me how this could be connected and what predictions are being made about the capabilities and possibilities of quantum computing. As I said, if you just say it's an increase in computing power. And then you simply have to say that the entire development that we have seen in recent years, regardless of the performance of the computing systems or what you can simply do with computing systems, that of course immediately plays a major role, but ultimately this increase is always based on the progress of the technologies, i.e. simply on the availability to increase computing power. And what is or is not possible with it. I know it's very general, but it's difficult to say. It's not clear to me how it can be concluded that quantum computing in particular could solve this problem, apart from the fact that it is hoped that it will lead to a further increase in computing power and therefore somehow more possibilities. I couldn't draw any direct conclusions.
Interviewer	Very good. Then let's move on to another topic, namely mobility, and our first point has to do with route optimization, so that Eva gets on the bus and her bus always arrives at exactly the same time and her bus ultimately drives autonomously and maybe even there. So to the level that already exists today. If they know anything about it, because ultimately there is already autonomous driving somewhere, what do they think of it, would they trust it, would they ultimately get on such an autonomous bus, just give us their thoughts.
Interviewee	That's a topic we're also working on a bit. We actually have a project, I don't know if you know it, Monocab, which is not a bus, but a rail vehicle that is supposed to drive autonomously. It's about the topic of ATO automatic train operation and that's autonomous driving on rails. So your question was, would I get into such a vehicle? Yes, I would get on board, but I would say that this topic needs to be addressed. I mean, quantum computing is of course another way of increasing computing power further and further. But if you look at the topic of autonomous driving today, there's actually one key sticking point at the moment, so to speak, and that's securing the technology. We have a lot of artificial intelligence in such systems, but trained neural networks, for example, to recognize objects and analyse situations. And so you no longer have any so-called deterministic algorithms and can therefore no longer validate such

	systems well using classic, let's say, validation and test procedures. And that's basically where we are right now. Of course, this could also be important in other contexts, for example if, as you just asked about medical systems, you also have to have a high level of security. That they don't mess up, that everything is safe. So this question of security in autonomous driving, for example, can actually be transferred to other areas. Medical technology, for example, is currently still a major challenge when it comes to all these things. For example, when you have vehicles today, they have had a lot of software in them for years, but they were mostly relatively conventional, deterministic algorithms created by programmers. And with safety-critical systems. I don't know to what extent they are informed, for example, when something like an ABS or ISB that intervenes in the braking system and then they have redundant signal processing inside with two CPUS, whose software has been developed quasi independently of each other, i.e. by different development teams, and which monitor each other and that, for example, with this mutual, i.e. two development teams, has the background that you want to avoid systematic errors, any errors in thinking, which are then somewhere inside the human being. You have to do it this way and that way, and then he builds in something where he somehow overrides an option, a decision option, which can then somehow take place under certain conditions if something happens that is not wanted at all. And that's what you try to avoid. And we tested the whole thing intensively, first with sill scenarios and then with the help of hill scenarios. In other words, hardware in the loop, until the whole system is qualified to the point where we can say that it is now so well secured that it can really be used, and we are very sure that nothing bad will happen, and usually nothing does happen. I haven't heard of any accidents in recent years where any elementary vehicle systems such as ABS or ISP or similar have failed. And if you think about automated driving now. Then you don't have some of these deterministic, systematically developed algorithms, but trained neural networks, for example. And validating this is a huge problem because they would have to drive - I think there's a figure somewhere that I can't remember exactly, but I have several million kilometers before they have driven through all the situations - so that we can say that we have a validation of such a system that is so good that we can adjust it to the road. At the moment, this is not yet possible, and these test capacities do not even exist. We are currently considering how we can safeguard this. For example, just like a situation you know that there have been accidents, Tesla for example.
Interviewee	Tesla has always been very progressive on the subject of automated driving, they didn't let the vehicles drive on their own, but some of them did and then there were accidents, and there were situations like a cyclist being run over because she was simply overlooked by the system. There are also some strange arguments, some of which I don't think are correct. They say, OK, the system has now learned that it must not run over cyclists. That's nonsense, of course. The system has said from the start that I'm not allowed to drive over an obstacle, the system knows that, but the problem is that if someone is riding a bike and the image that appears doesn't correspond to that of a cyclist, because, for example, they have a big double bass strapped to their back or something like that and then it looks very strange. Then it is not recognized as a driver, then such accidents happen and now you can of course say, well, then maybe

	the system has learned to recognize a cyclist with a double bass on his back next, but if the cyclist with the trombone on his back then rides along, he will still be flattened again. So they understand that it's very difficult to safeguard such systems in such a way that things like this can't happen, because you have to have all the situations that could arise in this system. And to come back to this quantum computing, here again I personally have the problem that I can't say exactly, technologically speaking, to what extent quantum computing does something completely different at this point, taking into account reproducibility and complexity, I would have said, well, it might be more powerful and can do more, but at the moment we are actually more concerned with this question, this safeguarding. But the question of safeguarding is something that, especially when you think about advanced algorithms, artificial intelligence and things like that, you can project the problem onto your question of medical technology and other things in the same way.
Interviewer	But what do you have to say about this typical example, because of course you can tell the computers in the end, if this and that happens, don't run over the cyclist, but this very typical example: on one side is a grandma, on the other side is a small child and you have to run over one of them. Ultimately, you have to give the computer some kind of solution for the situation beforehand, which it then has to do at that moment.
Interviewee	In the broadest sense, if you think it through, this is a relatively difficult legal and philosophical problem. However, I believe that the current state of the discussion is that the computer is not allowed to differentiate between the value of the life of an older person or a younger person. That is my understanding of this discussion, that it should choose the path that is most likely to cause the least harm. But that is a difficult question. But I believe that it is a bit like that. If you think a bit about the relevance of this problem. Of course, the situation can arise while driving, but what human driver is in a position to make the right decision? In other words, I think that this discussion about autonomous driving is also going a bit in the direction of saying, well, if we can ensure that we have fewer road deaths with automated driving as a whole than with manual driving, then we have achieved an improvement and from then on we should actually be allowed to put this system into operation. Irrespective of the fact that accidents can of course still happen, which can never be avoided. And of course there is also the discussion that says, well, it's not quite that simple, so first of all, of course, you have the question of what you are actually assuming if you take the accident statistics, for example. Then, of course, many accidents or the majority of accidents are not simply human error in the sense of I made a driving mistake that simply happened to me, but there are of course also many cases of points, drug driving, excessive speed, simply unreasonable driving and then the question is, can these statistics be set against the personal responsibility of individuals? Can they be upgraded or set against automated driving in this scenario or do you have to say, no, we'll just take a statistic, i.e. a theoretically calculated statistic that only happens due to driving errors that are not related to misconduct per se, but where someone really just said, yes, I overlooked him or I misjudged the situation, but otherwise you didn't do anything wrong, that is. where you weren't speeding, weren't too close, weren't drunk or on drugs, weren't overtired and so on. If you take statistics like that, it is of course much

	harder to implement automated driving, for example, when you have much higher requirements, that is clear. And so such discussions are already taking place. And we're not quite at the end yet. But at some point we will actually have to say. OK, now we are so sure that we actually have to introduce this topic. We have other aspects, for example. And that is that we actually have to get away from private transportation. In other words, we need to invest more in public transport. And there is the huge problem that companies cannot find drivers, whether train drivers or bus drivers. And if you now want to roll out this system a little bit in such a way that you get some individualization into it, i.e. shuttles that you can call, then you have a much greater need for drivers and then of course the question is, how can you cover that and that is currently creating a lot of pressure in public transport, which is why, for example, more intensive thought is now being given to ATO systems on the railroads and at some point you have to say, OK, if we don't introduce automated driving now, then we may have damage in a completely different area. For example, greater damage to the environment. And we don't want that either. So it's like always in life, at some point you have to weigh up certain things against each other, whether road deaths are the right currency to protect the environment, that is of course also the question, but at some point you will of course have to make a decision. Personally, I would get into such a vehicle, I would have no problem with it.
Interviewer	Very cool. That was definitely a lot of exciting insights into mobility, thank you very much for that. Then another topic, I don't know if you're so familiar with it now, but in any case, quantum computing, as we've read up on it, has made it possible to find new and better materials in various areas thanks to all the higher computing power and optimization. Ultimately, one area of energy is solar panels, where quantum computing can be used to build new panels that have much more power and can absorb and convert much more energy. What is your opinion on this, do you have any insights?
Interviewee	Unfortunately, no insights. We are actually the Institute for Energy Research, but we are not so much involved in the development of PV or anything like that. But that is, of course, a very general assumption to say that if we have higher computing power, we can optimize things in many areas, i.e. develop new materials, would be just one facet. Of course, you could also say that we have completely different possibilities elsewhere. For example, with materials for lightweight construction or something like that. We could calculate completely new structures that are perhaps lighter. We might also be able to let go of completely different optimization problems. I really can't tell you now in the area of PV panel solar cells how much optimization potential that would give, whether you could make another 5% or another 20% on top, so to speak? I simply don't know. But I would assume that it's a very conservative guess that something can be done somehow, especially in the simulation, of course. If you do simulations that go into the materials, i.e. the interaction of molecules or things like that. These are extremely complex simulations that take a very, very long time, so computing power can of course make a difference. But I think it's very, very difficult to estimate where all this will end up and what the real delta is compared to what we have. Unfortunately, in many areas we have to say that I am involved in optimization, as we have in the energy sector, that we do

	optimization calculations. This involves, for example, the question of how to pre-control certain systems, how to operate an energy system, when to use storage, when to use external energy, when to use which storage, things like that. We have been doing this for a relatively long time in the context of building supply. We're a bit into the area of optimizing production facilities. Our focus here is actually on energy-optimized or energy-efficient production, i.e. ensuring security of supply is an issue, but also using as little energy as possible or as much self-generated renewable energy as possible. And the optimization calculation that you make there and what you can achieve with energy management systems, that's what it's called, is not zero, it's worth it, but if you look at it closely, it's in the sobering few percent range. So if you take a reasonably intelligent, not completely stupidly designed, but not super-optimized energy management system and an optimized energy management system. You can get a few percent out of it, that's in a software, you say, why not, so you get the percent for free somewhere, but it's not like you can say that it saves us in terms of climate change or that's what brings a lot. So what brings a lot are actually structural optimizations in the companies, so investments in appropriate facilities and equipment, that, you can say, it brings a lot. But as I said, that's not what you were asking about.
Interviewer	But that's actually great. Later on, ther person gets her electricity bill because she has also optimized her entire house, so what you've just mentioned with power distribution optimization is already great, so it fits.
Interviewee	Yes, you can achieve something through optimization and computing power plays a role in this. For example, we have now also been involved in the development of a new hybrid vehicle transmission in the area of hybrid vehicles. It was always about optimizing this transmission, so I don't want to go too deeply into the technical details, but one of the tasks afterwards was how do you actually drive a hybrid vehicle, i.e. how do you control it. The possibility of saying I take the energy from the battery or I take the energy from the combustion engine if you have a longer journey and say I want to use as little energy as possible, i.e. as little fuel as possible, then you have to know how to make optimum use of this energy in the battery. There are rather unintelligent strategies that, for example, drain the battery at the beginning and then we continue driving with the combustion engine at the end. That's the stupidest thing you can do, because the battery should actually be used electrically where the combustion engine is then optimally supported - in any case, you can also calculate optimization and a limiting factor was actually always the computing time, so to speak, to have a result, a solution, before the journey is already over. Such things are of course easier to solve with more computing power, that's definitely the case. But you also have to criticize digitalization because it also costs a lot of energy. And now, of course, let's just say that a lot of development has gone into making digital electronics more efficient in the past, i.e. reducing the size of structures not only ensures that you can calculate faster and fit more into a smaller space, but it also means that computing operations, if you price them in terms of energy, simply become more efficient. And yet, all in all, the demand for computing power in what we simply do has of course increased so much, also due to networking, that today - and there are statistics on this - we need so many power plants simply to maintain our digitalization. Of course, if

	you now say, OK, that's going to increase further, that's also the question with quantum computers and I have to say, I can't answer that either, I have no idea to what extent that will now lead to the individual computing operations somehow perhaps becoming a little cheaper from an energy point of view, but on the other hand, but if you say I want to do an incredible amount with it, then in total an increase in energy is necessary for such things and then the question is quantum computing is that something that everyone now has at home or is that something that perhaps takes place on central computers? That brings us back to networking and data traffic. Then we are back to the question of where there may be limiting factors, for example what can be transmitted at all or wireless networks. We can see that the standards are getting better and better, that more and more is possible. But I said at the beginning that we can't rule out the possibility that there are limiting factors somewhere that we can't see at the moment. In the optimization calculation, for example, when I say I would calculate optimization in the vehicles. Let's just take that as an example, then you could now question whether there really is a quantum computer on site in every vehicle or take something else, don't take a vehicle, take an airplane, take a ship, take your own home, or whether it's not rather done centrally somewhere.
Interviewer	OK, maybe we'll stick to the topic of energy in the sense that we've already talked about electric vehicles. We were thinking, OK, what if we have an electric vehicle that we can plug into the socket in 10-20 years' time and it's fully charged again within 5 minutes, which also involves certain batteries that can be manufactured accordingly. What is stopping us today from being able to produce batteries that are capable of doing this?
Interviewee	Well, that doesn't have much to do with computers, does it?
Interviewer	Yes, speaking a bit from the side today. What would be necessary for this to work and perhaps Quantum Computer could help?
Interviewee	Yes OK, so with batteries, it has to be said, we talk about the so-called C-rate. It's not difficult to explain, a C-rate corresponds to a certain charging current, you could say a certain charging power. If a battery is charged with a C, this means that it is charged from empty to full within an hour. It can also be discharged with a C, which means that the energy is removed so that it is empty within an hour. But a C is always scaled to one hour. You try to detach this a bit from the capacity of the battery, because that is independent now. So if it's a large battery, a C is a greater charging capacity, a greater charging current than for a small battery. But a C is always scaled to the capacity and you can say that certain battery types are always associated with certain maximum C values when charging and discharging, that you say, for example, a medical ion battery, for example, depending on how it is made, you should or can discharge it with 4 to 5 C, but you should charge it with a maximum of 2 C, charge it with a maximum of 2 C, which means it is full in half an hour. If you now say that we want to charge batteries within 5 minutes, what is that at the moment 12 C? So charging at 12 C would not be possible if you were to do that for the lifetime of the battery, because certain processes in the battery must of course be able to take place without the battery overheating, without any incorrect layers building

	up in the battery and so on. So you have to go relatively deep into the battery technology. We've worked with batteries because we deal with energy and I've also worked with battery electric vehicles for a long time, so I know a bit about that. But I don't think we should go too deeply into battery technology. It's difficult to say how it might develop in the future. There are vehicles today that can charge quickly and are fully charged in fifteen minutes. I can't rule out the possibility that this could be achieved in 10 minutes or 5 minutes at some point, that's a question of battery development. I think the limiting factor for electric vehicles will be less and less the charging time. I think that can be made relatively flexible. The limiting factor for electric vehicles is actually the question of where we actually get the electrical energy that we use for electric vehicles. After all, electric vehicles are only environmentally friendly to the extent that they really do run on renewable electricity.
Interviewee	OK, and even if you say we have renewable electricity in the grid, you always have to be aware that electric vehicles are additional consumers that basically cannibalize the other classic electrical consumers that we can't simply substitute. So the idea is that we take the remaining electric vehicles in traffic and calculate the electricity mix, for example, in order to calculate the energy balance. However, we ignore the fact that with this electric vehicle as an additional consumer, the energy mix for all consumers across the entire grid is somewhat worse than it should actually be. That is, if this electric vehicle were not in the grid. So quantum computing or, let's put it this way, an increase in computing power in relation to this topic. I could also imagine, if you've just talked about it, that you can develop better PV panels using better computing power, then I could also imagine that you could perhaps develop better batteries, that this would also help with the simulation of such processes and that this would then simply have a supporting effect in the regulation, that is conceivable. Another direct influence:I think you always have to say that this distribution of energy is also an optimization problem, which clearly helps computing power. You can get a few percentage points out of it. If you increase this at will, you somehow run into saturation. In engineering, this is also known as polishing the nipples. I don't know if you've ever heard the term when these copper nipples are somehow polished to make them look nice. That's the proverbial term for this over-engineering according to the motto: At some point, I'll put another 100% of my manpower or other energy into an improvement that will ultimately yield another 2-3%. But otherwise I don't know exactly where this could help. So of course, computing power, the issue is clear somewhere.
Interviewer	And if we take electric cars even further: Eva orders a drone cab because she needs to get from A to B quickly in the afternoon. Ultimately, people are already working on drone cabs and flying cabs and all sorts of things. But ultimately, quantum computing can also help in terms of computing power and optimization problems, because ultimately a lot of things have to be calculated and included in air traffic. Take-off, landing et cetera. Do you generally believe that we will be driving around in air cabs at some point? Do you think that quantum computing can help with this?

Interviewee	So to get back to your core topic. We've actually established that now. Quantum computing can help wherever more computing power is needed. So, I would have categorized the topic of cabs differently. I don't know whether that will happen or not, because it's always a different story. I'm always very, very cautious about predicting the future. But if you want to hear my personal opinion, that's the biggest nonsense of the century. Because we know that it costs a lot more energy to move these things through the air than, for example, electric vehicles on the ground, and while we're talking about the fact that we have a problem with energy, want to remain more efficient and people are being told to leave their cars at home and take more buses and trains, on the other hand, we're dreaming of flying drones that can take us somewhere in no time at all. That's kind of crazy. I know these things from drones, which also have a niche purpose in certain areas. For example, supplying the North Sea islands or something like that which is now being tried out. Maybe they will simply exist because people want to fly around in the air with these things, but to be honest, I can't comprehend the idea of this becoming a mass means of transportation for many people.
Interviewer	OK, very good. Then one last question, perhaps about finance, and that is have you ever heard anything about how quantum computing can ultimately help with Monte Carlo simulations, i.e. quasi risk minimization in portfolios, by increasing computing power again?
Interviewee	Well, you've caught me in the area where I know the least about. Again, I can only say what I know. Is this danger of cryptography, i.e. the dangers of cryptography, where I don't know what the impact will be, where quantum computers will have a negative impact, and of course this will be a big problem in the financial sector in particular, if we've already talked about it. Yes, with problems such as risk assessments, these are of course also computationally intensive problems. Of course, one could imagine that this would simply be easier to calculate, but to what extent this could become a game changer, i.e. where there is no gradual improvement, where you simply get it a little better, but really such an improvement that you say it's a game changer or something like that, I can't estimate that now. Because I'm talking about risk assessments and that basically also relates to the optimization problems we have in the energy sector. For example, there's also the question of solar irradiation, how it will develop over the course of the day, a lot depends on whether I'm able to optimize my system. Incidentally, that would also be an aspect that could be mentioned, perhaps we will be able to predict the weather much better in the future with quantum computing. But I would almost say we are at theoretical limits, for example with the weather, as we know, chaotic system, butterfly effect and so on. We have just predicted somewhere into the future, then an ever greater uncertainty and whether you can really narrow this uncertainty corridor even further, so to speak, through quantum computing, i.e. through massive computing power, how far you can narrow it, I don't know. But I believe that we will certainly reach some theoretical limits where we can say: OK, you can't do anything more here with computing power. This is simply inherent in the systems and I soon believe that there are similar problems in the financial sector. Because in the financial sector, a lot simply depends on psychology and a lot of external effects, which is what we're seeing again now.

	Then a terrorist organization like Hamas thinks of doing something really stupid. And that clearly has a huge impact on the global markets, apart from the other bad things that have happened. Can you really solve something like that with massive computing power? I would doubt that for now.
Interviewer	Then perhaps I have a social question to follow on from the last thing you said. One scenario that we have also just considered is that technology is exploited maliciously, so that we would actually have to reckon with cyber wars that could happen in the world, and that is perhaps a fundamental question, I know technology has been with us forever and somehow our society has always managed to adapt to it, but do you see quantum computing, which ultimately has a strong influence in cryptography in particular, as a greater threat than technologies have had in the past or a greater impact that this could really have on our society?
Interviewee	Ah, another very difficult question. I don't necessarily want to say it's like this or that, because it's difficult, I'd have to say I can't answer it. But perhaps I can give you some food for thought, maybe that will help you. With regard to the security of our security, especially in terms of destruction. The biggest game changer in the last century was the development of the atomic bomb and I think something that is still on top of that now. It must be a really big thing. Of course it's conceivable and we also face the dangers of digitalization every day. Cybercrime, people being ripped off. The costs associated with this, i.e. the damage on the one hand, but also the costs that institutions incur to make their networks secure. Companies, but also our university, for example, now invest, I believe, a total of three hundred thousand euros plus every year in various measures to make data processing more secure. You simply have to see this as damage from computer crime. Or, for example, this idea of cyber warfare. Sometimes I wonder whether we haven't already been in it for a long time, because how else should we assess the impact of various trolls in the various crisis scenarios we have? Whether this can somehow take on different proportions, that, I don't know is hard to say. Of course, when it comes to artificial intelligence, there are always concerns that some people think it will take over the world at some point or something like that. There are also apocalyptic scenarios like that, I'm relatively skeptical, so I don't think that's necessarily the case yet. And in terms of other social developments, for example the question of the extent to which massive computing power and artificial intelligence will make us a bit redundant. Even the profession of professor, because artificial intelligence can do that much better, or the profession of designer, of engineer per se. So I'm very skeptical about that, I'm relatively relaxed, because I'm someone who always looks a bit more into the past and says, what have we seen in the past? For example, ever since automation technology started using robots, there have always been fears that robots would take our jobs, but what has happened? Robots have essentially taken over activities that no human would do today and ultimately it has increased productivity, which has benefited society by simply making more available. And so in many places there is always the fear that there will be upheaval, that these are changes, of course changes hurt. It could also happen that people who are in a bad position are then left with losses, i.e. they no longer have jobs or something else happens. But basically, developments in the past have always

	shown that things have actually got better and better and society has more at its disposal, society has also been put in a position to solve its problems. I don't take such a terribly pessimistic view of future developments. Incidentally, it must also be said - and this is perhaps also a very general comment - that we have the feeling that this digitalization is a huge development, something that has never been seen before. In history, what a total game changer in all things and so on. I can't say maybe it is, we don't know what it will look like in 30 years' time.
Interviewee	But if you look at other developments. You actually have to realize that there have always been technologies that have developed rapidly and it has always been the case that people have always seen their time as very rapid in terms of technological development, and this can be proven by certain quotes or certain stories, even in some literature. For example, we simply have to put certain things next to it. Take the development of the airplane, for example. When was the first powered flight? 1902, I think. So 25 years later, in 1927, there was already something like the aviation industry. Another 25 years later, somewhere in the early 1950s, flying was something completely normal for many people in the USA. Perhaps not yet in the rest of the world, but now another 25 years later, of course, in our country too. So it's been a super rapid development. You don't always have to look at the wars, but wars are always a bit of an indicator and technology driver, whether you like it or not. In the First World War, just a few years after the first powered flight, the airplane already played a significant role. In the Second World War, it was the co-determining weapon system. So that was a huge, rapid development. Or take the railroad, I think the Adler here in Nuremberg-runs the first line in Germany, that was in the 1830s, so around 1835 or something like that, 15 years later, so in the 1850s, there was a network in Germany that connected most of the cities in Germany. Around 1900, the rail network was much denser than it is today, and everyone used the railroads. You just have to look at how things have developed and what about digitalization? The first computers were built in the 1940s. Ne Konrad Suse and the Eniac in the USA. 25 years later, in the 1965s, the first computers were actually used in companies.
Interviewee	They did simple things like, I don't know, bookkeeping or personnel administration, and another 25 years later, somewhere in the early 90s or something, computers were slowly arriving in private households everywhere. Today we are another 25 years later, of course, but if you look at it that way, we have 75 years of digital development behind us. And that's where we are today, and if you apply the same thing to technologies such as railroads or airplanes or something like that, then you have at least as rapid a development and in the 1930s, for example, there was a magazine called The Mechanics in the USA. It's always quite fascinating as a collector's item, I don't have that either. It depicted utopias based on the technologies available at the time. Of course, it wasn't massive yet. electronics or computers, they didn't know that yet, but everything was thought about mechanics. We bring ourselves via mechanics. But even then, there were already utopias such as flying, or what you just said, flying drones. So people have always perceived the development of their time as very rapid and we do the same today, but somehow it didn't turn out that way, for example the airplane. If you now extrapolate the development of the

	1930s, you could perhaps have said, OK, in the year 2000, everyone will have their airplane, it will only be flown or something, that's not the case. There will be obstacles at some point. The obstacles are also clear somewhere. For example, the enormous energy consumption of flying, which simply can no longer be covered, has led to this. OK, of course there are still airplanes today, there are still flights, more are flown than in the past, but it is no longer the exponential development that we might have assumed in the past.
Interviewee	Now we have to be honest and say that we don't know how it will develop. So I'm not saying that you can take any past development and apply it to new developments and say that it will happen in the same way. But we can at least say that the idea we had in a certain phase of technological development of how things could continue does not necessarily correspond to the future and, above all, obstacles can also become apparent that somehow slow down this development or shape it in a completely different way than we currently imagine.

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Interviewee	Yes, I'm happy to do that. I've been working at XX since the beginning of last year, mainly in the field of quantum computers, so my job title is Research Scientists, which simply means part of our central research and development department, where you can now deal with such preliminary topics. My background is in physics, so I also have a doctorate in quantum simulation, which means I also come from this field. That's not quite what I'm doing at xxx now, but experimental physics. That means it comes from hardware, so to speak. But that's also very helpful if you have a deeper insight, of course into a special hardware platform, which I've done myself, but also in other related areas, even if you have a physics background, it helps to understand that, which is also very useful, even if we at Siemens concentrate more on the application. That's exactly where I come from, from my studies, from my doctorate and then I saw that quantum computing is slowly growing. And there are also jobs in industry, not just at university. And I found it super exciting that you can also work in deep tech, it's still or just for me the physical properties behind it, which I found so exciting before that they can now also have a meaningful application if it works and that's what I personally liked about it, because before I did basic research, that's also exciting, but somehow that was no longer enough for me to say OK we're just looking at hypothetical models. It would be cool if that had a direct impact and you could use it to solve real problems, that's what I liked about it.
Interviewer	And in what area do you think quantum computing is most likely to have a real impact on our lives?
Interviewee	So what are the first applications where it could really make a difference, I would personally say in the field of materials science, chemistry is one, as others have probably already told you. Because you can really see a clear advantage, perhaps even an exponential one, that it's always very special, but a clear advantage over classical methods, because there are problems that you

	can't even solve theoretically yet. And then you have a chance of solving them at all. These are the kinds of problems that you want to solve one day. So mostly in research, which you can then work on. Another area we look at, which is a bit abstract, is solving differential equations, which is used in various simulations, for example computational fluid dynamics, which simulates fluid mechanics in a flow channel, for example. For example, when a car is standing there, preferably over the member stand. Stories like this are very special, but there is also an area where quantum algorithms are already available that are really much better than classical ones. You just can't implement them on the hardware yet, but if you can then. You would really gain an advantage there.
Interviewer	And what timeframe are you looking at? So when do you hope this will work?
Interviewee	Yes, that's even further in the future, because I think that if you think about when really realistic problem sizes could be solved, even for other types of problems, maybe something could be done. As a company that would do something in this application, you should also be quantum ready. So you already have a lot there. What can then really support the development of quantum-supported products, for example, in the beginning rather like research activities or Synology monitoring and later, sometime in the future, if it is really, it would be realistic that there will also be important products that will then also work with quantum computers, that is roughly a period that we have in mind, but of course it is all subject to error, such a future can be predicted, maybe we will already have strong quantum computers in 2 years, maybe only in 15.
Interviewer	And what is the biggest challenge before these important breakthroughs are made?
Interviewee	So I think a lot, I'm involved in applications at Siemens, which means we're not developing the hardware, but rather the software side, so to speak, and we're looking at where our products could actually benefit from quantum computing. For example, it's not necessarily chemistry and materials science at Siemens, but rather perhaps machine learning optimization and things like that. One part is certainly that it is still so far in the future and the predictions are all future predictions. It is generally difficult for more than 5 years and the technology is also developing very dynamically. We have also seen in the past that there has suddenly been such a leap in development, so it is probably not simply linear that you say, OK, in the last 2 years the number of qubits has doubled, then it will continue like this. And then what do we need here and there? That's probably not the case at all. And there is also a variety of hardware implementations that are very different, that also have very different technical problems and challenges and then perhaps there is a leap somewhere in such an enabling technology, then that just helps some of them and not others. There are also a lot of research fields around it, where new materials are being developed, for example quantum computers. And then it could also be that something is happening there. So that makes the whole thing very complex, there is such a variety of technological approaches, but there is also an incredible variety of software and algorithms, where there is also further development.

Interviewer	because you just mentioned machine learning. In the literature, quantum applications are often subdivided into simulation, optimization, machine learning and encryption, or what is it called? Prime Factorization, where do you see the greatest potential of these applications?
Interviewee	Well, the first one will probably go in the direction of chemistry, depending on what falls under simulation, I would say that it definitely has great potential. It's more difficult to assess optimization and machine learning. There's definitely a lot of application potential there and there are a lot of problems, but at the moment we're not that far along on the algorithm side. In principle, these are all heuristics. In other words, you find a better approximate solution. Most classical algorithms for optimization, which are state of the art, are also like that, and there's just nothing you can prove mathematically that the quantum algorithm is faster than the classical one. Not with machine learning anyway, because it's even more difficult, because we're generally more of a black box that you put in and then do something, you don't know exactly what's happening in there, it's actually quite different if I replace the core of my neural network with quantum circuits, at least in the areas that are more difficult to predict. At the moment it's still a bit of trial and error, but it's possible that something will happen. In simulation, for example, or in the field of chemistry and also in the factorization of Shor's algorithm, there are algorithms that have already been proven to be faster. You just can't run them yet. Now the question is, is there a big error correcting quantum computer first, with which you do these things, or do you somehow find clever approximations for optimization problems beforehand, which you perhaps already execute on intermediate state quantum computers, because you don't need error correction? Yes, it's possible that something is happening there too, it's actually happening at the same time.
Interviewer	Let's go to the industries. Energy, for example. Exactly, that through the new material developments much better batteries can be developed and thus both the cell phone and the electric car can be charged within 5 minutes, so simply much faster, because the battery is so much better. Because of the. Do you see this realistically with better materials? Do you have an opinion on this?
Interviewee	So basically, battery development is definitely a use case. So I would have liked to have actually put this under automotive, because this is one of the use cases that the manufacturers themselves are looking at, so also quasi developers, for example Bosch was interested, but BMW also both. It's certainly a use case that many people think is promising in any case, if you have materials like that, whether that means that it charges faster, maybe the battery lasts longer or in the sense of a longer range for the car or you can charge it more often, because at some point they are over after a few charging cycles. So I'm not an expert on that, but having said that myself, it's definitely an important use case.
Interviewer	At Health, we have considered, also based on the literature, of course, that there could be a personalized medicine app, which already exists, that can tell you exactly how long you can expect to live, for example, based on a quantum sensor in your body. Exactly, thinking very far into the future, but I also believe that such a quantum sensor is possible. Do you think that's realistic?

Interviewee	OK, only if I had thought that this is actually a different area when I say I have a quantum sensor and that is actually the crux that improves the whole thing, so to speak. Exactly again, what else then is not the quantum computer that is really used there. Otherwise, I wouldn't know if I could do anything directly with quantum sensors and the things I know. I could do something like that.
Interviewer	But we can also go further, for example, in cyber security, we have considered a scenario in which a bank account is robbed due to a lack of security measures and because they have not introduced quantum-safe measures. The bank. Is that a fear that Quantum Research has, that there will be a lot of cybersecurity threats in the future?
Interviewee	Yes, that's definitely the case, yes, that's a very good point, of course we have other applications at the bank. People are already on the move and there are already classic alternative algorithms that are currently being developed and should be more secure against quantum computers, i.e. post-quantum. Alternatively, there are also techniques that use quantum effects and generate keys from quantum communication. These are then also really secure, so to speak. However, quantum computers are also technically more difficult to implement. That's why you need different hardware, a different network, but in principle it works technically, it's just that at the moment it's more likely that users like the military are interested in it or where data is being exchanged particularly quickly and constantly everywhere, but it's so important that it's secure now and remains secure for longer. But that is also developing itself. The question is whether we can now imagine it being used everywhere on a large scale. Then you have to go in the direction of quantum communication.
Interviewer	Exactly then we have one more thing on automotive, namely in our automotive point in the simulation we have 3 aspects, namely the optimization of routes. Autonomous driving and controlled by quantum computing and actually there are also articles on air traffic and specific air cabs and drones, cabs, all optimized by quantum computing, do you have an assessment of whether these 3 things are really feasible? Is this also included in the companies' research?
Interviewee	So about the air cabs. I haven't heard anything yet, then the other two points, yes. So what you need in automotive, very important is this battery and fuel cell development, so these material sciences are also involved, so many are active. In quantum research, there are usually two tracks, these material science topics or alternative drives and, on the other hand, exactly what you say about autonomous driving, so they are often interested in quantum machine learning or exactly such optimization problems, for example, an optimization is also really relevant for the railroad, for example. but that is then a huge use case if you can really solve optimization problems well, as I said, it is difficult to predict, there would be many many use cases of a kind of route optimization or other optimizations in production
Interviewer	And with autonomous driving, is it more likely in research that every car would be centrally controlled by a large quantum computer or are there also theories where a car could have a small quantum computer in it?

Interviewee	I think the former. I had a conversation with colleagues from BMW because I had exactly the same question about how they actually imagine it. I think it's more likely to be a centrally controlled quantum computer. It's centrally located and runs on it, so to speak, which would of course presuppose that 5G is available everywhere, on the highway and the car communicates all the time, and I think it will probably fail in Germany. But you would also need that if there were a classic supercomputer, but I've also heard people spinning it around a bit and saying that maybe we have the quantum computer in the car, which is more likely. It depends very much on the technology, whether you can make it so mini. But that would perhaps be a case where a small quantum computer would really make sense.
Interviewee	Perhaps another point that comes to mind with Energy. Were you also an interesting use case, is something like grid optimization? Yes, but exactly the question, with the optimization problems is still more at the moment. Not yet the first use cases and would say, but if it works. In energy optimization or optimization in general. I think optimization in general, but an important use case for something like this routing for cars, but also for trains, would be something like quasi energy distribution via the power grid. Especially if this is also to be intelligent, if renewable energies taste irregularities given, then I still have battery storage in it or something like that.

Interview Dialogue 12

Interviewee	So I work on something called quantum control. OK, so a quantum computer is a. Its like a chip like your CPU in your in your PC. It's a very different CPU because it's actually QPU quantum processor unit and it's not digital. So your your laptop or your iPhone or whatever you have it it would be called classical is is digital so it has bits one on zero as you know and a quantum computer is based on analog. Actually the digitization in our laptops is also analog, but we just limit it. So we just kind of say if it's here we call it zero, if it's there we call it one. You don't have an understanding for whatever it's been between, but the actual electrical pulse that goes through our through silicon is analog. So that's kind of what was leaked with quantum computer what we have is a analog signal that that we use all of its spectrum more or less to to control the quantum computer so. We have real electrons inside that chip, similar to your laptop, but it's a very specially designed electron or let's say with what they call a qubit. t's like a register or like it's like your bits one and 0, but it can also be anything in between, so it can be 01 or anything in between it. So it's there are unlimited possibilities. For it to to be in that state, on top of that, it can be in a, it can be in a very, I guess interesting position called superposition where it's zero and one at the same time. So that's kind of like what makes it very interesting. That's the kind of the almost the most useful state has. So the superposition is what we really need, and so we have that and. Basically that the quantum chips consists of these qubits which are built very specifically for, for, for for us for example at IBM we use preconducting qubits. So that's kind of the basics of that. And we put this chip in something called the cryostat. It's basically a very large fridge. They cool it down almost to absolute 0. So which is -272 centigrades and

	basically we have then cables. Going to this chip, so this chip has inputs and outputs which are similar to your CPU. So if you have seen the CPU has many pins similar to this chip and those are basically ways where you can communicate with the qubits and this cable come out and then now you have to generate signals or electric Electro electric pulses to send to this through this cables. And then we kind of discounted the control we get. So we have a lot of. Specifically designed computers for this purpose. So we have, let's say you have your CPU, but then there's something called the digital analog converter. So we we basically generate a digital program like like let's say code put it, but then you kind of generate the, you convert it to analog from digital and we have also the vice versa version. Also, when you want to read out from the quantum computer, we have the Devices where we can read analog signals and digitize it, I think these two and then we have if you have 100 qubits you have hundreds of these control devices which are like specifically designed for this purpose. And then we we have, we call this control hardware. So all of these pieces and on top of that they have also very specific software for controlling all of this hardware. So this kind of together Is quantum control. So I kind of be at IBM. We built this ourselves. So this is kind of where where I come from.
Interviewer	And right now you're working more on the hardware or on the software part of things.
Interviewee	I work on both, so I lead a team
Interviewer	So as quantum computing could be as the benefits of quantum computing could be divided into simulation, optimization, machine learning, also prime factorization. In which benefit do you see the most potential?
Interviewee	This is not something there are clear answers out. There are many candidates that are famous as well, like the famous ones I would say are cryptography as well as chemistry as well as some of the optimization tasks. These are kind of the candidates, but we have so far to prove exactly. To what degree they are useful. So there are, there's something, there's a terminology called quantum advantage which we use and we are, we haven't still published anything in that regard. But that says we are not getting quantum advantage and there's a lot of debate. So for example, what Google did back, I don't know if you know what Google did something in 2019 where they kind of said we did something that was like across the computer many, many years. But later on there were there were many, many people who kind of didn't didn't believe it. So this is something open. But I think if if it if you were to get something quick like one of the first applications, I would say it's like whatever. It takes you many iterations or many many times doing the same thing and to speed up like to to get to your results let's say for example if you're working on discovering your formula. And then in that regard, you're doing like you're testing 1 formula, it doesn't work. You get your analysis back from that formula, you try next one. So you maybe you are not doing 1 by 1, maybe you are doing 100 tests, getting all those hundred tests back, looking at the results and then coming up with the next set of 100 tests to do based on their results. So this is one of the kind of, I would say very typical. Iterative steps in pharmaceutical processes as well as chemical processes to kind of to figure out what is the best formula or what is

	the most optimized. So this is kind of also has to do with optimization and here because of the nature of quantum computers, of being able to do things in parallel much better than a classical computer, that's that's where I would say is one of the very interesting. Very interesting application is where a lot of companies want to do. So yeah, that that's whatever involves that. So that includes chemistry because they're like working a lot on iterative processes. Then there is of course pharmaceuticals more or less the same and then there's also even financial market. So if you are, if you're doing like something, some analysis based on your data and you have a member you want to try it to to get to the most optimized. Value for that you kind of make your most profit. That's going to pay very quantum computer can be very useful. Classical computers can do the same, and they are actually doing the same, but it just takes a while. If you're in a hurry to make that, that's quantum computer can give you much better results in a shorter amount of time.
Interviewer	You just mentioned pharmaceutical and finance. Are those the industries you believe will have like the most benefits from from Quantum or?
Interviewee	Not necessarily. I think many, many other industries can also profit from this. I would say that, yeah, the kind of that depends on your type of application. So if you're for example doing, yeah, chemistry, chemistry, chemical and pharmaceutical processes, definitely perfect from this. But also like. If you're doing any type of optimization, so if you're for example a a traffic regulator like you're designing a traffic system for your city, quantum computer can figure out much in a much faster way the the types of, I guess the the types of traffic management systems you might need. So like where to put your red lights, how to organize your your traffic for the most optimized way. The things that require many reiterations, so that that's what I would say is kind of one of the biggest, but this is kind of the first type of publication. There are a couple of other ones that are unrelated to them, but this is kind of the first type. So if I think many companies can benefit from this actually. So if you are, if you're a cell comp provider, I think like in Switzerland we have Swisscom and thinking. Like if you have Orange, I don't know if you have something like that. I mean you have something like that also in Portugal. So there are many different companies that for example provide solutions where they need to figure out what is the best optimized way to to provide let's say a service to people that is kind of a very large service like self self-service that is that is optimized for people. So that's kind of also the other the other one like. How to figure out this kind of numbers across the city or that kind of very large scale systems? Another one, automotive, has been discussed. I don't know if how deep they will go, but machine learning is also another one. But at the moment, machine learning doesn't look so good because of it's. There are some lags that people haven't figured out compared to classical, obviously, so it's not yet as attractive as classical. I think in physics as well, there are many many problems. Like there are some problems in physics like figuring out the like the physical attributes of materials that it. But this is that that is a bit unrelated to this iterative process that is more related to the nature of quantum computer. Yeah, I think these are kind of the generalization. Again, I think this is quantum advantage. A lot of industries also haven't approached this field. I think I would say yet because they're unsure of its, its usage for them. I think as soon as it becomes more

	obvious and you you ought to know more about what how we can apply it, where we can apply it. I think we will, we will take more and more. If you want to think about it, it's like similar to GPU. Like a GPU is like the graphic card you have on your computer. In the beginning it was only used for gaming or video gaming industry actually that was where it was designed and then it was used for videos like to make videos and then it was later used for doing like animation, renderings, all of that. And then later on it was used for machine learning and optimization. So it has to figure out its industry, slowly I would say. But yeah, because we are still in there, I would say very much beginning phases of quantum here.
Interviewer	Thank you for these insights already.
Interviewee	Do you also see any time of time frame for these applications you mentioned?
Interviewer	I think they're slowly coming. There was a paper by us not long ago, a couple of months ago, which was quite, I think this is kind of the the beginning where we call quantum utility. Quantum utility is where we kind of argue that quantum computers can be used now. So in a in a in a way or another. So we are, we are kind of argue that you could you can't start using quantum computers in a way that you cannot use classical computers. So you already have applications, but not to the scale of classical computer. I would say there's still work to be done. But you could already start using quantum computers as of today, even for free online actually. But of course you need to know a lot about how to use it. But other than that, other than that, I think at the moment you can use it. This is not providing we are not saying this is quantum advantage yet. But at some point when we have more I guess cubits, that's kind of the goal and we can scale up to many, many more cubits. I think that's where where we can come up with a more, I guess stable answer on or like more I guess a more substantial answer towards quantum advantage. So and then that would be. There's a very wide range of thoughts on that subject, so from five years to 20 years, so. Yeah, again, this is very beginning. It's like the 40s in the mainframe computing for classical computers.
Interviewee	Thank you so much. We also saw that IBM has many collaborations. Can you maybe tell us about them or is that not allowed? Sorry, can you tell us about the collaborations you're doing with some of the companies?
Interviewer	Oh I'm I'm, I'm not involved on the on that side. So I'm mostly on a very deep level on the engineering side and yeah, so I I am not exposed to clients nice.
Interviewee	So maybe we can have a look into the our actual simulation and we've already touched upon the industries. You've said some things about it and maybe you can, if there is something to say, add on it how realistic you think it is. So from the literature we've seen that there will be many cybersecurity security issues going forward. And so in our simulation, we've set up a scenario where, for example, the bank account of our person who's walking through the day is being hacked. Do you think that's the sort of level where we will see cybersecurity fail in the future because of quantum computing?

Interviewer	I mean you have to adopt. So there's there's a terminology again here called quantum safe. So what do you do to make your application quantum safe? There is a lot of talk on this as well and I don't think anybody has this. I mean there are some basic rules. Like for example the basics of cryptography, One of the very traditional algorithms is you pick a prime number, a very large prime number that is very difficult to calculate for a classical computers. Or classical computer always has to figure out if this number is divisible by anything else in itself, then it has to kind of do all of these divisions. So without knowing exactly what is that prime number in advance and you need to calculate it an algorithm for. Where prime number takes enormous amount of time to figure out a very large number. So the quantum computer can do that in matter of milliseconds very very fast just because of this nature of to being able to do the things in parallel. So it can run, you know, hundreds or millions of divisions at the same time and the same number and figure out if this is, this is if if it's going to be that number.So that's kind of the basic. So that's why for example, if you have your password and it gets encrypted like your e-mail password and it gets encrypted usually with a with a key. And this key is usually a combination of some prime number and some other, let's say some other, let's say multiple, some other factors. But the hard part is this prime number figuring or this prime number. The other part is not that difficult to to kind of to hack or to crack. So if you are able to figure out this prime number very fast, obviously your e-mail password is in danger very fast. But this is kind of where the kind of the nature of this algorithm is questionable. Like can you come up with an algorithm that is not suitable for quantum computer to crack and that there already are some answers in the work. So there are already people in in the industry that are that have already applications where it's quantum safe. Now this is kind of a big question because nobody has really put quantum computer into real like real works of figuring out if they can really crack everything. But of course to your point not everybody has done this. So if people do not take action, of course there are there will be dangers and there will be cracks into the system. And this is kind of where where I think it gets really you have to change change applications and update your application and if you don't do that, of course that people will will capture it. And the other part is this is more more I guess security from a security perspective as is kind of the the problem for many or the the the thoughts for many. So like if you're there's something called information harvesting. So for example, if you're communicating, if the countries are communicating with each other, they usually use encryption to in their in their form of like in their e-mail or and whatever the format they're communicating. And let's say other other countries who do not like the other countries, they they only record this even encrypted data. They will not crack it, but they just record it because they can't like if it's radio frequency or anything like that and they just keep it. This is called harvesting. So they keep it for the hope that let's say in 10 years they can crack it all. So that's kind of the, the the other interesting part of this story.So there are rumors that big countries in the world like US and China and I don't know where the others are just collecting for now in the hopes of cracking them later. So this kind of this can also happen of course with anybody else. But this is, this is one of the I guess the scary parts of it like what is going, what is going to happen. The the short answer is that that we need to I guess not be as everybody on the planet, but companies who

	provide a service need to take action for protection reasons. But not everybody but not not me and you like as normal citizens.
Interviewee	May maybe you're looking looking at the time because we only have 5 minutes left. Could we ask you one to one more industry, so maybe maybe you can tell us in which industry you are maybe also familiar with. We have energy, pharma and automotive left.
Interviewee	I mean sure, I guess pharma is easier. I mean I have I have thought about this. So in pharma we thought that it could be possible to discover some drugs.
Interviewer	So maybe even against Alzheimer to heal Alzheimer in the future?
Interviewee	Yeah, I don't know about Alzheimer's enough, OK? But like for looking at the drug discovery process, which as of right now takes years.So if if you have faster results that could come up and show themselves, we will get the time that the classical computer needs obviously down because of the current computer. And that definitely does speed up the discovery process. This is, this is exactly one of those iterative processes. So I think there definitely is hope.
Interviewer	And also do you reckon it will ever get to the level where the drugs will be personalized personalized to the specific DNA of a person could be.
Interviewee	I mean yeah I know I don't know about enough what drugs about how they make it so that if if there is anything like that involved in the process.
Interviewer	But if that's the case, if if they are not doing that just because of sake of amount of time things to personalize it definitely like if you're if you're just scared of number of parameters, the quantum computers, your parameter scale is enormously larger than a classic computer a simple amount of time. So we can if if that can be added to the algorithm, yeah, definitely correctly, we can handle it.
Interviewee	Thank you so much for your insight. What do you think? Will be the next my next big milestones in regard to five to 10 years.
Interviewer	Larger computers, larger, larger computers is the goal of the of quantum computers and of course quality. So at the moment the quantum computers have error rates and large error rates considered. I mean comparably a classical computer, you have an error rate of 10 to the -14.So every every many, many, many instructions you execute you will get one error. In a quantum computer it's like sometimes 1000 thousand instructions will give one errors. And if you build errors on top of each other then your and your calculations are wrong more or less. So that's kind of the two goals scale up and quality and these are the two most I would say. So if he and you're working on them both at the same time, OK, so yeah. Noise

Interview Dialogue 13

Interviewee	Yeah, sure, cool. So I'm Fabi, Fabian Viehoff, I'm a physicist, I studied in Karlsruhe and Berlin. And last year I was in Barcelona, where I also did research in the field of quantum computing. I actually started my doctoral thesis at the institute, but after a lot of back and forth, I dropped out because I realized that I somehow wanted to do something more applied, more industry-related and less basic research. And yes, the industry, the start-ups and companies that are now active in this field are desperately looking for people. In other words, it wasn't a disaster, I'd say, that I didn't complete my doctorate and yes, I've now got a job here in Munich at a company that actually comes from the field of Hyper Formance Computing, Super Computing and is now building up a new foothold. Exactly, and I've been working here in Munich for 2 months now.
Interviewer	Great, thanks for the intro! Then we'll just start with a few general questions about quantum computing and then go into our scenario later. And just so you know again. We're both studying business administration, so we're not from a technical background and we're not writing about that in our Master's thesis, but it's more about giving people an understanding of the technology and what impact it can have on our lives and doing a bit of research and validating it with experts and gathering their opinions. Exactly, do you have any questions?
Interviewee	Great, no, we can get started.
Interviewer	Very well then, you've already teased us a bit, but the first question is when you first got involved with quantum computing and in what context.
Interviewee	Well, the first time was probably during my Master's thesis, which was about quantum communication, which is kind of the counterpart to quantum computing. So it's about encrypting messages. You could also call it quantum cryptography. I was at the Institute of Photonics Sciences in Barcelona. That's exactly where I did my research and it's actually about encryption to make communication absolutely tap-proof, because the danger with quantum computers is also to crack the encryption technology that we currently use, even for online banking or browsing, because the encryption that we currently use is based on mathematical problems, mathematical approaches that are simply very difficult to solve and with a quantum computer you could hack them much faster. And that's why we have this quantum communication as a kind of counter-technology, or to counteract it, I should say. That's where I first came into contact with it. And then later through my doctorate. Yes, that was a year later or so, when I really got into it, actually in that area.
Interviewer	The second question is very cool: what would you say is the time frame in which quantum computing will ultimately be felt for the first time in our lives or really applied, because ultimately it's still a lot of research.
Interviewee	Exactly, so the question is whether we as end users will even come into contact with it, because there are already very special applications or problems that a QC can solve. In general, however, it will certainly take another 10 years, if not 20, before quantum computing really has a benefit, i.e. an advantage over

	conventional computers. You always have to compare where we stand with classic technology, with supercomputers, with normal semiconductor processors, which are already very fast and very powerful. Exactly, and it will simply take a few more years, decades, of research and development, both on the hardware side and on the software side, to understand all this and exploit the potential.
Interviewer	And if you now look at the three areas of simulation, optimization and machine learning, where quantum computing ultimately has an effect. Which of these three do you think will be decisive first or where will a breakthrough be achieved first?
Interviewee	I think simulation probably, because you can already simulate small molecules on the quantum computer, but you can also simulate them with a laptop or with a powerful normal computer, I say. But yes, I think simulations of other quantum systems or molecules or chemical elements, I say, that will be the first application.
Interviewer	And then maybe one last question, what do you think are the biggest challenges at the moment when you think about quantum computing research?
Interviewee	So scaling, because at the moment these systems are still very small somehow, you don't have 50, 100 maybe a few hundred cubits, and they are also still very susceptible to interference and noise and have errors and you want to scale the whole thing up. You actually need hundreds of thousands, if not millions, of qubits that all work well, that work without errors. And yes, there is simply a huge discrepancy. Exactly, so scaling and also the error rates I say and susceptibility of the system to errors.
Interviewer	Thanks for that! Based on this, we would now start our scenarios. First of all, we have based these on literature research, but they are nevertheless fictitious in the sense that we have deliberately formulated them provocatively so that we have something to discuss. We have divided the scenarios into our 5 different industries, Healthcare, Mobility, Finance, Energy and Cybersecurity. Does one particular area appeal to you or do you have no preference?
Interviewee	I don't really care, just give it a go.
Interviewer	Okay, great! So the first scenario comes from the field of healthcare and involves a digital app on a cell phone that uses a quantum-controlled sensor in a person's body to provide precise information about their current state of health as well as forecasts for the future. Examples here would be the exact representation of life expectancy in 93 years and 4 months, or that the perfect ration of vitamins is already flowing from the dispenser. Can you imagine such things in a future with quantum computing?
Interviewee	Yes, there are already quantum sensors or there is research and development going on that measure brain waves, for example, I think. There is certainly an application for that and it could certainly go as far as that. Yes, we could somehow have an app that can read this out for medical purposes. I don't know

	whether we'll have that at home or whether it will happen in a clinic, but who knows, it could happen, I can imagine it.
Interviewer	Okay, great! The second point is ultimately about cyber security. In our scenario, our fictional person wakes up and realizes that their bank has been hacked. You've already mentioned that. Do you think that our security, when it comes to passwords, banking, etc., will ultimately be jeopardized by quantum computing in the future?
Interviewee	Yes, it's generally at risk, I'd say, even without quantum computing, but even more so with quantum computing. Exactly, if you really achieve a breakthrough and have a fast, strong, high-performance quantum computer with enough qubits and enough power, then it will definitely be able to break and hack our current encryption. And that's why there's a bit of a geopolitical race, I'd say, to see who will be the first to have the quantum computer at a national level, so that they can possibly spy on us. Yes, that's very realistic.
Interviewer	But there are always two sides to cyber security: on the one hand, quantum computing is supposed to provide greater security, in that sense, but on the other hand, of course, it also poses a threat in some way. Do you see more of a risk or, in that sense, the encryption benefits of quantum computing?
Interviewee	Yes, so the development, or the still abstract danger I would say, is of course also promoting developments to counteract this, such as quantum communication or post-quantum cryptography, i.e. algorithms and encryption methods that can withstand a quantum computer attack. Of course, both are being developed and both are being advanced. If the danger exists and then you think OK, if that happens at some point, what can we do about it, of course, if we already know about it. So both, the danger is there, but people are already thinking about how to get around it or how to ward it off, of course.
Interviewer	Okay, thank you! Then the next point is ultimately that Eva reacts to this cyber attack and changes her bank. And we've read in the literature that quantum computing can ultimately help with this fraud detection, which is crucial for banks. Do you think that this is possible, that ultimately the right customers can be distinguished from the wrong customers even better than is currently the case?
Interviewee	Unfortunately, I don't really know that much about it. Mhm, so that the identity of the user can be better identified, or the creditworthiness? I don't know if the computer has an advantage there, I would even say not really. But I don't know that much about it either, to be honest.
Interviewer	Okay, no problem at all. Our next point is in the area of mobility and we have chosen a fully electric autonomous bus that picks Eva up at exactly 09:03 every morning and takes her to work. Do you see an advantage in the area of autonomous driving that can be achieved by Quantum, ultimately also a bit of optimization that plays into it? How realistic do you think the influences are?

Interviewee	Yes, route optimization in any case. And yes, perhaps all this data processing, this real-time data processing in autonomous driving, that's a very large amount of data that, I think, has to be processed in real time. And also the topic of quantum sensor technology, because you mentioned that a bit at the beginning in the healthcare sector, there are already products or research that can measure the battery charge status better and more precisely with the sensor and that can then optimize the driving time or how long the battery will last, because that is of course always subject to certain fluctuations. How full the battery is, whether there is still a residual charge in it. And I think a quantum sensor like this can definitely be an advantage. Yes, more accuracy I say. Better estimation of how far you can still drive.
Interviewer	The next point is ultimately very good in the field of energy, or rather in relation to the whole field of materials research, which is also to be improved by quantum computing, so that better, more efficient materials can be found and, in our scenario, in relation to solar panels, that there can ultimately be much better solar panels in the future through quantum computing, so that much more energy can be absorbed and much faster. How do you see the chances?
Interviewee	Yes, definitely, that's a huge area of application, materials research. I don't know exactly what the current status is with PV, but in general, I know that catalysts, for example, are also an issue with electric batteries, that new catalysts are being researched or can be calculated with the quantum computer? But yes, generally new materials in all areas.
Interviewer	Perhaps to stay in the field of energy. We've looked at batteries again a bit, and we can assume that an electric vehicle can be fully charged within 5 minutes. When it comes to batteries, there are other obstacles that are currently preventing them from being as powerful as we would like them to be. Do you see or do you know more about how quantum computing can help here?
Interviewee	Yes, those catalysts I just mentioned, but I'll have to think again about whether that was exactly what I read the other day. But in any case, yes, new types of batteries, I think made from other materials, lithium is being used in particular at the moment, but research is also being carried out into other materials that can be used for batteries that can absorb more power and can be charged more quickly. So I think there is definitely a big advantage that can be achieved. You have to simulate it in advance, before you do any experimental research or tests, ideally you can simulate it and I think that would be a good advantage.
Interviewer	Okay, good. Then the next point ultimately relates a bit to the fact that quantum computing can also offer personalized support, which is already quite advanced in the meantime, but in our scenario, Eva receives an email with a portfolio that is perfectly tailored to her and in which she can invest. Based on data that she has previously entered and she also receives this perfect customer support from her bank, she can write to the chatbot, enter her data and then receives this perfect portfolio. Do you think that quantum computing also has an effect and can help when it comes to personalization online?
Interviewee	Yes, there's also quantum machine learning, so as far as I know that doesn't make things any better per se, but I'd say it's cheaper. So if you take the

	computing time and power consumption into account, because all these AI stories and artificial intelligence are very computationally intensive, I think computing has an advantage in that it is faster and cheaper and, above all, more efficient, which is often the case with quantum computing in general. Computing can solve various problems that are still very computationally intensive and very expensive and require a lot of power, I say, so quantum computing can offer an advantage, be it in terms of time or cost. And then, of course, ideally more precise results, better results. Yes, I can see that as a scenario.
Interviewer	Okay great! The next one is again from the healthcare sector, it's very specialist, but we thought about the fact that her family has already been diagnosed with lung cancer, so she had a screening appointment and suddenly recognized cancer cells on the high-resolution screen that you couldn't have recognized before on screens that we have nowadays. And this results in the perfect chemo plan that can tackle the problem DNA-specifically. Of course, it's also very dependent on research in the field of medicine, but do you see any applications?
Interviewee	Yes, I think it's also going in the direction of image recognition or pattern recognition. I'm currently considering whether the quantum computer, yes, I think that actually goes in the direction of quantum machine learning in the end. If you think about what's behind it. Yes, I think that there is also an advantage advantage if quantum computing really works, that you can differentiate between things more efficiently and better and more clearly. Whether it is a cancer cell or not, i.e. the differentiation as such. Unfortunately, I can't say whether the therapy will have any effect afterwards. But yes, the healthcare industry is also a large area of application. New medical products will certainly be developed there, including new pharmaceuticals.
Interviewer	Very good. One last question, then we've already ticked off the financial sector. Have you ever heard that quantum computing is supposed to optimize this whole Monte Carlo simulation and ultimately help to minimize the risk for investments and deliver better results?
Interviewee	Yes, this is definitely a very active area of research. Of course, the banks are behind it and are interested, so portfolio optimization, risk minimization yes, these are all mathematical models, somehow, and I think quantum computing has a strong influence and advantage there too. Yes, many banks have their own research teams that are already working on this or in the insurance industry and so on. And I also know people who are researching it and have published papers and so on. So if you still want to get in touch, I'm really more of a hardware engineer, experimental physicist, and the whole application history, programming, algorithms and so on. That's not my area of expertise, others know more about that. So if you want, I can also put you in touch.
Interviewer	I'd love to! We would be delighted! OK, then we have one last example in the area of cybersecurity. This is more of a social issue, so we thought about whether this could lead to a cyber war if some politicians take advantage of the

	new technologies that are now available. It's probably a difficult question to answer, but just your opinion on it. Do you think that's realistic?
Interviewee	Yes, it is. It's still a bit of an abstract danger, of course, and there's a lot that we might not even know about the technology that the national security services NSA or BND or I don't know what they're already using, so they all have their quantum computing programs, some of which are secret. But there are also some public research programs, so a lot of money is being invested in computing worldwide, I'd say. Because, of course, everyone wants to win the race somehow or get involved. Yes, it's really difficult to say how and whether this will really degenerate into a cyber war, but yes, it will be a sensitive issue. In any case. Maybe at some point there will be quantum hackers who take advantage of this or governments who somehow want each other. I mean, it's already happening today, whether it's a quantum computer or a normal computer that's hacked or used for hacking. It's already happened, so it's a realistic threat. At the moment, I would say it's still a long way off and a bit abstract, but you can imagine it.

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Interviewer	And yes, we are also currently in Lisbon and writing on our thesis. And maybe to Ellie, yeah, so I'm also here at Nova with Emily, but I'm doing my Masters in Business Analytics. So slightly different, but we've decided to write our thesis together on the topic of quantum computing. So what we did is we have created a hypothetical day in the future, so a sort of scenario which covers 5 different industries. And in those industries, we have looked at the potential applications of quantum computing going forward. And So what we're doing now is we these, we've all derived from the literature that's out there and now we're kind of validating it with the expert interview such as yourself to see what the actual opinions are. And yeah, I'll quickly introduce how we want to go about this interview, if that's OK with you. And then we'll get right into it. Do you have any questions before we start?
Interviewee	No absolutely. I was just laughing of the positive of the literature. I think there is a little bit of hype on high performance computing right now, or at least this was. I'm not an high performance computing person, but I just started an activity, a new project on that with colleagues that do I performance computing. Normally I bring the energy inside experience and they also try to be careful because we are here in a moment of hype on the topic and obviously it's very easy to get overly excited, but that's the normal thing. So please go ahead, let's start, let's start.

Interviewer	So we saw your background in energy and want to do the deep dive on energy with you, but maybe you could first quickly introduce yourself and how you first got in touch with quantum computing.
Interviewee	Yeah, sure, sure, sure.
Interviewee	So, well about myself, standard introduction. I'm Italian. I start working in the energy, in the power system. Actually not really energy, but purely power system. When I start my PhD here in Germany, actually in 2009, then obviously as I said, I did my PhD here at Takan. I spent quite some time in the US and then I came back here in my current position between XX and XX. I'm an electrical engineer by training, so I come from the electrical side of energy systems. But since I joined here XX, English start looking a little bit more to energy system as a world. So especially to the integration of different sectors, electrical heat and and gas systems, hydrogen maybe now in the future how I get in touch with quantum computing, well, I just really get in touch that's the reality. So we just really started actually we had the so last summer, not 2023 but 2022, there was an initiative of the Nora and Australia Stadium for binding culture and for profile binding initiative. And basically what they look at is they want to receive proposal for projects, they try to define new area of research that are not covered by existing program. And so we submit a proposal. There was quite a long evaluation. Finally was awarded actually two weeks ago. Yeah. We had the meeting with the ministerial to take the official picture to start the project. The project is officially starting tomorrow. So we have literally really on day -1, not even on day zero they keep. So this is how I get in touch with Quantum.
Interviewee	What they want to do last things is about the project is really know there's the energy sector and we know why it's important and why it's relevant. We have the quantum sector that is going strong and has a lot of momentum and so on. The key point here was trying to see which value can we create the interface of the shoe systems so that we benefit a little bit about the community and also we create something that is relevant for the economy in Germany, in rural Australia for the future.
Interviewee	So how I get in touch with Quantum is simply because it's a big topic, so you start talking with colleagues, OK, Seems to be an appealing and interesting topic. We have some challenge in power system, especially in power system.

	Now, not the energy system, but in power system that can be approached with Quantum.
Interviewer	Really cool. Thank you. And maybe to continue what you just said and what are these challenges in the power system right now?
Interviewee	And the main, so mainly, OK, so you focus mainly on quantum computing from what we tried to look right now is quantum computing and quantum communication as another technology. So there are two main challenges that I see, one behind quantum computing and one behind quantum communication. With our focus on quantum computing, I think it's the most critical for you. Bottom line is power system though you probably heard I don't know what is your background in power system, but there was a big change on how we operate or how we design operate. Power system started about 2025 years ago. So historical power system work with a very large generation units could be gas or carbon or or nuclear power plants, basically very few of these very large that were regulated to fulfil the needs of the customers. This one was how systems were always operate. Now we'll start, OK, we want to decarbonize the energy structure. We want to move to renewables.
Interviewee	What happened is we have now a lot of very small units, and these very small units are also very distributed in the system. No, they are owned by different entities, all of different sizes, with different function, different characteristics, and they are not really controllable. Now if you have a photovoltaic system, eventually you can cartel. So we could normally say cartelling in the sense that you can decide to reduce the output power, but you cannot increase it if there is no sign. No. So so this one change a lot how we operate the system and this means we need to have there have been a ton of consequence. One of the consequence is the mathematical problem that we need to solve to design and optimise and operate. The system became much bigger, much, much bigger. Simply that. So we have a problem of computational capability, let's say and and quantum seems or has the potential to solve some of those problems. I don't know how much you you dig into the the quantum computing advantages and so on. But one of the key aspect is the quantum computing could be very good at solving problems that we call NP hard problems. So this one are a particular class of problems, mathematical problems that are normally very very difficult to be solved on traditional machine. So so the advantage of quantum computing could be these problems. Now the question that may be maybe you want to spend on this or not, but the question is how really are we able to formulate the problem that is relevant for power system that is also fitable for quantum and that's not obvious.

	So then that's the first question. And then the second question will be, do we have a quantum computing infrastructure that is powerful enough to solve a meaningful problem for power system? So these are not true. We need to answer both of those. In my opinion, the second one is less important than the first one in the sense that once we are able to formulate the problem that fit the quantum architecture, mathematically fitting the quantum architecture, then the second one can be merely they can lock their technology development problem. So maybe we cannot we don't have we just work on Troy problem today, maybe we work on on smaller systems but if we know that in 10 years there will be the infrastructure then it's fine. So the second one to me it's a little bit less difficult. The first one is really the the challenge of 10, please.
Interviewer	OK, thank you already. Maybe I can I can dive deep into the three scenarios we thought about. So the first scenario is very smart energy distribution which allow which allows that your excess energy is efficiently stored and distributed to other homes and industrial productions and that it will be possible that you even get more money back due to your energy supply, then yeah, you have costs. This is the first scenario, so maybe you already have an opinion for this or how likely it will become true.
Interviewee	But so the the the question is out of these scenarios, how quantum will play a role in these scenarios.
Interviewer	So maybe so how important do you see quantum computing for the efficiency of an energy grid?
Interviewee	OK, can let's do one thing because can you tell me all three scenarios and then we we talk later we work on because I want to understand how different they are between them, what do you mean examples and terms of language issues. So go ahead.
Interviewer	So rather in the field of quantum chemistry, I've developed a second scenario that due to the design and new material developments of solar panel panel materials, the efficiency has increased enormously. So as an example, this morning for one hour the sun was shining, which is already enough for two days of energy use in your household. And the third scenario is that it could be possible to charge your mobile phone and your electric vehicle within 5 minutes due to better material developments in batteries.
Interviewee	So the first one I can answer for sure. The second one and the third one, I have a little bit of issues, not really my field material and especially chemical engineering. Honestly.The third one looks to me a little bit optimistic.

Interviewee	I would like to know where it's come from but maybe it's it's possible? No. It's very difficult to say in this way in any way they're all quantum. They did similar, no. And it relates to the the stuff before. No. The one of the problem we have is you use the word optimization many times no. So optimization it's. So basically I think you have a mathematical background for sure through business. So optimization means to find the minimum of a function and you define this cost function that you are interested in as the name suggests, basically the cost of your system and then you want to minimize. Obviously doesn't have to be a physical cost that can be parameters, doesn't have to be a cost in euros. Now Quantum seems to fit very well. Optimization problems actually right now are the only problems that we probably can try to solve. There are two main classes of problem on which we are interested in, in power system for example. But in many sector, one is optimization problem, the other one are simulation problems, simulation. It seems a little bit more difficult at the actual stage. There are two main technology in quantum. There is a quantum annealing as normally called and another one that is gate based quantum IBM. For example, the famous query based computer from IBM Quantum annealing seems to be very fitted for optimization. Is actually basically made for that. So, there are possibility also for increasing efficiency. It's a difficult word when it comes to greed.
Interviewee	Know what do we mean by efficiency? It's not the traditional efficiency in terms of power in power out. That would means reducing the losses in the system. Yeah, maybe there can be A at all also to reducing losses, but I don't think it's what we look at. What we want we are interested in is in improving how we operate the system so that we are more flexible so that we can integrate more renewables that will be a big goal improving efficiency will be a marginal gain. Actually we don't have so many losses in in power system to to justify just improvement of that or or for that improvement to be significant for sure. But better optimization or the possibility of considering that maybe because of this the way the possibility of considering larger and more involving scenarios for optimization. It's what we look into when we look at one and I have mentioned this one. It's probably possible also for the material science. I can imagine material science, they have similar issues, similar computational

	problems, but I'm not familiar. It's OK.
Interviewer	And when looking at the first scenario, what sort of time frame do you reckon that might be?
Interviewee	It like in your field of study, what are you looking at? It's very difficult to say, not in the short term, but we are not in the short term. So first term, I mean five years, yeah, No, for sure, not in that time frame, 5 to 10 it seems maybe it's a chance to do something. It's very difficult right now as I said in the start no, the first things is to understand if there are problems that can be formulated so that they take advantage of quantum even on very small problem or or toy we often say toy problems. Then once we have done that we can make a projection and to understand when the infrastructure will be ready to to tackle real issues. But first of all, right now it's even difficult to say exactly which can happiest we will be able to use quantum and which benefit. It's really starting and so you touch a hot topic, but it's really starting. So yeah, we know it's early on. That's why we always ask for the time frame because it's the no, no, it's very good. I think it's a very good question. I mean it's an important question, doesn't mean that I have an answer. I recognise it's important. That's my best answer.
Interviewer	Thank you. But do you think it's more difficult to use quantum computing in the energy sector than maybe some of the other industries?
Interviewee	Similar challenges. I think actually energy sector in my opinion can have also a word in English kind of or pushing role in the sense no, the energy sector it's so important right now politically or better is perceived by the giant population correctly as an extremely important area. There's also a lot of political support in this moment. So actually in my opinion identifying a viable application for quantum computing in the energy sector could be a way to also speed up the advance of quantum technology because the dependency that our society has on energy is so big that everything would move quicker if we if we should link to that Note I not always but a couple of times I made the parallelism with them destination development and COVID know in the start you know everyone was like oh we will need five years for that and so on. Then when all the economy depends on that things get done much weaker and and so similarly if we show that there is a benefit in energy system. I'm sure also once the technology will develop quicker because just because of the relevance the energy sector has in our life and is there field in the energy sector you think quantum computing will have the biggest impact on. I think that this one may be too technical for for I don't know what is the scope of the, I mean different projects you're having, but I would say more into the

	design rather than into the operation. So in the design phase, I think maybe we have better chance than in operation operation. There is a lot of first of all the infrastructure is probably too expensive to support operation, but also the there is a lot of interfaces, a lot of things that will be needed before we're able to also use quantum computing in operation. But at least in design phases, I think that there is a chance OK.
Interviewer	And how how much do you think will be the impact on sustainability? So for example that you can store more renewable energies and will it help the transition to renewable energies or is that just happening by itself? And just to add on to Amelie's whether it will help the transition to renewable energies or is that completely individual to quantum computing that that that's it's difficult to say.
Interviewee	So a honest opinion is we should plan for a full comparison to renewable sources independent from quantum. We should work on quantum with the hope that make the transition faster, better, cheaper, whatever is possible. We cannot make the carbonization dependent on quantum computing because that will be a big, too big of a bet. But but at the same time, we can hope that that helps.
Interviewer	And do you think that there's one specific scenario we haven't covered in our scenarios which is So what are the scenarios that you consider?
Interviewee	I mean, I know, so the three scenarios you mentioned, OK, yes, OK. So it is more operation let's say and design and you have two about my team. So I think actually you have a good very good umbrella of of topics in the energy for sure in the energy for sure what that the other in the staff you mentioned you had five, yes, yes, yes what that was 5.
Interviewer	So energy, energy, automotive, finance, cyber, sorry.
Interviewee	I was just going to say cyber security communication, yeah, put that because that's a very good field on which they can have a lot of impact.
Interviewer	So I think it's a good point that you have it there, but are you worried about cyber affecting also the energy sector?
Interviewee	Yeah, yeah, yeah, we work on that. So this, this project will create with the encavae here on one side looks at computing problem, on the other side we look at automation architecture and security of those. So we look at what is called quantum communication and quantum key distribution as how they can play a role in power system obviously for semi security complication. I'm not a cyber security expert, traditional cyber security, but we try to look to the in this direction and honestly there I think technology is much more advanced than what it is for pure quantum computing. So the quantum computing can also be used for communication purpose, that's a

	different story. But quantum communication especially I think it's it's much more closer to an industrialization. So I would say that we can really expect an application in the next 5 to 10 years. Quantum computing, we can open 5 to 10 years to be able to say if there is an application, it's one step behind. I'd say, yeah, nice. I think that's basically it.
Interviewer	Maybe in general, do you have a feeling? I mean, you already touched it, but in which area do you think will quantum computing play the most important role except of energy? Or maybe it's energy.
Interviewee	I think in this one you have better luck just looking online. I don't want to tell you something wrong, so I think there are other fields on which there is closer application than energy. For example, I know the routing problem of communication, network, traditional communication, but solving the routing problem through quantum computing. It's something for example, where there's been more concrete work in the last years and know something in finances, but 'm not a quantum computing, let's say technical expert for this one.

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Interviewer	In which area of our daily life do you see the first quantum computing applications?
Interviewee	The first ones I would argue is material science and pharmacology. Kind of like drug design, stuff like that.
Interviewer	And then what sort of time frame would you assume
Interviewee	10 to 20 years?
Interviewer	Is there a reason?We've heard other experts say much smaller time frames, such as next three to five years. Why would you say it's more like 10 to 20 years?
Interviewee	So the the main thing is that the hardware,currently, for quantum computers, it's just not there yet and it will not grow fast enough to be able to solve, for example, small optimization problems, but we can do that on classical computers already. So classical computers are actually really good at very many things because they've had 70 years worth of engineering behind them. And to have an actual quantum advantage or something that it will likely take a good decade at least in terms of like actually doing something that classical computers in a decade won't also be able to do.
Interviewer	OK. Very interesting. you just touched upon the topic of simulation and from the literature most of the quantum applications are based on simulation,

	optimization, machine learning. In which of these areas would you see the most opportunities or the most uncertainties as well?
Interviewee	Looking at simulation, I think that's where the the kind of initial use case will be, where it really is successful to do something that we just cannot do on classical computers. I don't think quantum machine learning will succeed before then, mostly because the data that require that it requires.
Interviewer	And what about optimization?
Interviewee	Optimization is kind of an interesting one. It could. The problem is, classical computers are really quite good at optimization too. And we have a ton more classical computers than quantum computers. So as soon as someone proves that an optimization problem can be solved better on a quantum computer, on a classic computer, everyone will want to do that and the quantum computer availability will basically disappear. So it's kind of a market dynamic thing, right? As soon as it actually it becomes useful, the resource will become very scarce. The problem is people will then migrate back to classical computers to solve their problems because they just can't get their hands on, or at least not have a cost efficient way onto a quantum computer. And then you have a whole bunch of work that's being done on the classical side for optimization as well, right? This has been a big topic for decades.
Interviewer	But is there were to be the availability of quantum computers? Would you say there is one area or one industry where the quantum computer could actually replace the classical one?
Interviewee	I don't think replace ever. Because quantum computers by definition are good at solving a small set of problems and we don't know the entire set, right? They are good in combination with the classical computer in the sense that if your problem can be split up in some way such that you can focus on some sub problem that is good on the quantum computer, that's really where they shine. Quantum computers don't excel at being computers, right? They excel at solving a very specific problem or a set of problems.
Interviewer	And then maybe one last of the general questions in terms of innovation, is there any innovation like which was introduced maybe 20 years ago, which you'd say is comparable, will bring like an equally big change of quantum computers might bring maybe like artifical intelligence? Is there anything that's comparable?
Interviewee	So I mean AI and machine learning and so on is the big one, biggest. We just lived through it, slash are living through it. Other technologies don't really know. There is a lot more subdued ones. So the ones that don't have as much hype as quantum computing in AI. So I mean classical HPC work, there is a lot being done in that space that is very interesting and very kind of useful and will be fruitful such is, but it's not as attractive for venture capital money for example, simply because it's been around and it's being it's an it's an improving kind of situation, not a completely new disruptive technology.

Interviewer	And just touching up on that. Do you think the hype is justified right now or will it eventually die down?
Interviewee	It will definitely die down and we can already see the scenes designs. And no, it's not justified. And everyone that I talk to is afraid of it.
Interviewer	All right then, I think. Yeah, we can head over to our scenarios. We actually we are a group of five. So we divided it into five different industries, healthcare, mobility, energy, finance and cybersecurity. Hearing that, do you have like any speciality that you think you have the most knowledge about that we could start with that one or is it?
Interviewee	I think anything, I'm not very application specific, I'm more system software specific at the moment. So anything is what I can comment on, but maybe not very deeply.
Interviewer	OK, we just start and try, OK, we created Eva that is our person in the future. We have not yet created the exact time frame, but we imagine full quantum computing capacity. The first one is regarding healthcare, that a quantum steered sensor is in your body that sends information to an app and can there like visualise your current health status and future predictions so that you are even able to show your exact current life expectancy of 93 years and four months. And the perfect ration of multivitamins is already flowing from your drink dispenser. Do you think that quantum computing might have an effect on that, or do you have any concerns?
Interviewee	I think quantum sensors will be very interesting. I don't know how quantum computing can help with that, because it's kind of a quantum computing is good at solving for example optimization problems, right? If part of the problem of your your scenario is an optimization problem, then it could be done quicker for example. But I don't know how it like at the end. The goal that that like being able to predict perfectly is a mathematical and a knowledge problem. It is not a problem of using quantum computing or classical computing.
Interviewer	All right. And then we head over to our second part, which is energy. And Eva forgot to charge her mobile phone overnight. Same with her electric vehicle. And because of quantum computing, she's able to charge both of them within 5 minutes quite easily.
Interviewee	It's, yeah. Regarded to material science. Better battery. Yeah.
Interviewer	What do you think about that?
Interviewee	That's probably possible. Not not in terms of the charging, but of course, how do you invent or how do you find a particular type of battery molecule that would be really good at something? That's where quantum computing is being applied, yes. In fact, we just had a meeting with the BMW about that, so.
Interviewer	All right. That's quite interesting. OK, great. Our next scenario is regarding cybersecurity. And I think that is a very common application or a topic around quantum computing, which is that our bank had a cyber attack because multiple

	banks all over Europe were slow to adopt the new techno technological advancementsAnd yeah, what do you think about cyber attacks because of quantum computing?
Interviewee	Yes. So, we have known about this for a while in that sense and we have been preparing for the potential of having something like that exists. That's why a whole bunch of post quantum computing ciphers and so on are being invented. That's more on the adversarial side. Quantum computing doesn't help us on the safety side of this problem. It's more the attack vector is much easier once you have quantum computing in play. But that's why for example, even 20 years ago NIST and so on they said use 4000 digit keys otherwise you're not safe Fred. So it's a problem that we're well aware of, I think, yeah.
Interviewer	Would you say that companies need to adopt now and change their security standards to not be affected by them in the future or is it just inevitable?
Interviewee	Yes, they should adopt and adjust. I know the companies and institutions in general are really slow at adopting and adjusting, right? But the problem that has happened or the problem that we're facing is that kind of store and crack attacks have already happened, right? Like the NSA and GCHQ, they're storing everything that's going over their undersea cables. And they're, you know, the the fact is, you cannot go into their data center and modify the data. So it's already happened. If someone is using something that's insecure, they've already exposed themselves and the only thing they can do from now on is to make themselves safe from now. But your business data, whatever has already been compromised, it's just waiting until they can actually access it.
Interviewer	The next, yes. So I'm doing the mobility part of the scenario and it covers three different aspects and the one is that in the morning she takes a completely autonomous bus. There is no more driver and due to route optimization it is always on time because it in real time can get all the information she needs to get there and so autonomous driving route optimization. And the last one is a bit more in the future. I'm assuming it's about drone taxis, which? Can be operated because they can use all the information in real life powered by quantum computing. What do you think of these three individual scenarios? How likely? Uh huh.
Interviewee	Route optimization is a very traditional optimization problem. I don't know that quantum computing aspect could help it particularly much, right in the sense because. It's already so exactly. It's already really good, and to get really much better you need to have data that we cannot have. So for example, how does everyone's routing affect each other?How does congestion happen? Right. These are problems of the data is not there for various reasons. The congestion part is that you just don't know because some people are not in the system of planning routes and you know accidents happen and so on. If we're talking about unsafe drivers or whatever. And then in terms of everyone could have like we could have some kind of central service that optimally routes, everyone's routes for example. But the problem is that then you get into data privacy issues and so on and so forth, right. And both of those are not really technical problems, they're more like data acquisition problem and I don't know laws, I

	guess. What was the first one, Sorry. The other one was autonomous driving, OK. And that could be improved, I guess. I that really depends on how much quantum machine learning comes along.
Interviewer	OK. And would you imagine that then there is one central quantum computer which is completely connected to all the cars or will it ever be that there's a small, very handy quantum computer inside the car?
Interviewee	So, currently in the current technological direction, the whole quantum computing as a service in the data centre is much more the case. If we're talking about when will quantum computers maybe become deployable in a car or a cell phone, that will be probably 50 to 100 years at least, because at least there's a single technology from, well, there's a single technology called quantum vacancies, quantum time vacancies, which have room temperature, truly room temperature quantum and qubits, right. And the issue is that they have a lot of noise, so you have to have many more qubits and much more work to actually make them usable. So technically this could be fit into a a cell phone. The company Quantum Brilliance and there's some other ones, are working on miniaturizing it into kind of the size of the GPU. Well, and so in 2027 is their forecasted road map that they will have a 64 qubit GPU in that sense. The problem is you can't really do much with 64 qubits. Not more than on my classical computer, right? Exactly. Well, you can do more because the simulation limit. The pure simulation limit is around 50 qubits, where you can really maximally get to with a classical computer. But if you use more intelligent methods to simulate, then you can get up to thousands of qubits, so really 64 is not very interesting. And the last one was the drone taxis, right? I would argue that's a material science direction, right? Like how can we create materials that are lightweight enough and strong enough so that you could build a helicopter that is tiny and has, you know, capacity in that sense in addition to the battery that you need, which also needs to be really lightweight. So it may be able to help, but it's probably more of an engineering problem. Even if we designed or if we find magical materials that don't yet exist, it becomes a design issue in terms of engineering, I think.
Interviewer	OK. And is there any other application within autonomous and within automotive or mobility which you think I've missed in this scenario?
Interviewee	I think the application of material science to the cars themselves in terms of lightweight but strong materials, not necessarily for flying but for actual cars. You know, if they were all to wait half the the weight, the mass that they are righ#t now, we would be saving a bunch of fuel slash. We could make electric cars a lot more feasible.
Interviewer	Yeah, definitely. And a little bit off the topic of our simulation, just because we touched upon fuel and there are many articles out there which are like really drastic like quantum computing to change. Change the planet or save the planet? Do you think it will have big effects on sustainability?
Interviewee	Not directly, no. It's kind of similar in the sense if you can solve your optimization problem in a better way or in a faster way, or find a better solution, a faster way doesn't matter much, right? It's it's kind of unless you're for

	example let's say DHL or Amazon, they have their fleets of delivery vehicles. If you can solve your route delivery schedule better, that would be good because you're driving around less, right? But it depends on how much right and how how good are they already and chances are they're already pretty damn good.
Interviewer	Not directly, no. It's kind of similar in the sense if you can solve your optimization problem in a better way or in a faster way, or find a better solution, a faster way doesn't matter much, right? It's it's kind of unless you're for example let's say DHL or Amazon, they have their fleets of delivery vehicles. If you can solve your route delivery schedule better, that would be good because you're driving around less, right? But it depends on how much right and how how good are they already and chances are they're already pretty damn good. Like just avoiding one additional street probably won't. Or like cutting away one truck of delivery probably won't massively affect the impact of it could. Environmentally, solving it faster probably won't either, because of course it'll cut down the amount of classical computers that we need to use and so on, but computers are fairly efficient that that might be the bigger environmental impact, actually.
Interviewee	Maybe referring to that one scenario regarding energy, it's all. Yeah. Also around the topic of new material developments is that we can have new solar panels which are much more efficient than the ones before. We imagine that even one hour of sun in the morning was enough to provide enough energy for the day. What do you think about that?
Interviewer	So this is one of the kind of places where I think quantum computers will have the kind of point of breaking through in the sense that we can do things that we just can't do classically because they're just it's always an approximation on the classical side. So this kind of gets to quantum simulation, which is where I think the initial actual use case will be. But I don't know whether a solar panel has some kind of maximum efficiency, right? That's that's more of a science problem than a quantum computing problem. If we had a quantum computer, we might realize that, you know what, what are they in the lab at the moment? I think like 30 ish percent, maybe 40% is the best we ever get, we can ever design, right? And then even if we get there, we still need to put solar panels all over the place or have them harvest energy throughout the day.
Interviewee	OK. Thank you. Then a topic which we have not mentioned yet is finance Back to the cyber attack of the bank we had this morning. Eva decided to change her bank and to banking secured with quantum computing. And it's not only secured with quantum computing but you're even able to verify much more yeah time efficient than with the bank before.
Interviewer	So security with quantum computing, I would imagine you mean security in the sense of quantum networking, is that right? Yes. OK. Then yes, very secure. Arguably that'll be much more successful before quantum computing will be biggest quantum networking is deployable or will be deployable in the next like five years.
Interviewee	So security with quantum computing, I would imagine you mean security in the sense of quantum networking, is that right? Yes. OK. Then yes, very secure.

	Arguably that'll be much more successful before quantum computing will be biggest quantum networking is deployable or will be deployable in the next like five years. And this exists. And actually there won't be like a quantum link to your cell phone for example, because that's not how it works. But for like main trunk lines on the Internet, those could be quantum secured in the sense that they could be used to exchange keys in a much more secure way, for example, or exchange small amounts of data much more securely.
Interviewer	I think looking at the time, maybe just a couple of finishing questions. So as I said, we we have covering finance, automotive, pharma, cybersecurity and energy. Is there any other industry would you say will have major effects? Which?
Interviewee	I don't know about industries, but one part of the energy, so not for example, solar panels. Of course that'd be great if we got more efficient solar panels, but one huge thing that would be actually huge is if we were to discover a room temperature superconductor as we heard in the summer. In terms of that quantum computers could help us with that. And if that were a result, if it's room temperature super conductor were a result of quantum computing, that would have. Significant impacts on our everyday life, right? So there is a grid. So in South Korea there is a implementation of a superconducting electricity transmission line and they have to cool it down and all that. But for that particular situation, it's economically viable. There was a YouTube video about this recently actually, with all the hype around the superconductor that they might have found in the summer, but if that's the result of a quantum computer, that's definitely where it probably would have a huge impact on all of our lives.

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Interviewer	Just to shortly introduce the topic again, we went and dived into the the topic of quantum computing and we created a potential future scenario of in a couple of years and let's say 2040 how quantum computing with full capacity could impact our life. And for that we selected a few industries including energy, finance, cybersecurity, pharma and mobility. Now with your help we could some sort validate this scenario and see what if it is potentially possible and also maybe have some more general questions on quantum computing as well. But before we start, feel free to introduce yourself 1st and let us know who you are and what do you do at Quantistry
Interviewee	I am a quantum chemist, so I did a lot of research in using quantum chemistry for the sliding biochemical system. So DNA, proteins, the cancer agents and stuff like this. But then I moved into a different sector. For about 10 years I actually did the medical device and I was doing sales and marketing there. And since a year I moved to XX and I take care of sales, marketing and partnerships. WHat we do is to use anything possible, the technology quantum computing & AI to basically address use cases of from R&D, industrial R&D, chemical R&D. We collaborate with quantum computing players and machine learning / AI players too. Basically we're doing basically something similar to what you just described before, like we see a future where research in chemistry is

	strongly based on simulations and AI and quantum computing playing a key role. We are working on that from today. So our focus is not developing quantum computers or algorithms based on computers. We are working with people who do that.
Interviewer	So maybe to start, which area of our daily life do you think is most likely to be affected by quantum computing,?
Interviewee	So let me say this In the last conference I went in quantum computing, I asked what is your dream To my audience, let's assume that the quantum computing we have quantum computers working. What is your best case scenario? And one guy said that my dream is that the word quantum disappears. We will have computers, we will have simulations, we will have algorithm in finance. The word quantum becomes so entangled with everything we do that we forget about it. So I think in principle, every single Aspect of our life could be disrupted by quantum computers if we think that quantum computers is already working .I think it would be embedded in everything. If we think in terms what would be the first industry to benefit from computers in a sort of a timeline, I believe that chemistry and finance will be the first ones to be benefiting strongly in particularly chemistry because. In principle, you need a bit of a smaller quantum computer to run effective quantum simulations for chemistry. So I would expect one of the first thing that comes becomes, you know, disrupted by quantum computer will be the way the chemistry is done. We think there is a big industry gap between someone who creates the algorightm and someone who is on the business side of things. What we're doing is translate, we want a better battery into simulation units that somebody who has a computer can actually understand. Quantistry is a translator between those two stakeholders. So it's important for you to know that we already have a significant amount of customers. So we already doing multiple simulations from random to AI to support chemical RND in Germany, Europe, US and Australia at the moment. The customer doesn't care if my chemistry calculations are performed on a classical computer. They want to know how to make the battery better.
Interviewer	Lets' talk about that, so chemistry, let's say, it's going to be one of the first points that are going to be impacted the most with quantum computing, What areas of industries are we talking about? Because chemistry can be everything, right? It's in pharma, it's in, it's in immobility, it's in batteries like you just mentioned.
Interviewee	Yeah, so chemistry is, especially in Germany, but I think everywhere chemistry is a conservative industry. They are dinosaurs. Yes, yeah, the usage of AI computer or quanto simulations and chemistry in the R&D is not so quick. They are still doing trial and error approach. Funny enough. I'm preparing A lecture for Monday. Except for this trial and error, they need to go beyond this and they now understanding this. So in principle, the whole industry, whenever you do chemistry, quantum simulations can help. So in principle, the whole industry, whenever you do chemistry, quantum simulations can help. Having said that, there are some industries that are more receptive to the relation. First one is drug discovery. It's probably the only industry that is using simlaution already, I

	believe. Many of our customers coem from energy industry as well. In particular battery materials - why is that? Because we have the little energy buttons, they were fantastic but they don't know how to improve it anymore. We are at a point where you had increasing improvements in the last 20 years. Now they're working and improvement is done. So you need to do the next step And so a lot of this industry is understanding the simulations will make a difference and if you understand the simulation will make a difference. Next step is I need to jump on the money because the first application of one will likely be chemistry simulations.
Interviewer	One question therefore, because one of our scenarios is energy and do you also know use cases that it could develop solar solar panels?
Interviewee	So if you talk about, so when you talk about energy, you need renewable energies, right?
Interviewer	Yes.
Interviewee	OK, for renewal of energy you need two things. Basically you need an energy storage that works and of course the probably the green production system that works. So the energy storage is the same story as batteries, same thing.There's a lot of work in next Gen. One use case is use simulation or the simulation from quantum to the AI to basically do one thing, improve the performance. And reduce the rare elements in the battery because, for example, Legion material elements are so difficult to mine that you have a they're very expensive. They come from Chinese and that is social, politically complicated. And then there's a lot of to spend to actually mine these elements. So this is one thing. All the energy production energy, then the solar panels, then of course is going to be this all sort of solutions and chemistry in solar panels and solutions. Really, it's one of the major topic here.
Interviewer	We actually built scenarios, so and like, yeah, build it further into the future, yeah. And and so, so one of it was energy with the battery and also the solar panels. I mean you've also been in pharma for quite a while now that the new drug development which you also mentioned was one point we were considering that in the future really big diseases such as Alzheimer may be thinking of further cancer can be healed. Do you see quantum computing here at the at the front of drug discovery?
Interviewee	So drug discovery, that's true already. That so for example you are reading everywhere, quantum computer will speed up to a discovery because you will be able to simulate this and calculate that you will be able to do this. You can already do the simulation today. People have been doing the simulation for the last 16 years. So what you're going to speed up is not that a drug will come up quicker to the market, no. What you're going to speed up, there's certain aspects of the process, so it's not just aquantum computer would be sort of a in view, but the two things that will help more strongly development are machine learning, AI, and calculations so for example: Already now you can use machine learning to predict some properties, springing through the chemical strains and blah blah blah; already now you can do calculations to, instead of going to the lab and you bounding the measurements, you do bounding

	interpolations. It takes a month or two months and you get the numbers and these calculations are pretty much accurate once I have quantum computed at work. And maybe when I am going to computer, instead of spending a year training a model for AI and consuming half of the energy of the world to do that. Maybe it will take me a week and will be very effective and a chance of so I will do basically the same things I'm doing now that will much faster, much more efficient and perhaps much more accurately in this sense on the computer you will make the term discovery more effective. Yeah, but you won't get from taking taking years to find a drug to a couple of weeks. It would take maybe eight years, seven years instead of 10. Because a drug is not just finding the drug, it's human trial, clinical trials, synthesis, rubber buys regulations. So it would still take a lot.
Interviewer	It's interesting to also have a time frame on this and maybe with all the opportunities that we just discussed, are there any risks or yeah, let's let's call them risks, involved with the whole quantum age coming upon us?
Interviewee	I'm not a fan of risks in the sense that every technology has risks. Of course, if I want where a villain from a horrible hero movie I could I use quantum computers to attack everything. So, so I wouldn't say that will lead to bad things. I think there should be an extra caution to to do this thing.
Interviewer	Would cyber security will also be a risk you?
Interviewee	It is the two phases at the same point. You will have a better cyber security and you will have better hackers. It will be the same rush or race, whichever 2. It's always like this, you have a better technology, actually become better about Social Security becomes better, so on the computers will just make things faster hopefully. So yeah, I don't see an intrinsic danger with quantum computers. Maybe with the AI, it's different with AI there might be an intrinsic danger, than quantum. But I do not think it is like AI because it does not make intrinsic decisions.
Interviewer	we saw on your website that you also offer this combination of AI and quantum computing.
Interviewee	We don't offer, it's not that it's not exactly as you said it we offer, we offer the customer any available tool that answer the question that the customer has. And this could be any possible combination. It could be just quantum calculations on a classical computer, it could be quantum calculations upon the computer. It could be machine learning, could be quantum machine learning, etcetera, etcetera. What we mean when we say multiple simulations from quantum to AI is that there is a range of methods that can be used between. So maybe I can show you, I will just tell you so the platform that we offer which is a cloud based platform which means even the computing. (shows us his own website) In the platform we put 11 or function molecules reacting together and you know like some sort of result like maybe for example you put. Yeah, basically molecules like hydrogen and methane at 700 degrees at some election is in there and you get at the end acids, which is basically the story of the from the reactions from the beginning to the end. You get mediums of reactions like this which are basically impossible to analyze by hand. So we use machine learning

	to analyze the reaction pathways and tell you which one is most likely. And it's all automatized.So in this sense there's a combination between quantum chemistry and machine learning. So you can imagine that we are providing a highly refined tools that answers possible question in the already which are combination of methods depending on the two of the attack on that.
Interviewer	Do do you also have a time frame in mind when all these could become true and or maybe when the first applications could apply to our lives?
Interviewee	So I think would be much longer than people say. So if we talk about chemistry, I wouldn't be surprised if it takes 15 years to do real stuff not to play with it. Because you can already play with it, and you can already do stuff when you you can tell you when you read anywhere online, they work from the dances for the computers today if you go and look at the at the system they're working on. But it's something that's classical computers we could do from the 70s. When they say one of the visual calculations in a battery, they're not doing the battery, they're doing 2 elements which instead of doing parametric so you have a model that I think this I can show it to you. I think I've added on my blog and we'll just look quickly and so you will see what I mean. (shows us blog via screen share) OK, so this is actually in this example is carbon Nitro systems. It's called Metal Organic Framework. This is actually the video from the industry lab. We are basically calculating how CO2 interacts with this molecule. In this you see the system has probably hundreds of atoms. So it's kind of the model is reflecting A portion of reality, right? We've we've done the same calculation with the quantum simulator. So it's an aligned classical based computer, but it simulates the behaviour of quantum computer. All you can do with a quantum computer is this. That's the same system that's interesting to see.
Interviewer	Also, it's interesting to see a a visualization of this. And maybe as a final question, and we also took ethics into account. From your opinion, what are potential ethical considerations associated with quantum computing that you might or might not already take into account?
Interviewee	So I think ethical aspects are more geopolitical so. You have some countries that put in a lot of money and some other countries that either because they are not so able to or because they're blind to it or because historically they're not so much into innovation. For example, my own country, italy, - i was checking the numbers - it sucks it is ridiculous and it is a danger when certain countries will be ablet o use this for miliatry reasons and other war stuff. Some countries will take advantage of the difference will create even a larger divide between parts of the world. And this is a strong danger. I'm sure there's a lot of military things happening. I think it's always going to be a a win about the race then in the end. Yes it's it's not going to be like the nuclear race, the Super weapon race because one of the once you have on the computers it probably it will be everywhere within 10 years So but there will be always an edge probably and some countries will benefit this. I mean, you can imagine that it's makes sense. And so other countries that they decide they have the money, decide not to do it, like, which is their decision. There are other countries which cannot decide because if I am a country with a very stable economy and politics, I won't think about putting money even more ground compared to the one percent, 5% of

	countries. So it's going to create a more divide and yeah, all right, I I think this ends our our questions and our our interview in general.

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Interviewee	So yeah, I work at XX and I'm a quantum algorithms researcher there. So the idea is to say, if and when can a quantum computer be useful for different problems that different companies or institutions have. Maybe a typical example is if you're trying to optimize like a delivery system, you have like whatever all the all the places you have to deliver and you have this many trucks and you have some algorithms to optimize that. Maybe if you have a quantum computer you can find better solutions, or the same solution the faster and things like that and I think the things that. We usually say that we hope quantum computers can be better at is you know speed and or accuracy and or requiring fewer data points and or energy consumption like to run the physical computer. But anyways yeah so I've been here for now like I guess six months and yeah and and so I work on and I've been in the field of specifically quantum algorithms for maybe like 3-4 years. And I was, I should say, most since first three years I was in the financial quantum algorithms for finance and then I've moved over to a more general role quantum algorithms for.
Interviewer	Super interesting. We're excited to get some more insights from you. Maybe before we go into more scenario specific questions, we can ask some general ones as well. Maybe just a very general is that, I mean you've touched upon different industries that your work is in, but maybe when you think about the future, what and where do you think quantum computing will first impact us in on a daily basis?
Interviewee	So I think there's where quantum computers can impact is in stimulations of quantum mechanics. So this could be for your chemistry purposes, this could be for material science purposes or even things maybe like drug discovery and protein folding. So I think that's one of the cases where we're like OK, you know, as we go along and as the quantum computers get better, at some point we will probably hit a hit a point where we're like hey that's but that might that might be longer term. So that's more of like AI guess. And then in the shorter term to answer your question is probably like machine learning, so potentially making machine learning algorithms better. However, the flip side is it's more of an uncertainty whether it will happen like in the short like like it could happen in the short term, but I don't know if I can get like I could be like, yeah, it's about to happen. So if if there's a shorter term use case, it will be machine learning.
Interviewer	What are challenges involved for that to happen or or to be limited to happen?
Interviewee	So I'm gonna talk from an algorithm's perspective. So it'll be a biased answer unfortunately. But I think, OK, first of all, it's the the hardware.And that's a very hard engineering problem. Not only is it in general hard to make them more cubits and less noisy, but you need the error correction ideally so that like once you have this error correction in place then really you switched over the regime.

	Not only is it hard to implement, but the algorithms are difficult. And then finally, I would say, given all that, given that you have quantum computer - Physically. I mean, quantum computers can solve lots of problems, but the question is, can it solve it more efficiently or more accurately than what we have today, right? And so to find those algorithms that'll really outperform the current state-of-the-art, those are those are the hard part. I mean, unfortunately I kind of fit all the different aspects of quantum computing, though I don't know if that was a very useful answer. Maybe one other aspect I will say is, yeah then it would be really nice if people had access to it, like it was like widely inaccessible because yeah, it would be sad if it sort of was only there for the certain privileged or whatever.
Interviewer	Thank you. But maybe we dive into the scenarios then straight away, yeah, maybe. First of all I would start with the healthcare part. Some of them I actually based on the information I gathered from Mr. Flöther actually reading. So the first one is actually an app that can provide the most accurate information about your current health status as well as prognosis for your future health. That is working with a chip that is within your body. And examples are that your app can show your accept your exact life expectancy of 93 years and four months and your perfect ration of vitamin is already flowing from your dispenser. What do you think about this scenario?
Interviewee	I think it is something that I think I feel a few people have thought about. It would be great. I think the, I mean, you mean like the dispenser would also be inside you?
Interviewer	There's like a sensor in your body or a chip in your body, and that information come to your app, and your app then is working together with your fluid dispenser and then your vitamins.
Interviewee	oh okay, I was going to say, what if you also have somehow a vitamin dispenser inside you, so you don't even have to like yeah, do you think that would be possible as well? But well I don't know about how big your chunk of vitamin sitting inside your body needs to be, that only gets dispensed. But yeah, I think that, yeah, I think that seems something that a lot of people talk about it. So but not that I know very much. But then there's a question like centered around how quantum could help that?
Interviewer	No only Regarding quantum comptuing, how quantum computing could help that
Interviewee	Yeah, so I think you could. So, so if we're a little bit, if we're a little bit nice and crazy, you can say like maybe the sensor, right, the sensor that that is inside your body is a quantum sensor. And so suddenly it can measure things quite precisely, but it can also keep things in a quantum state, and then somehow, if it's transmitting to your app. It transmits as well the quantum state to the app. So instead of transmitting like ones and zeros, it transmits the quantum state. And now suddenly whatever analysis needs to be done, either it's done on chip, I suppose, like it detects everything and it does the analysis on chip using a quantum chip, or it sends the information to your phone and your phone does the analysis. Then suddenly everything is Much more precise with fewer data

	points. So in a scenario where you have both the the sensor is quantum, but also you somehow take that information that the sensor has and you transmit it, the quantum state itself to either like whatever computer that's in the sensor or you transmit it to a phone that has a computer in it and then you compute and you your AI model. You use that and it's a quantum AI model, then suddenly you will you could get much more accurate results. I think that would be a way in which maybe quantum could could help. But this is, yeah, this is like engineering fiction because I don't want to say science fiction, but yeah, but it's cool.
Interviewer	Can you imagine a time frame when it might be possible?
Interviewee	I dont know but I think definetly not before 10 years, probably not before 20-30 years. Maybe 50, far far away. But well Every time somebody makes a prediction like this to get proven wrong, that's all right.
Interviewer	Then another scenario within healthcare would be that, yeah, a drug will be discovered, actually a pill against Alzheimer's disease that can actually cure this disease. What are your thoughts on quantum within this topic?
Interviewee	So I think, you know, I I think I've been sort of ingrained in this for drug discovery, I think to discover that pill, if you can have a quantum computer as suddenly you could. The dream is you can make the process of drug discovery faster and cheaper. You can like instead of trying, you have you do some so initial analysis. You try a bunch of different drugs. You can maybe narrow down the amount of drugs you need to try in real life before getting to it because you simulate everything that's happening. So yeah, why not, right? I imagine the idea that a lot of people would have in this scenario, like, yeah, OK, you, you find the pill, but you find it much faster and and you know, much cheaper by using a quantum computer to do it.
Interviewer	And one last scenario within healthcare would be a high resolution screen that can detect the smallest cancer cells in your lungs and then you can get a specific or adna specific chemo plan actually tackling your disease.
Interviewee	Well in imaging, I have very limited knowledge but maybe the the device that images is a quantum center and so that can improve your precision. But then the, I think the DNA scneario, yeah, the the, the treatment that that is specific to your DNA, think maybe you could be like, OK, well how do you know which treatment you should do is you can again like stimulate everything that's going on to a really precise level and then suddenly you could say, OK what would happen? You know all the like, many different options and you get a much more efficient result of like what the treatment should look like because of the fact that you have this computer that can potentially do simulations.
Interviewer	when you now have to imagine the time frame within these three different scnearios, what are you thinking?
Interviewee	First, second and third? So the the first one is far; I think and - the other two? maybe the Alzheimer's one is closer. I don't have, like, an idea of when it happens. How, like, you know, will it be like, oh, it's made the process twice as

	fast or like 10 times as fast. But yeah, maybe the Alzheimer's one comes first and then the second one with this imaging, right. or maybe the imaging, just the imaging without the the part about the DNA. I think a quantum sensor it's an image comes first then the maybe making the drug discovery better and then if you have to like find the treatment with DNA cause DNA is like tends to be more complicated than in the molecule that will come and then the yeah and then the the cool sensors inside your body where I think quantum can be useful for that but maybe you don't.
Interviewer	Thank you so much. We know that Patient data is very, very sacred and important to keep secure. And what we have read on everything when quantum computer comes into place is that cybersecurity will be big threat but also big opportunity. Have you any do you have any like, general thoughts on this before we deep dive?
Interviewee	I think the so far it turns out that quantum competes. You have a powerful here you can break RSA encryption, which is the encryption that is used when you're typically transmitting data from one place to another. And there are some really smart people that have worked hard since, well, since a while now, but officially since 2016 that I've said, oh, you know, I can, so quantum computers can. The way the cybersecurity works is that it's it's a math problem that easy to solve one way and hard to solve the other way. And the actual problem is pretty simple. It's A * B = C so if I tell you like A&B like three and five OK, 3 * 5 = 15 OK, but that's easy. But if you keep making the numbers bigger and bigger A&B, OK, fine, you do it on a piece of paper or at worst you ask the computer, you're like, hey, A is like 3438 and B is like 5,000,032, What's C good? But now if I tell you, hey here's C, tell me A&B, alright, that's a much harder problem. That's an even number in like there's some situations where it's easy, but if you have A&B that are too large. First, two large prime numbers. It's actually a really hard problem to solve. And the way you essentially solve it is you try like all the numbers until you say, oh, so that's what makes encryption. I mean, this is a very low level, and then we don't need to go through all the steps of how it connects to the to the end, end case. But it's like you encrypt by doing the math problem one way and you decrypt by doing the math problem the other way with some hints. But if you don't have the hints, you can't decrypt it. Unless you have a quantum computer. Sorry for the mini lecturer, but that's how like the cryptography works and and and some very smart people were like, OK, well that's a * B = C problem that's kind of been cracked right the other way. But let's find another problem that you don't need a quantum computer to even do. You can do it with a regular computer, but that you know that's hard. That's easy one way and hard the other way for both regular computers and on some computers. I think by the time we have a powerful enough quantum computer that can break this A * B = C problem, we would have switched over to using a different math problem that'll be used for encryption. You know, maybe somebody clever will be like, oh, even this different problem I found AI found like a quantum computer that can break it. I am Not panic about it. I think people kind of, I mean they're working really hard and it's a very difficult task because after you come up with the algorithm, you also have to like actually get it implemented. You have to go and change the way the Internet works and stuff, which I think they'll do. And so that's kind of my take on the

	cryptography, but I think it's a really important like discovery and it's very mathematical, beautiful and it's also was important for the generation of like the whole industry, right, This you can break cryptography with a quantum computer and. The last thing I'll say about it is, the cool thing about it is that it's a it's a problem that's solved exponentially faster on a regular on a quantum computer than a regular computer. Yet the problem has nothing to do with quantum mechanics like, it's just a random math problem. It doesn't stimulate quantum particles or anything. So that's a very, like, beautiful and encouraging results to be like, oh, maybe there's other problems that have nothing to do with quantum computing that we could. The quantum mechanics, that would be the quantum.
Interviewer	So basically quantum computers will be able to solve all of those today's encryptions So because I mean, I've read about the whole harvest now, encrypt later thing, that seems like a problem. So that would basically mean because one of my scenarios is that. National security is threatened because who like some country like China invasions the the US by being able to encrypt there is security channels through quantum computers and so is this something that the US or any nationality should look out for to change the whole encryption method to a quantum safe encryption is is that what you were saying before?
Interviewee	And yeah, and that's that's also linked to post to post quantum encryption, right. So people are should, should be and I think are generally working hard to try and do that as soon as possible.
Interviewer	OK, and how big of a challenge is that to change an entire encryption based model to quantum safe encryption?
Interviewee	It's definitely big. Partly because you know many reasons including the fact that sometimes people are just lazy and so they're like, I don't wanna update my stuff. But it's the the nice thing about post quantum cryptography is you don't have to change hardware because it's the post quantum cryptography doesn't involve quantum computers to encrypt. It just is a different way of encrypting. So thankfully you don't have to like create new infrastructure like new fiber cables or whatever.You just need to, you just need to change like kind of the code, right? But but I think there's like there's a big effort to make sure the algorithms themselves are safe mathematically. And then there's the effort to make sure that the way you implement the algorithm is also safe. Because just cause in theory the algorithm is safe. If you implement it in a way that's not foolproof, then you could also break that. And then, yeah, then the last is like to get everybody to be like, all right, let's all adopt it. I think it's hard, but I think I think enough people in the world are taking it seriously, including like big institutions that it's like it's gonna be a challenge.
Interviewer	It and and do you think that apart from governments and big institutions also like any sort of company will be affected by this because one of my scenarios is and you can tell if this is feasible but.
Interviewee	Yeah, 100% I think if if it could, that could like I mean that would be the scenario if banks and stuff are not ready. I think the the question which I am not so clear on is like if you're a bank you have your cybersecurity division but you

	usually use you don't build your own software scratch. You usually get software from like whatever even Microsoft or whoever right on on various.So the question is like should the like, should the banks.I think the banks should be aware and kind of understand the situation and maybe even implement some things. But I think the I think maybe I might be wrong, but my feeling is the ultimate implementation of it comes from the the vendors, the people who are building the technology that are selling it to the bank as opposed to the bank itself that has the in house code. Something like I I think so it's more like on the onus of both like the technology companies but also sort of these open source protocols like HTTPS and all that stuff that they're working on.
Interviewer	I was also thinking about what organizations can do to Prepare for the quantum age. -wh at do you think?
Interviewee	I think it actually starts with the big companies, the big organizations like IBM providing such an infrastructure for companies using it. The one thing that they can definitely do, the organizations is to see which of their data is encrypted and what what, what part of their data is encrypted and what part of the data needs to be encrypted. And make sure that when the protocol gets like, hey here, it's ready. It's like, OK, good, please apply to this data set. Please, like do it to these servers. Like be ready with the inventory of their data that needs to be secured again, I guess. I also think it is vey important to have the right set of skills in the firm. It will be a valuable skill to be an expert on this topic if you are for example a cyber security guy.
Interviewer	maybe because you have worked so much in finance, we could use the opportunity to ask what are your thoughts on quantum within the finance sector?
Interviewee	So yeah, I think it's one of those things where it's felt like it's been tough to find algorithms which are very like, Oh yeah, as soon as we get the begin of computers we're good to go. I should say in general finance it's it's nice as an industry to to work on algorithms because once you if you find an algorithm that works really well, first of all it's easy to go from finding the algorithm to implementing it. For example compared to like a drug discovery process where it's like OK, it's like part of this much bigger pipeline that involves experiments and stuff. And two as well, even if you if your algorithm gives a little bit of an advantage, it can be useful for finance right In some cases if you get that like 2% edge or whatever it's like fine, let's use it. The the downside is that you don't have quantum problems in in finance. So it's typically it's hard to find where quantum computer could help to solve non quantum problems much faster or even a little bit faster. And so I think it's still up in the air whether or which applications it will really be useful in, for example for portfolio optimization and and derivative pricing and things like that. It's so far, there's no smoking gun example of like, yeah, these are great algorithms and we just need to wait until we have a good enough quantum computer or like it shows real promise. It's more like, yeah, we're exploring and then you hit a few dead ends. You hit a few like blockers that say, you know, and we can get into the technicalities a little bit, but like you get it faster, like in theory. I think if something might

	come up, it might be in this machine learning business of like quantum in machine learning that people use in finance. But it's hard to say, yeah, and I'm not sure.
Interviewer	And how far in the future do you see this?
Interviewee	This is also something that's super far away such as the pharma part that we had in the beginning. Yeah, I think I think if you unless you get some machine learning stuff that happens to pop up, then yeah, I think it's like pharma in terms of when it can be useful. So we've looked at some numbers like hey, this is how many qubits you need and this is how many gates you need to like have a algorithm that we know for sure is at least in the theory faster. And that number is like you need you know 7000 qubits and and something like 10 to the power of 7 gates. So that's some big numbers and especially the the extra thing is you can need 10 to the 7 gates. Your qubits have to be what's called error correcting. So, yeah, that's that's all a little bit, a little bit far, but those are the ones that we kind of have a good idea maybe something pops up and I'm you know, I'm surprised in a pleasant way, but if finance is OK for the pharma or like drug discovery or something more interesting if if something pops up in it.
Interviewer	We also want to talk a little bit about ethics, because with any technological advancements, ethics are always considered.
Interviewee	Yeah, I think our company is starting to take things into account. It is a startup So things are like a little bit all over the place, but there isn't there is like one of the things that we want to address is ethics. I think for me the couple of things in ethics are access like you know, making sure that it's not just in one place or the the bridge have it the haves and have nots. And then I think there are lots of similar ones to well, this is including the the problems of AII think we could learn a lot from the conversations that are happening with AI like the haves and have nots, the data privacy the. Also you should consider accessability At some station there will be a quantum computer and maybe it would be then like sort of, yeah, quantum as a service, more than quantum computers are actually within households to name it like that. I mean it's we're not going to be building huge computers everywhere in everybody's house. And yeah, right now that's how it is and I see it in the, you know, definitely short and even medium term.I think it'll be like like that for a while before we we need it. Also I think in a business case, it also sort of the reason that's the case is we, I don't think quantum computer usage is gonna be like the iPhone where like in 2007 the iPhone was mentioned, in 2000, like 12 everybody had a smartphone, right. It's more gonna be like, hey, if you have a problem to solve where you're trying to simulate something that kind of looks like this, maybe a quantum computer. We found an algorithm and the hardware works really well. So use use that, use a quantum computer for that. But everything else you're trying to simulate or all their problems, just use a regular computer. I think because of that, especially at the beginning, you're not gonna have everybody's like, oh, I need one in my house to like write a Word document. But like, I don't think you need to have a quantum peers Instagram, that's.

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Interviewee	Well, I don't do quantum computing directly. Yes, because that's really reserved for the research institutes, because the universities don't have the financial means to afford such computers. Yes, so it's purely about those who then come into the source for quantum computers and then question. But then you really have to contact the research institutes that develop such computers? Yes, that's it, I think you can find that, universities, so I know an address, I've also looked it up, it's in lernt, for example. Now I don't have that. Somehow I didn't write, yes, just a moment. Exactly, so in in S research center is called Kutec Mhm and that's in the in the Netherlands.
Interviewer	Mhm.
Interviewee	Yes, and they are actually developing this quantum yes quantum technology. Yes, if you're lucky, you might be able to reach someone there. That's really the case, because the scientists who are working on it every day.
Interviewer	Let's do that, thank you very much. Thank you very much. Then the second question is about general quantum computing. From what you now know about quantum computing, which industry or ultimately which area of our lives will be affected first?
Interviewee	Definitely the industries that are geared towards communication technology. Like AEG, for example. That was the very first company, i.e. industry, that really used this communication technology, i.e. in quantum energy, a great deal now also runs via communication technology, which means transmission. So simply put, how do I transfer information from point A to point B and the pioneers who really brought the whole thing into industrialization. That was AEG. That's what you see in these communications companies, in any case they will continue to transfer this technology from research, so I, you already have the right application scenarios. Energy too. And even a company that specializes in energy will definitely benefit from it. Cybersecurity won't be there at all, that won't be an interesting question, because there won't be any cyberattacks when the quantum Internet is introduced because that will no longer be possible when the quantum Internet is introduced. Yes, so of course it will be very exciting when you look at the topic of remote-controlled mobility and Bluetooth.
Interviewee	So, if you know, that's just a very short range, it's applicable. Yes, if quantum technology gets that far, then we can really introduce such technologies in different places and other galaxies. so it goes on in such a way that you really have the idea, not only with us, on our planet, our universe, it goes even further, so other universes are then also discovered and yes, you have to think that way. yes, the order of magnitude. The mobility, then yes to the other planets in our solar system, but also, yes, it goes even further, other galaxies, so that's really, you can't imagine how far you can go.
Interviewer	It's definitely interesting, yes.

Interviewee	And there is of course the topic, they mentioned that. So, that also has something to do with energy, new materials. Yes, that means if we can visit other galaxies with this technology. Then we will be able to imagine materials from other materials that we don't even know yet. So chemical elements, you know what I'm talking about.
Interviewer	Very cool. That was very exciting, the first two questions, I would say, let's just start the scenario. Do you like the first question? Exactly, I think I sent them through just like we did, who ultimately wrote down what they would rather we go through from top to bottom or should we organize it by technology or by industry, starting with energy, for example.
Interviewee	So we'll just go through everything now, I think.
Interviewer	It's OK.
Interviewee	Perfect. It's like you can assign it afterwards. Yes, because I didn't even think along those lines. Let's start with health. So you introduced this quantum controlled sensor here. So life expectancy yes, it's just, I would say now, for ethical reasons, don't make it exactly 93 and 4 months, but make it more than 90. Because ethically, of course, it's not so nice if you know exactly when it's time, it's just a recommendation. Don't set a specific date. And then, well, it's really a very rough estimate. That's 4 months, then maybe 3 days.
Interviewee	9 hours. 4 minutes. 40 seconds 20 nano seconds 10, pico seconds. So the time will then really become so precise that we break seconds down to nano seconds, that's a million seconds.
Interviewer	Yes, madness. And they believe that you can ultimately predict that precisely using sensors.
Interviewee	Ideally, yes. So theoretically, I think it's feasible, whether it can be implemented now. Yes, industrial implementation is always very complicated, it's always such a gray area, how do you transfer scientific findings into practice, yes, you always have to reckon with a loss, yes, of accuracy, precision, yes, so it then depends on transfer of industry transfers. How well the theory with yes, with technology. How well the physical principles can be industrialized. How does the technology with yes, of course, know technologically how they are like, then often come up against the limits. It may be that everything is physically provable, everything works in theory, but to implement it properly in industrialization or now in the application, that is then really a complex task, because to produce such a sensor. Yes, well then. I think it's a challenge for the industry. You can theoretically design it. But yes, building it is the next task.
Interviewer	OK, but it's good news if it could definitely work in theory.
Interviewee	That's the first step, of course. Yes, so if it works, that's a first step, already taken.
Interviewer	Very good. Let's move on to the next point from the energy sector. We wrote that in the future you will be able to charge your cell phone or your car within 5

	minutes. This is because there are so many better batteries in the end. What is your opinion on that?
Interviewee	Yes, that's again. It's simply eternities, what they've stated, so minutes, yes, that's really yes it's finally a long time, then you can really do a lot of things in that time, if we're in this quantum technology, if we're ready, then again names and that's for us, so we as humans can't even perceive that duration. So for us it wasn't one at all. We can't appreciate how boring it will be right away. It is, it really takes such a short time, yes, with measuring devices, with physical measuring devices that are able to measure these femto seconds, seconds, they can register that, the time, this time, time, interval, we as humans, thank God, cannot resolve it so hostilely, so it will simply be there immediately.
Interviewer	And that's what the quantum computer thing will allow the materials industry to ultimately develop such advanced materials that can implement everything in such a short time that we won't even be able to do it properly. Exactly.
Interviewee	That's the, that's going a bit in that direction. Yes, science fiction, so materials, yes, that these new materials are actually possible. Developed here or then found in space, somewhere in other galaxies, that can do this, that can also be ethically yes Mhm, we'll see if that becomes feasible now.
Interviewer	But very cool. Okay, then maybe directly into the third scenario regarding cyber security. He mentioned earlier that you don't assume that cyber attacks are even possible with quantum computing, could you elaborate a little more on that for.
Interviewee	Us exactly. It's the buzzword of the quantum Internet and the quantum. Internet is that the information that you send out. Exactly, exactly the same. Information also reaches the receiver, so that's the sender and receiver, they receive identical information and that means that there is no loss along the way, which is currently the case with communication, the current communication is always with a loss. There is always a loss because the information that is then sent does not reach the recipient in exactly the same way. This means that something is lost along the way. And cyber criminals take advantage of this to tap into it. And that won't be possible at all. Yes, with the quantum internet, because you know exactly. This is my point and this is my point d and there's nothing in between. So that's where it comes from.
Interviewee	Nothing is lost.
Interviewer	OK.
Interviewee	So unless, then, cybercriminals really have to be either A or b. OK, to get information, that's also called quantum cryptography.
Interviewer	Mhm, but in itself. In our example, it's more or less a bank being hacked, but we're probably still of the opinion that we first have to change and adapt a few things in order to ultimately guarantee this quantum security, because on the one hand you always read about how secure everything can become through computing, but in this transition phase there is ultimately also a risk. Because

	the current encryption methods that we have. can ultimately be broken very easily through quantum computing.
Interviewee	Right? Yes, that's the case now. The considerations, which also work in theory, are that you can send information without loss. At the moment, this has not yet been implemented at all, there are the problems of quantum repeaters, for example, how do you develop quantum repeaters, so we know that from the Internet, such repeaters yes, so there are a lot of construction sites, they are simply not yet so far along that quantum computers are really suitable for things, just as we imagine them here, our Internet. Which works in a similar way to quantum computers. But yes, yes, that consists of certain components, so what is this quantum repeater called and that is simply not there, technologically.
Interviewer	OK, very good. Thank you very much, then let's move on to our industry, namely finance, and our first scenario was that this whole thing would significantly improve the tection and authentication of banking accounts. It works better and faster simply because the right customers are better screened out, the right customers are better accepted and the wrong customers are more likely to be screened out. Do you think that computing could play a role here and help?
Interviewee	Yes, well, that's the issue now, so it's more about data security. Yes, how do I still access personal data? Well, I don't know if that's how, so I can't really imagine yet. How will I find out whether the person, whether I can trust the person or not, yes, that's really there then, life is probably no longer fun afterwards, if everyone then goes and then a, so a kind of traffic light, then appears over the people then is green, yellow or red, yes that's very good, that's such a one. I no longer really believe how that will be possible, but whether society can enforce it socially, because that actually makes people, so then. How will the quantum computer judge a person? According to what criteria? So I can't say anything, because I think these ethical and social issues also play a role here.
Interviewer	But I definitely OKOK. It's great that they're also addressing this. In any case, it hasn't been a frequent topic in our expert discussions so far. That brings us to our last topic, at least mobility, and that was mainly about the autonomous bus, which picks us up at exactly the same time every morning and since the route is so optimized, there's no time for traffic jams. This is exactly how we can avoid traffic jams so that we always get to our destination on time. How do you think quantum computers will help?
Interviewee	Oh yes, so that's it. So maybe you could think a bit further about this scenario, that you. By this, by this route and the accuracy that you are really picked up to the nanosecond and then brought to your destination, during this time still optimally design that you still build in this, in this bus even more options and then really optimize these and the time very much from yes, certain computers must then still be built in. So, I think it's really just a matter of going from A to B, that's the simplest option.

Interviewer	Mhm. K.
Interviewee	So maybe you should think about that a little bit further, yes, fantasy or what that, how bold this accuracy from, this perfect time.
Interviewer	And do you think that quantum computing can help, even when it comes to autonomous driving, because our bus also drives autonomously in this scenario?
Interviewee	Yes, I think so, because it really will. It will be possible to make all these calculations for autonomous driving so fast. Yes, that really every car or E, so every person or so that is, that will of course be feasible. So now we are failing because we. Yes, certain situations are not foreseen. Yes, so with autonomous driving and. So this supercomputer power will really. So if you want to provide for all possible situations, this means that a technical problem in computer science has not yet been solved. Yes, and that is of course the hope that quantum computers can also solve such problems.
Interviewer	OK. Very good. Thank you very much, then back to energy, one point from our scenario, or rather I'll almost put the two points together a bit, because they both ultimately revolve around energy optimization. One point was once again back to materials research and the fact that in the future, quantum computers will make it possible to build much more efficient solar panels that can absorb much more energy. And the next point was ultimately that this energy can also be made perfectly usable in the grid through quasi simulation and optimization when energy is needed. The energy is also available and can be stored. What do you think your opinion is on this?
Interviewee	Yes, so you, I can give you a number for comparison, so to compare a bit, what is a quantum computer? And what is our normal computer? That's actually also, so now in our modern age, our computers are actually also powerful, so quantum computers don't work with bits. It works with quantum bits. Yes. And a quantum computer, which is 300, so 3, so if they're like 300, up for a computer is nothing. Yes, well, but for a quantum computer 300, quantum, bits.
Interviewee	Yes, would be a conventional computer that uses all the atoms in the universe as a memory cell.
Interviewer	OK.
Interviewee	So that's the big order then. Yes, I can send you this example so that you can see a little bit.
Interviewer	With pleasure.
Interviewee	Inside. Have numbers yes. Gladly yes, it will expand.
Interviewer	Yes.
Interviewee	So our ours, yes. So the possibility of. Store energy, energy then further. To use it efficiently. These yes. These capacities will really expand.

Interviewer	OK, very good. So we can be prepared for the fact that quantum computing will ultimately be helpful in the future. Very good then. Perhaps we'll go back to Finance for a moment, as they've already talked about communication and we've also considered a scenario in which computing could ultimately also help to provide more personalized services, ultimately also a bit if you look at i. Something like chatbots, but ultimately also based on. Data about the person can now offer personalized portfolios and personalized services and products. Do you think that computing could also have an impact on this area?
Interviewee	Yes, if they do. So I can maybe go into your first scenario a little bit, this quantum controlled sensor, yes, it records vital parameters. And it's not just my, yes, my condition, it can also make forecasts. Yes, you already have a prognosis like that, for example with life expectancy, but that's exactly what the prognosis for diseases will be, that you really hope that you can beat cancer with it, yes, because every cell would really be analyzed so precisely and yes. The effects of the environment, of our diet, of exercise, in other words, the state of our parts, all of that is then analyzed. Analyzed and certain patterns are then created. Whether we then fit into such a pattern and might develop cancer. But that won't take place at the level where, for example, an image is taken and then you can see a tissue or an MRI in such a way that it can then be applied to organs or tissue. Organs or tissue are then also visible. When we are ready to use these sensors and quantum computers to really get to the molecular level.
Interviewee	Yes, at a molecular level, in our body. That is then broken down and yes. Then we know what we if. If we continue like this, if we are exposed to certain life situations, what does that do to our body, what does that do to our health? So these great orders are now not conceivable in the way we imagine, but really on a manipulated atomic level in our, yes, in our dialogical, well, this also goes back to the biology of the human being. And also work very closely. Do physicians work together with biologists again? Mhm.
Interviewer	OK, and do you also believe, who in this context is also very much about drug discovery, that new drugs can be found, that ultimately.
Interviewee	That is of course, that is the next, yes, the next possibility, the scenario that is of course very much aimed at, if we now look at the molecular level, how a particular drug works. Yes, preparation, which actually consists of certain manicures, like yes where, ducked in our body? Yes, if we have our manicure and then certain, then yes, you can imagine that it is key and key principle yes, so we are then our, we can imagine as a conclusion and then such a preparation is a key, where exactly does the key fit in our body? And so it was decided, and this is natural, that perfect preparations would be produced. Which are then really best suited for us. That's how it's visualized when we are now. Yes, and me?
Interviewer	OK. Very interesting, very cool. Then one more question back to pin. Do you think that the quantum computer thing can ultimately help optimize the Monte Carlo simulation and thus limit financing risks?
Interviewee	Mhm, well, I don't know much about Monte Carlo, but I can imagine that we would be able to immediately analyze and analyze a global financial situation.

	To analyze and forecast the global financial situation at any time. Whether we want that or not, I don't know. Yes then. Do we know exactly what our future looks like? Yes, that's the question again, do I want that, do we as human beings really want to know what's going to happen in.
Interviewer	In the next second or in the next minute? Yes, and if you change something, then it's immediately said that we'll go differently, it's like the Butterfly Effect, if you've already heard, but in any case, if you take the right control parameters into account. Yes, a quantum computer. That will develop everything in a positive way. It's a bit of a Russian question now, does the human being really want to control every second, yes.
Interviewee	Yes, that's right.
Interviewer	So it's a bit more complex. I think the question is complex.
Interviewee	Yes, that's true. That in any case
Interviewer	Yes, these social and ethical issues really do play a major role.
Interviewee	And, yes, you shouldn't forget that either, that's true. Then perhaps even a final question, also with regard to yes, quantum computing and society. You believe that cyber attacks will not be possible in this sense, but do you believe that the new possibilities will be exploited in some way? Quantum computing can be exploited for bad purposes. So in our scenario, we have depicted a bit of a cyber war, an attack by China on the USA, yes, that.
Interviewer	I hadn't thought about that at all, but I think that's a good point that should definitely be included, that you really have to take into account the powers that are then, like the one with you now perhaps with the nuclear bombs, yes, that's really a yes. To say a little bit. One, one armaments elements can consider the money powers that will have that. Of course, they will then have different positions in the world than the powers that don't, because it's not possible. Yes, I don't know if you can compare it ethically or socially with a nuclear bomb, but you can imagine that it could become a dangerous tool.
Interviewee	Yes, we actually had the example of the nuclear weapon in an interview the other day. An expert said the same thing. In comparison, perhaps one final general question, namely, what do you think are currently the biggest challenges in relation to account computing?
Interviewer	The biggest challenge is implementation. So, if we knew that now, or if we had the technology to build a quantum computer with several tubes, then yes, it would only be a matter of time before we could really put the whole thing together, but now, I think that. The existing quantum computers that are there as demonstrators. 2. pumpkin, I think we are still a long way from building them.
Interviewee	And do you have an approximate estimate of when you think a day like the one we're recording now will be possible?

Interviewer	So this Dutch Delft research by the year 2030 they have that on the agenda and the research agenda, that the quantum internet will be introduced and the name is called Web Q.me, that's a real number real date.

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Interviewer	The first question would ultimately be a bit about your background, namely when did you first encounter quantum computing and where and how?
Interviewee	That's good that you're starting with that, because I think it's important so that you can also categorize my answers. The first time I really came into contact with it was about 1.5 years ago. So I'm not a proven expert on the technical side, I'd like to say that in any case. In the end, I think I'm now quite well versed in the topic, especially when it comes to the perspective of the ecosystem in this area. Our initiative is actually responsible for building a quantum ecosystem here in Hamburg, which includes various areas of work, including providing strategic advice to local politicians to see what would be sensible investments and steps to strengthen the entire ecosystem. Then, of course, everything that has to do with networking, which means we are very familiar with the players on the ground. And we try to bring them together, i.e. to create various opportunities for a transfer to take place. And we are also the first point of contact in this area, if someone doesn't know who to turn to, we can also refer them on if necessary, here as an offer to you. Depending on what other questions you have, I will be happy to help. And that's right, we're also trying to gradually build up our site in terms of external communication. Exactly, that's first of all. And my background, I'm in my mid-thirties and come from the field of neuroscience. I have one foot in the AI world, so to speak, and the other in this non-profit quantum initiative.
Interviewer	Very cool! Then one more question, since you just mentioned AI: Do you think that QC can ultimately have just as big or maybe even a bigger impact on our lives? Compared to AI
Interviewee	Mhm yes, that is of course a difficult question to position yourself on. Of course, these are potentially complementary technologies in some way, so AI can provide other services and perhaps open up other fields if it can work in combination with quantum computing as a hardware platform, so to speak. But there are of course also questions that are separate from this. For example, whether computers that are not AI-based can have a very big impact. So if I had to give a definite vote now, I would say the same. However, I think it's very difficult to make a clear statement. And it also depends massively on how AI develops. And of course also on how well we ultimately get to grips with the quantum computers.
Interviewer	Okay, thank you. Then we thought that, since you come from the field of neuroscience, we could perhaps present our healthcare scenario to you.
Interviewer	The first question would be the following: In my research, I noticed these four areas that will be particularly affected by quantum computing in healthcare:

	Precision medicine, Diagnosis Assistance, Radiothearapy and Drug Discovery. How do you feel about this? Would you agree with me that these are the areas that will have the greatest impact on people's everyday lives?
Interviewee	Personally, I see quantum sensing as being at the forefront of development right now. And in biomedical research in particular, as well as in materials research, the potential will also have a major impact. This also falls into the field of radiology or diagnostics. But also other areas, for example by perhaps being able to produce even more precise clocks that enable even more precise measurements. When we look at quantum computing, the area that seems most important to me at the moment is clearly the area of drug discovery, or anything that has to do with being able to precisely predict molecular properties. That's not the case at the moment, so we're only working with approximations. And in my opinion, this is a core element of quantum computing. So if these were only potential candidates for drugs, that would be a huge area that could be opened up. As far as diagnostics, imaging or analysis are concerned, I don't know, but maybe I'm missing the use cases you're looking at. I would have preferred to see it in combination with AI, i.e. quantum machine learning or hybrid machine learning. Especially as AI will continue to evolve massively as QC develops.AI will be so disruptive in the handling of medical data that the effect of QC may be pushed into the background.
Interviewer	A very good insight, thank you very much. I would then start right away with our scenarios. The first would be that our person wakes up and, with the help of a quantum-controlled chip or sensor in their body, which then transmits information to their app, receives precise information about their current state of health and also forecasts. Examples here would be a life expectancy calculated to the month or the perfect vitamin ration, which runs directly from the dispenser. What is your opinion on this, is it realistic and if so, when can we expect something like this?
Interviewee	Basically, quantum computers will be available in the cloud for the time being. There will perhaps be individual systems that can also function at room temperature. So my first intuition is that you might not necessarily install a quantum-based computing chip, but one of some other kind, such as a neuromarfen, and then store and process the data more or less in real time in a quantum cloud. So parts of the data, depending on what you need. After all, it has been proven that there are certain computing operations that are not possible on normal computers. You will also have to weigh up the costs and benefits somehow and not necessarily calculate everything you can on quantum computers, but only the things that make sense. That's why my initial feeling is that it's very possible that quantum computing will help to do this kind of health monitoring in the future, but perhaps by analyzing the data in real time in a cloud rather than performing the calculations directly in the body. All in all, I think this is a very interesting thought experiment. That you can see your exact life expectancy and take appropriate measures here and there.
Interviewer	Okay, great thanks! In terms of time, I would perhaps like to briefly present a second scenario. We have considered that there could actually be a drug against

	Alzheimer's, which would no longer have to be tested on humans, but with the help of digital clones. How do you feel about that?
Interviewee	I think it will be possible, yes. If you look at how rapidly research is developing in this area and how much has already happened, also in terms of understanding, a lot will happen in the neurosciences. And quantum computing in particular was born out of the desire to find better answers to scientific questions. In the next 50 years, we will be able to solve the problem of having a therapy. And QC can make a decisive difference in the field of drug discovery with the ability to precisely analyze molecules, even if many things could be solved in advance with the help of AI. Plus, this idea of digital twins, there is also Musk's idea of uploading your consciousness at some point. And how you can achieve this is by creating a 100% image of the structure of the brain, which is only possible because there are further advances in imaging techniques, where quantum sensing could also play a role again. And in this context, in order to be able to animate such a digital twin in real time, I can well imagine that QC could play a role. Of course, this is a highly speculative area. In any case, a lot of research work will have to be done. So this is not a near-term scenario. And it is definitely a combination of different technologies. Above all, I assume that AI will be absolutely necessary for this, and that QC will primarily be seen as a computing platform. And for the time being, and probably also in the long term, as a complementary tool. There will be hybrid scenarios and they will continue to depend on the mathematical problem. Because you still have to weigh up the costs and benefits. But there will certainly be problems in which Quantum will be useful and can lead to the results you want much faster. In terms of real-time analysis. This computing power will be a necessity. But still in combination with other technologies.
Interviewer	Okay, great. And would you say that these digital clones are then used more in the creation of the drug itself, or afterwards to assign the right drug to the respective patient?
Interviewee	Well, the use of digital twins is definitely much more tangible in the production of medicines. It is to be expected that one of the earliest areas of application will really be in this production in general. After all, the basis of QC is to characterize and qualify physical objects. I actually see the actual calculation, not just the approximation, of molecular properties as one of the first areas of application and this includes the entire development of active ingredients. I don't yet see an acute scenario in which the drugs can then be precisely assigned to the patient with the help of digital twins. I can imagine that it will be possible for this to happen, but I don't see this particular application in the near future. But I think it will be possible to assess the effect. But I don't see an acute problem at the moment.
Interviewer	Thank you! The last scenario is in the area of diagnostics. I'm imagining a high-resolution screen that can detect cancer cells in the lungs, for example, much faster than conventional instruments can. How do you see the influence of quantum computing here?

Interviewee	I think the problems we currently have in diagnostics are less dependent on the quality of the screens, but rather on how high-resolution our imaging procedures are. And quantum technologies definitely have an application here. So quantum sensing, this whole area, including the examination of biological samples, there will definitely be something happening, and there is already some really interesting research going on. Various research projects are looking at exactly how quantum effects can be used to achieve better imaging or sensor data. If you now think about improving diagnosis, i.e. improving the analysis of image data, there are also possibilities here, but then it's more about image analysis, i.e. how to deal with the data that you then have and there are definitely possibilities that certain algorithms that are used to segment images in order to determine whether certain structures appear or are conspicuous, where it will also be possible to calculate these algorithms on quantum computers, or even better in the future. Then it would probably be much faster, which is normally not possible in the clinic because you can't afford the resources. I can definitely see acceleration. Improvements probably again in the interface to AI. As for screens themselves, I don't see an exact approach off the top of my head. Maybe you could make new screens through quantum, but that's not the bottleneck when you think about diagnostics.
Interviewer	Okay, perfect. And what would then follow on from this scenario would be that the perfect chemo plan could be created automatically, i.e. without the influence of a human being. How do you feel about that?
Interviewee	Yes, I can very well imagine such an automatically generated chemo plan. We're already relatively close to that with AI, so it will happen soon. These kinds of treatment suggestions that are also more individualized than they are now. Here too, quantum hybrid machine learning certainly has the potential to improve these processes and ultimately accelerate development. However, this is not as concrete as in drug discovery, for example, where quantum brings a direct advantage. Here, it's more about the fact that there are certain computing sections in the machine learning processes that can be improved or accelerated by quantum computing. And these would then be outsourced.
Interviewer	Okay, super cool, thanks for the great insights! Looking at the time, I think you have to go. So thank you again for taking the time to answer our questions. That really helped us a lot.
Interviewee	And finally, can you think of a timeframe for these developments?
Interviewer	That really is always the most difficult question. But have a look at this page: https://www.qutac.de/wp-content/uploads/2021/06/QUTAC_Paper.pdf I think the timeframes are actually quite realistic.

Interview Dialogue 20

Interviewer	When did you first come into contact with Qauntum Computing and in what context was it?

Interviewee	To be honest, I have to say it was in 2017, 2018. We were working with Tesla, with Silicon Valley, and at that time we had the task of developing a product for them that would be sustainable at the end of the production process, and we kind of put artificial intelligence on top of this product, and we kind of thought this process through and then this point with the quantum computer thing came up for the first time. I took it into account with what we did with Tesla in the area of cybersecurity. For example, we completely equipped a smart factory with artificial intelligence that is able to produce a carbon footprint and then the question was how can we secure such a production facility, what kind of systems are there, what kind of systems will we have in the future, i.e. what kind of encryption and cyber security, and that's where this quantum computing approach came in for the first time: for example, quantum computers that can hack or crack existing 256 systems. That was in 2017, in 2018, people didn't really take this topic seriously, i.e. smart factories, digitalization, artificial intelligence, I come from the innovation sector, we are also freaks for our company management when we deal with topics that are so far ahead and people also said, yes, come on, you've been smoking. Nobody knew what to do with quantum yet. We've always had it on the scanner, even to this day. Last week, we had a big meeting with Porsche about how these systems will influence cyber security in the future.
Interviewer	OK, very cool. And because you just mentioned artificial intelligence, do you believe that quantum computing will be the next big thing after AI, or do you not yet believe that it will have the same effect on our lives?
Interviewee	I definitely do. I've believed in it for a long time. I also deal with these issues in certain working groups. There are just as many who say that the area of electromobility is now set, that the next big step for the group will be hydrogen, and the same goes for artificial intelligence, with quantum computers. Yes, you have to have this mindset, you have to have this DNA, so if you don't have it, and I feel like everything is kind of spooky. It's all kind of bullshit. If you look at this topic, it's there, quantum technology is already very advanced. But if you ask someone today who doesn't understand anything about it and says you have the quantum yes, then you already know where the population or those who will deal with it in the future, like Chat_GPT today, which are also quite synonymous, yes they also think big spooky business, but they don't even know what's going on in the background about AI and many don't even know what's already going on about quantum today.
Interviewer	Cool. And what would you say are currently the biggest challenges in the field of quantum computing?
Interviewee	Firstly, it's the costs. At the moment, far too little is being invested in this area, as the money is currently being invested in other areas. We also heard again today that a lot is being invested in chat GPT and artificial intelligence, but some of this investment should also be invested in quantum technology, because the two will merge or will go hand in hand or quantum will replace artificial intelligence, AI technologies, but there is not yet an understanding of this. There was a time in 2020 I think, in 2021 when the first projects came out with quantum computers and everyone wrote, great super everything great,

	super IBM also has this quantum computer Amazon and then it went quiet again. The same issue as with Bitcoin, with cryptocurrencies. There was the hype and now nobody can do anything with it, even with Bitcoin and blockchain technology, but these are things that we have already internalized, many people say it's total bullshit, but all these encryption technologies are running in the background. But the understanding is somehow not there. The government lacks an institution that considers these processes holistically and not in the here and now, but in the future. Many people say that this is changing, in the next 3 to 5 years we will have a technical singularity, that artificial intelligence with quantum computing will become more intelligent than humans, that won't be in 5 years, it will be in 1-2 years.
Interviewer	Very cool. Then perhaps one last general question. Based on the literature, we have divided quantum computing into the 3 areas of simulation, optimization and machine learning, because ultimately these are the 3 main points. Which of these 3 areas do you think will be the most decisive or the one that really gives quantum computing an advantage first?
Interviewee	Machine learning, deep learning. Definitely OK.
Interviewer	And in which area? So in which industry?
Interviewee	Well, I can give you an example of what we do. We work with the big Googles, with the Apples and also with the smart cities and smart regions sector. We are now looking at the area of connected mobility. It will no longer be called a car, but mobility. In future, this mobility will be autonomous, meaning that the person using the vehicle will usually have a smartphone or smart glasses or a smartwatch. They have an appointment in the morning. He gets into this mobility, he logs in, he drives from A to B. During this time, he will use this mobility, which means you already have the first one. This mobility no longer has a driver, it is automatically controlled by artificial intelligence, then autonomous driving is added, it will drive autonomously from A to B. The user who uses this mobility will use the time to work, store and so on. In other words, you have this autonomous driving plus user experience. Then comes the next case, where this user experience or this autonomous mobility with user experience is used in smart cities, for example. For this, you need connected mobility, which means that all vehicles that drive autonomously and have a user experience are networked in a cloud with artificial intelligence and are thus completely controlled. This requires enormous computing processes that artificial intelligence hardware can no longer perform, so quantum technologies, for example, will take over these processes in the future.
Interviewer	This actually fits perfectly with our scenario, because the first thing that will happen in the mobility industry is that the people we have will travel to work on an autonomous bus. You definitely believe in it, but what do you think, will it be controlled centrally by a quantum computer or will it be internal to the car?
Interviewee	We're currently working with one of the largest companies, where you've probably already placed an order, and the issue is that all data on connectivity and collective mobility will be brought together in the cloud and controlled by an AI in the future. We're already getting there, although we're not talking about

	autonomous driving, the computing power is already so high that we're already thinking about moving on to the next technology. Yes, so that will come, so the big manufacturer starts with A and ends with n and of course they are now trying to bring all these technologies in the cloud with a technology called Q after AI or just so far that in the future it is estimated to be brought to market in 2025 2030.
Interviewer	OK, and once everything is connected, isn't that another big cybersecurity issue, i.e. ensuring that everything is secure?
Interviewee	It's a completely different topic. On the one hand, there is the issue of connectivity and computing power, machine learning, deep learning analytics and, on the other hand, it means that there have to be systems that technically cover all of this networking, including cybersecurity. It's a big problem, and I know that hacker attacks are on the increase. I don't understand it, the cyber security systems, they're good, but some of them are also assigned passwords by administrators, I can't understand what's happening, whether it's grandma 123's first name 123's date of birth, there's still a lot to be done, that's why there will be completely new systems, but where you stay on it permanently, because this quantum encryption or this quantum hacking or cracking I once tested a conventional system would take 3 years, a quantum system 3 seconds.
Interviewer	Yes, that is such progress.
Interviewee	And it's a race between hackers, between technology. So there is still an approach. In any case, investments should be made in both areas. There are many funding pots, including from the EU. For example, I am on the working group for these topics at the EU in Brussels. There is absolutely no understanding for this in Germany. In Brussels, there will now be a few pots that can be tapped into for this purpose. But nobody does, because we also have a very large bureaucracy here. We are talking,
Interviewer	You mean it only works if manufacturers and cybersecurity really work together from the outset, because otherwise it won't be properly protected, OK, yes, very exciting.
Interviewee	So far, I'm not aware of any research project where you can see the connection between analytics in the cloud and complete connectivity or that quantum technology is replacing this technology and then adding quantum technology and service security on top of that, that doesn't even exist yet. We're thinking about it, we're still talking about it, but it's not OK yet.
Interviewer	Oh, and now a bit of another question about the ethical concept of autonomous driving. It all has to be programmed, what decisions the car or mobility then makes. Is that a difficult question for the manufacturers right now?
Interviewee	We were in Sillicon Valley in 2018. Tesla invited us, we arrived at the airport and Model X picked us up autonomously. We in Germany in 2023 are still talking about ethical aspects like that. So autonomous driving has a huge advantage if you get up early in the morning, for example. You partied yesterday, you're tired, your reactions are very different to those of artificial

	intelligence or autonomous driving. Autonomous driving takes the decision out of your hands. But I'm sure that with autonomous driving and if it works properly, we'll have fewer road deaths and fewer ethical decisions than we would have if, for example, someone got drunk in their SUV again in Hamburg, turned on the carriageway and crashed head-on into a bus. That wouldn't happen.
Interviewer	So in the end, do you think we shouldn't be thinking all the time in Germany about how we can completely eliminate the risk of accidents with autonomous driving, but rather look at how the distribution is and that there are fewer accidents than on conventional roads?
Interviewee	So in the global ranking of prototyping and testing, we are in last place with Google, Amazon and Apple. If you say that Germany, for example, has such high regulations, such high resistance, it's totally uninteresting for us to test at all. Once we've tested it everywhere, we'll implement it in Germany at some point. But we don't need Germany either.
Interviewer	OK, then secondly, in our scenario we have the bus that the people take is always on time thanks to the route optimisation. What do you think there is really so much potential to improve the optimisation? Compared to the current systems we have?
Interviewee	Have you ever travelled in Holland?
Interviewer	Yes.
Interviewee	In Holland the motorway is strictly 100 km/h. Do you have traffic jams there?
Interviewer	Rarely.
Interviewee	So, now compare that with autonomous driving, if you simply translate this Dutch system into autonomous driving and apply it everywhere, there would be less congestion, there would be fewer road deaths. Energy costs would also be drastically reduced because people would no longer drive like crazy, because what costs and consumes energy and also generates CO_2 is this acceleration of vehicles. And that optimises the flow of traffic. There's a huge amount of potential here, just in the flow of traffic alone. People also slow down as a result, people become calmer. I notice that myself. I often have to drive to Belgium, then through Holland and as soon as I come down the German motorway and drive to Holland, nobody drives on the left. And here they just drive on the right, left across 17:00 they are all annoyed by the tailgating. Doesn't happen back there. You can use technology to track emissions worldwide, you can take the stress out of it and people will be one hundred per cent more relaxed.
Interviewer	So would you say that the biggest application for route optimisation is personal transport or are there others as well?
Interviewee	No, not just personal transport. If you're referring to the transport of industry and goods, that's included. How often is a lorry stuck in a traffic jam because

	someone was speeding? That delays everything. For example, if you now have a refrigerated lorry, planned for 4 hours, an accident caused by speeding and it is on the road for 8 hours. Then the goods can be thrown away or arrive totally late. So you also have an advantage with automatically controlled traffic routing for all the industrial services in Germany, Europe or worldwide.
Interviewer	OK, so that's getting better too. It's not getting better the way we imagine Google Maps to be now, which is simply more accurate systems that tell us here is a traffic jam and here is a traffic jam, but simply more route-optimised because everything is connected with autonomous driving?
Interviewee	I'm a very big fan of Google Maps. I can't think of a better system and if you combine Google Maps with autonomous driving, so to speak, and everyone feeds their real-time data into it, then you have a good system.
Interviewer	OK, very exciting. And if you look a little further now, I think you've already mentioned step Q or something like that, what are your thoughts on the potential of perhaps combining this with drone taxis?
Interviewee	With drone taxis. We are currently developing in the area of space aerospace at our company. What will come, drones are now such a transition, for example, if you still have a traffic jam, then rush hour is on the way and Rewe or Amazon now wants to deliver via drones, then that's all well and good. But I don't think it will be attractive at some point to have drones permanently flying around at eye level or at 20 or 100 metres. Then you would be taking mobility from the ground into the air, so to speak, and the potential for them to hit something is much higher. You also have to have terminals, so to speak, and systems to control all the drones. Flying one from A to B is OK, but imagine hundreds of thousands of drones in the city of Düsseldorf, Munich or something like that.
Interviewer	It won't be a conventional means of transport, but perhaps a few for the big companies?
Interviewee	I also see urban mobility when you look at all the Volocopter systems. If they now fly emission-free and you can just take an air taxi. Then it's OK, but I don't believe that all mobility will shift to the airspace.
Interviewer	OK, so if only for the most specialised applications, ok. But you can see that it could realistically happen and could be improved by quantum computing.
Interviewee	Definitely. They exist, the prototypes are there, but here too, where are they being tested? In Asia or in Dubai, because they just say let's do it, let's give it a try. They say it's a cool idea, try and error. But that doesn't work in Germany, which is why we are travelling elsewhere.
Interviewer	And the last point about the automotive sector in our simulation is that we see great potential for batteries in electric vehicles, for example, in terms of material design. Do you think there will be so much progress that it will one day be possible to charge our cars in minutes?

Interviewee	Well, the technology is currently around 80% 6 minutes. That works in the high-voltage range. We are also working with manufacturers to ensure that the charging technology continues to develop, the batteries continue to develop and the next trend is the same. There are more and more balcony power plants, so photovoltaic systems that the vehicles are used for regional charging. This means that the vehicle you use can also be used as an energy storage system. This means, for example, that if a house has a photovoltaic system, you can park the car downstairs, not only charge it, but also charge the electricity into the car and use the car as an electricity storage unit to feed into the house or have to.
Interviewer	And when do you think this will come onto the market?
Interviewee	This is also an insurance issue in Germany. It is already being used everywhere, the cars are being offered. They are not allowed to be used in Germany, but in Asia they are already being used to avoid so-called voltage peaks. Voltage peaks means that everyone leaves for work at 06:00 in the morning and comes back at 17:00 and everyone would charge their cars at 17:00 when they leave the office, then of course you have peaks, then the energy goes down somewhere because all the electric vehicles are being charged. But if these storage units are charged by photovoltaics, by wind energy and the car can be used as an electricity storage unit, then you no longer have these electricity peaks at all and you can even use what you don't need, you don't have to discharge it somehow, but can use it for the household or even sell it to neighbours.
Interviewer	So it's very exciting. I'd like to ask a quick question about one of our other industries that we're also looking at. Ultimately, the whole energy optimisation. Do you think that quantum computing also has an influence on this? If you've just mentioned energy storage? Ultimately, everything to do with storage, optimisation and distribution, could quantum computing still have an influence?
Interviewee	In any case, once we have developed to the point where we have good energy storage systems, these energy storage systems will have to be intelligently adapted to the use of the areas and that can only be done with AI or later on a larger scale with quantum computers. If you have such large server parks or large electricity storage parks and we have a demand, for example for energy, e.g. a foundry that starts up at 04:00 in the morning and the other a bakery that starts up at 03:00 in the morning and an office building at 08:00 in the morning, then of course this means distributing this energy, which is loaded, intelligently so that you don't have these peaks and the whole power grid collapses. This can then only be calculated using intelligent control, AI or quantum computers.
Interviewer	And now to shed a little more light on the fact that quantum computing really is a very powerful capability. How long do you think that will take?
Interviewee	There are many quantum projects that continue to develop very, very quickly. Strangely enough, this topic has become very quiet in the last 6 months. But I'm sure that if we don't do it here, it will be done somewhere else. Yes, and we should definitely keep our finger on the pulse. And we should also be involved in this topic. Because as quickly as AI has developed with chat_GPT, quantum

	technology will develop just as quickly, will become cheaper, smaller and will also be housed in small devices, for example. Yes, chip technology at some point. If you don't keep up with it somehow, then we'll have missed the boat again. So it will come quickly and I'm sure that we will achieve a breakthrough in the next two years. If we're not careful now that we don't invest, we'll give everything back to Asia.
Interviewer	OK, perhaps to conclude on the subject of cars, is there any technology that you think is very important that we haven't yet looked at or discussed?
Interviewee	Well, I really see electromobility as a transitional technology at the moment because we will have problems with all the energy requirements.In the meantime, maybe 10% of the vehicles have been converted to electromobility, if we convert the remaining 90 to electric, then we have a problem with generation and distribution and that's where everything comes together again, what we've just discussed storage, where can we get the energy from, is the energy also green, etc., so we still need an alternative energy and I'm talking about hydrogen.
Interviewer	Yes, I think I have another question about cybersecurity, because you just mentioned that. Not in the automotive sector, but more generally, do you see more opportunities or more risks in the area of cybersecurity through quantum computing, even when it comes to things like the banking sector, crypto, etc.?
Interviewee	So I see it as insecure for the time being, because the technology of computer technology is so immensely good that it will hack systems for the time being. That you go one step further with quantum computing and develop a system that can break into systems into a system that protects systems that can be broken into? I don't know anyone who is currently involved in quantum computing for this purpose. Everyone is trying to tackle this technology first, to develop suitable systems to combat this quantum technology, but this is a quantum technology, I don't know any manufacturers who are already developing cybersecurity systems, unless you have something.
Interviewer	No, I don't either. And if it's also about something like that, now really big. Do you also see risks in the area of quantum computers when it comes to cyber warfare? That it will become even stronger between nations.
Interviewee	What we are currently doing. Next week is Space Tech in Bremen, which is one of the biggest trade fairs dedicated to quantum technology, artificial intelligence and technologies in space. There are currently projects about satellites that are equipped with lasers, but the issue we are dealing with is that these readers are supposed to vaporise space debris. But it will be the first stage in developing so-called killer satellites.
Interviewer	OK and who is driving these projects the most? Which countries?
Interviewee	I can't tell you, but the sovereignty is just like at the North Pole over natural resources. Of course, people are trying to expand what is slowly being limited here on earth into the extraterrestrial or the supernatural. Of course, everyone sees the airspace above the land that is territorially limited, so to speak. So they

	will not only defend the airspace on Earth, but also the airspace in order to fly spy satellites over their countries and then defend them as well. It hasn't come to that yet, it's a bit of a war of the worlds. But you can discuss that with very few people because they'll think you're an alien. But it's there, so we're talking about it right now, satellites that used to weigh a few tonnes, like us, are now at the level of 10 * 10 centimetres. And we are currently developing a material made from natural plastic that is completely recycled. Which is only 10 * 10, which previously weighed tonnes, but has the same performance. That means you shoot one of these things up there and not just one, but hundreds or thousands in a few years. You have defended your airspace everywhere up there and you can then deploy small systems everywhere to defend the airspace, however you want.

Interview Dialogue 21

Interviewer	Can you please introduce yourself and tell us about your connection to quantum computing
Interviewee	Yes, with pleasure. I stole 10 minutes from you, no, that's why I've got 50 minutes until my next call, that's why I've cut a long story short, I'm a technology scout and everything that's crazy in the future, that catches my attention and I say I'm also unlike you, I'm Teckie because of course if I had been a business guide, then I would have thrown quantum computing out the door first because of its maturity, quite simply no nevertheless I say I actually come from this other side from the technical side and say. Number 1 must first be halfway through. Yes, what it's about, how it works and that's certainly where normal thinking people reach their limits, because quite simply we as macro objects, that's simply not our experience, but I'm sure you've noticed that too. Nonetheless, my job is to simply bring such crazy things to BMW. Yes, and I have to say that I didn't think it was that cool back then, but EA glasses were pretty interesting 10 years ago when Google. Glass actually came out, things like that. Yes, and at some point we have technology, trend, radar, you can google it, BMW technology, trend, radar, then you have one of these things and then there are all these trends on it and one of the things on it at some point was quantum computing, which I put on there because that's more or less my go for being able to develop this topic for BMW and what that means for BMW is that we simply deal with number 1, that's the strategy to bring the computing strategy when it's in the strategy. Is it evaluated, where can it be used, where does it have potential? And because of this, there is actually, let's say, no business case for it yet, it just has to be approached strategically and then we sort of said, what do we do, o we make partnerships with the academy world, we have chosen the TUM as a chair and are there, I say endowed chair holder or have a chair quasi endowed at the Technical University of Munich finance it in good German and so get the talent back on and I say that was the story, so to speak. But of course, we also have 2 internal teams that deal with this. 1) I'd say more IT and the other more research-related, and the one that is currently the richest, where you don't need too many qubits to calculate it, is simply Material sciences and I say materials are already quantum by nature, so no, and then it's

	simply a matter of I say now trying to make I say now 23 layers of glass on top of each other and let them age, you can simulate that very well with computers, even with classical computers. It's just that the precision is different with classical computers, you always have to make assumptions and these assumptions can easily be taken back a bit in quantum computing, which means you can simulate more precisely, get better results, etc., well, I always say that's the white side of quantum computing, there's also the black side of quantum computing, the risk, so to speak, and you know that. Of course, there are also quite simply our limits. Cryptographic algorithms are ultimately based on solving mathematical puzzles, i.e. these hashes, and you can't solve them with normal computing technology, they just take too long. Yes, and now it's just that the quantum computer has a few algorithms and when a lot of qubits are ready, which are not yet ready, then things can ultimately be cracked. Unfortunately, we are now designing our cars for the next, let's say, 10-15 years. And it's entirely possible that quantum computers will be able to do that. In other words, we have to make provision now for the possibility of having algorithms in the vehicle that can then be updated, but which are then ready, i.e. resistant.
Interviewer	So you are already setting the course for the future so that you will be ready then. When Quantum is also ready.
Interviewee	Exactly right. So I say, that was the one that's Black, the danger, the great potential. And there are of course, but fortunately from my point of view there are much more positive things like material, science, yes, it's always attracted, the topic of optimisation and I've become a bit cautious because we simply, I say, such proof of concepts, we simply take, that is, the first real place from BMW, any optimisations because of optimisation, so there are thousands of optimisation things. Yes, but our experience is that quantum computers are currently no better than classical computers. That's why we've now moved away from these examples to some extent. I would say that there were certainly two reasons for this. We also organised an open innovation initiative last year. We did it together with Amazon, they simply, I'll say, took the initiative, we selected a lot of problems from BMW and then we kind of said to the world: Hey world, help us solve this issue with quantum computers and the solution provider for this was simply an Amazon cloud where they donated their quantum computers. Yes, I'll say that of course caused a stir. First of all in the whole world. We had quite a lot of work to do to separate the wheat from the chaff. Nonetheless, I think that was the case again. We launched the results at a conference in Mountain View in the USA and made the winners, I'd say that was a bit more publicity than a bit really ah helped us now, but of course we got to know people, we formed partnerships and so on.
Interviewer	These are really the most important steps right from the start and with what you've just said, you've actually already covered two of the scenarios that we've included in our day. Because in the automotive industry, we have seen that our people of the future will get on an autonomous bus, i.e. autonomous driving, and that it must always be on time because the routes are so optimised and real-life information always comes in, then later in the day they take a drone taxi and the last point we have included is that they charge their car, their EV, and

	thanks to newly developed materials, the battery is so good that it charges in a few minutes.
Interviewee	Both exactly. Very valid.
Interviewer	So if we now move on to optimisation, you mean it's not necessarily better than what we already have, but what is the status of autonomous driving? Will it be further improved by quantum computing, will computers really bring it to market?
Interviewee	Yes, the good question is, what about autonomous driving? Yes, so we at BMW, we see the world logically from now until autonomous driving, in other words, we think that we will successively bring autonomous driving functions into the vehicle. Yes, we don't see it going boom and you suddenly have an autonomous taxi, yes, but logically that's not our way of thinking, so we say OK, our customers enjoy driving, that's why they want to drive themselves, but nevertheless, I can also tell you that I have a button on my steering wheel.I love it, when I'm driving on the motorway and you're just driving along with all the other cars, you can press it. You're not allowed to pick up your phone yet and I do the whatsapp anyway and you don't have to be afraid that you're going to crash into something.Yes, that works great and I'd say you can actually think of the whole topic in this way, that you are driven to the pub in the evening by your vehicle, it looks for a parking space itself, it has, you can just drink a few more beers and come out again and let yourself go home, I say that immediately, I'll take something like that but I don't need one yet. Autonomous vehicles know everywhere, whether the traffic flow in San Francisco is completely different from that in Rome, driving along there.Yes, and that's why we're seeing the successive and. Where exactly will quantum computers be used? I don't think we've even got that far into it yet. Of course, route optimisation is such a point and if you have to optimise the routes of the entire autonomous fleet and one, I'll say, has his preferences and wants to drive past McDonald's, the next wants to drive past Burger King and you have to optimise everything against each other and do and do and do 100,000,000 people and want to have it in real time, yes, it may well be that this is valid, that you then have quantum computers. The application.
Interviewer	So for larger problems, but not for the smaller daily ones
Interviewee	I don't think so, but I don't think anyone is actually getting highly customised routes at the moment. Yes, it's simply a route. Yes, it may be that the traffic situation is also integrated, but I now say my profile as I actually want to drive, I don't do that and that may well be a future scenario where you say OK, an optimal route for everyone and if you want to give everyone their optimal route, of course you have to give it to the others who are driving right now, It all has to fit, it all has to fit, but then of course it has to be cross-automotive OEM, because not everyone drives a BMW, but some drive a VW, and then we need a standard for exchanging them, it becomes arbitrarily complex and it is precisely because of this complexity that a quantum computer should help us.
Interviewer	OK, and now a little bit away from the car itself, but from your perspective as a tech scout. If you look at the Volocopters and so on. Do you have an opinion on

	drone taxis, whether this could be incorporated more into everyday life if it is made possible by account computing or will it be incorporated into everyday life at all?
Interviewee	I'm a big fan of multimodal mobility, i.e. car, drone, aeroplane and soon space travel. And I say the nice example that I then take, I simply OK BMW should detach itself from this car, but BMW should simply have this seat as an asset, so a seat ne so. Your environment, such a cocoun and exactly this seat, you can drive it in the car. No, then this seat is taken out. It always annoys me when I have to drive to the airport and then drive into the car park, go out of the car park, check in, stand in the queue for 23 hours and that if you could make it all a bit more intelligent, then that would be cool, no, then I'll just sit in my BMW, and then I'm on the aeroplane and then I'm on the bus and that's what we call multimodal mobility and yes, of course, we're looking closely at what the aviation industry and the space industry are actually doing and are doing and we're also in the process of initiating joint discussions, yes, of course, in any case. So you can really incorporate that into your scenarios.
Interviewer	OK and for the 3 things now, what time frame are you looking at, so when?
Interviewee	Yes, that's great of course. Super. So what I've just told you is not in the next 5 to 10 years. So my time frame is a bit further ahead.
Interviewer	And what would be the next step? when you have the qubits? You have full quantum computing, where do you dream of going?
Interviewee	Well, I think that first of all we should actually use it in the company itself or in the supply chain. Yes, that you simply optimize these processes so that there are no waiting times, that energy is not consumed, that CO2 is not produced. I think we still have a bit of time to focus on these points for the end customer, OK, that they have the ready iphone. I don't believe it yet, although I'll just say that if we think back 20 years. Think back 20 years and we would never ever have thought what the iphone and what can be done with the iphone nowadays, i.e. with a mobile phone, actually everything and the incredible and I also believe that the development is simply accelerating, that means we will no longer be in the next 20 years, but we now have another 10 years and then we will simply have been like that, that has always been the case.
Interviewer	And now to look at the last point again. This material design is, I actually had a very exciting interview yesterday in the automotive sector and the expert said that hydrogen is the new thing that is now EV.
Interviewee	Yes, there is the following statement from me. Which forests are the healthiest? They are mixed forests. Yes, they are actually the healthiest. Neither pure spruce, plantation, the bark beetles are furious in there, nor what I call monoculture is always bad and I say that quite simply, we also follow the philosophy, we actually offer all currently available technologies, that means both electric and combustion engines as well as hydrogen. Hydrogen, yes, and I say super mix and nothing better can happen to us than when such a super mix is created when all people drive EVs at once. It won't work, the power grid will collapse, we've shut down the nuclear power plants blah blah blah yes and

	therefore technology neutral. Yes, I don't think you can always leave everything up to the end customer, because of course they do, so humans are simply optimized beings who always take the easiest route. Yes, and that's why you certainly have to impose a few restrictions and say, no, you have to do this and that now. Yes, and I'm a big fan of mixing. And yes, hydrogen, even hydrogen will probably be the solution for trucks, yes, and when trucks, when the infrastructure for trucks comes, then it will be there for cars or other things or our friend Elon, who shoots his rockets into space, he has to use hydrogen, otherwise he can shoot so much CO2 around. We don't want that. OK, I'm looking at the time, so unfortunately it's going by too quickly, so I'll shoot you the last question very quickly, again about the batteries, are there any thoughts on how quickly you could charge such a car? What is the goal? Just as fast as refueling. OK, just as fast, I'm curious. No, you get to the gas station, I'd say you need a maximum of one minute to fill up your car or maybe let it be 2 minutes to fill up your car. It should happen in that range, I'd say that's what the current people are used to. Yes, of course, if you talk to EV drivers, they don't mind at all, they'll just have another coffee, maybe that will change the world, but our goal is to get the energy into the vehicle in 2 minutes, so to speak.
Interviewer	We don't want that. OK, I'm looking at the time, so unfortunately it's going by too quickly, so I'll shoot you the last question very quickly and that's again about the batteries, are there any thoughts on how quickly you could charge a car like this? What is the goal?
Interviewee	Just as fast as refueling. OK, just as fast, I'm curious. No, you get to the gas station, I'd say you need a maximum of one minute to fill up your car or maybe let it be 2 minutes to fill up your car. It should happen in that range, I'd say that's what the current people are used to. Yes, of course, if you talk to EV drivers, they don't mind at all, they'll just have another coffee, maybe that will change the world, but our goal is to get the energy into the vehicle in 2 minutes, so to speak.

Interview Dialogue 22

Interviewer	Use the conversation today to address this in particular? Exactly. But we will perhaps start with a few general questions beforehand, as far as the procedure is concerned. Would you like to introduce yourself briefly and if you have any questions?
Interviewee	I'm Amelie, I hope it's okay that I've brought my colleague with me, because we're writing the Master's thesis together. First of all, thank you very much for your time and I'm glad it worked out.
Interviewer	So we've set up our scenario, which is a day in the future with full quantum computing capacity. We have considered real-life applications in 5 areas, namely finance, energy, healthcare, mobility and cybersecurity. As part of our master's thesis, we then held interviews with experts to validate this, so to

	speak, because we also tended to find that a few things are more positive and, above all, that opinions on the time frame differ greatly.
Interviewer	How did you come to write the article and what exactly do you do at Quantum Link?
Interviewee	At Quantum Links, we are the link, so to speak, hence the word between companies and their interests, so to speak, in the field of quantum. So what we do a lot is that we also assess Startups and so on, simply look at the market situation and also look at and assess the technology, then just look, OK, what does that mean for a technology strategy of different companies. Mhm, exactly and for which topics are there any cooperation partners? What we have a bit of an outreach topic and what also comes from the fact that you realize in the topic, so there are still a lot of, let's say, on the algorithm development side and on the getting as much as possible out of the hardware side and even the use cases that are often made. Do we often not have that much to do with actual use cases? I have, simply because the people who don't speak the language somehow, because they don't know the problems and so n kind of bridge this gap, so to speak, we have launched this planned challenge. To do this in the area of technologies or problems that are always relevant. To say, OK, every year we look at what's available in this area. The climate-relevant problems are now bleeding. We've done optimization once, then this year we've done optimization of materials for Director and next year will be disaster prediction.
Interviewer	Will and exactly. And then we say OK are the problem and try to solve problems as realistically as possible. Solving quantum computers is a two-stage process, so the problem is always broken down very much and then, if the participants are encouraged to develop concepts on how to escalate it. Active technology, scouting a bit. Exactly from this direction, because I was personally interested, I looked into it, I thought, hey, it would be really cool to somehow write a current report, other consultancies have already written reports about it perianal what should the World Economic Forum write about it, but even if I now have a technical scientific background, I was interested in it and then we wrote this report.
Interviewee	So my overall idea of quantum computing is a bit like this, it's just a new tool, so to speak. It won't immediately solve any problems that we've always had, so it's not the magic pill that somehow solves everything. But it's definitely a new tool that allows you to take a look at things and see if you can solve them. Of course, the time scale always plays a decisive role. So which problems can we really solve with near term? Which can we do better with quantum than with classical? And which problems do we still want to solve in the long term, so to speak? In this sustainability, I think it's more about things that we simply have to do now with the technologies we have. Where we don't have to develop anything else, where we say, OK, we have solar cells that are sufficiently efficient, we have

	them as systems, we can build them, great, we are currently building several nuclear power plants equivalent to solar power plants per year in Germany. This will enable us to reduce our dependence on coal and gas. What are the technologies that we use today and the other question is what are the things that we want to improve in the future. Everything that has something to do with energy efficiency, including building management and so on. What about the fact that you need so much energy to keep the quantum computer running at minus. 30 degrees is absolutely zero, that's just what we need.
Interviewer	Do you also mean that power cuts are avoided?
Interviewee	Exactly, so there are two problems. Firstly, we have the challenge that local energy production is sometimes insufficient or there is too much at peak times. The aim here is to achieve better distribution throughout the day. That is one problem. On the other hand, when we talk about storage, we tend to have a scenario that you may have heard about in the intraday sector. The other problem relates to longer-term energy consumption, so to speak. In Germany, we are producing more electricity overall, but unfortunately often at the wrong time. The existing energy storage systems can only cope with this for a few hours or a maximum of 2-3 days. For a longer period, for example for the next 3 weeks, we would need both advanced storage technologies and technologies that can better predict energy demand in the future.
Interviewer	And do you think that wouldn't be as possible without quantum computing?
Interviewee	Yes, it's already being done, and it's possible without quantum computing. It seems that there are many optimisation problems that do not necessarily require the power of quantum computers. Nevertheless, I mean with quantum computing definitely an efficiency increase of 10% would be possible which is already good.
Interviewer	A brief digression, because you just mentioned optimisation. What do you personally think the most of, simulation, optimisation or machine learning? Where do you see the greatest potential?
Interviewee	It's difficult to predict, but the greatest potential for quantum computers probably lies in chemistry. In chemistry, simulations and property calculations of molecules often rely on approximations, and certain simplifications do not apply to all molecules. A quantum algorithm called Quantum Phase Estimation could help to perfectly calculate all properties of a molecule, which would enable enormous progress in chemistry. This could be used in the pharmaceutical industry, for example, to speed up the development of new drugs by testing a large number of candidates in the laboratory. This would significantly speed up development cycles in chemistry.
Interviewer	OK, proposing quantum chemistry, I have another scenario for batteries, which was also mentioned in the article. It's just kind of spun around now, but I once read in an article that it could be possible, for example, to charge a mobile phone or electric car within 5 minutes.

Interviewee	Well, I'm a bit critical when it comes to predicting exactly what advances in materials science can be achieved through the use of new tools such as quantum computers. It seems difficult to assess what fundamental laws of physics might militate against the idea of charging an entire car in minutes. I doubt that such advances can be easily predicted. Especially in the context of new batteries that can be simulated by quantum computing, it is pointed out that batteries are complex systems. The interactions between electrolyte and electrode material are difficult to model classically. Although the calculation of material and system properties could be improved by quantum computing, the accurate prediction of advances in materials science remains a challenge. In my reflections on the use of quantum computing in materials science, I draw a comparison with the introduction of microscopes. In doing so, I emphasise that quantum computing could hold potential in previously unforeseeable areas, similar to the development of transistors. Despite these potential opportunities, I remain sceptical and point out that it is difficult to predict in advance exactly what advances in materials science can be achieved through the use of quantum computing.
Interviewer	When can we expect to see these applications?
Interviewee	I personally believe that applications need to be developed first to realise the full power of quantum computing, and many advances, such as the Quantum Utility introduced by IBM, are already showing a big push. However, especially in areas such as chemistry and machine learning, thousands of logical or physical qubits are already required. Scaling is not linear, and various technologies, such as neutral atoms, still face challenges, but their solution could enable the scaling of quantum computing. However, it remains unclear when exactly these problems will be solved and the technology will be available on a larger scale.
Interviewer	What's your opinion on quantum computing and the scaling up of quantum computing?
Interviewee	During my studies, I gained extensive experience with solar cells, including practical work in the laboratory where I produced solar cells myself. In particular, I have worked with crystalline materials such as perovskites. With such materials, the challenge is to find the optimal combination of ions that have certain optical properties. Simulations can be used to predict both the optical and electrical properties. A precise simulation makes it possible to optimise these properties and thus increase the efficiency of the solar cell. A central concern in research is also the search for alternative materials for solar cells that are not dependent on rare or environmentally harmful substances. Simulation plays a decisive role here in identifying suitable substitute materials. We need solar cells to further reduce our dependence on other sources. Quantum computing could play a revolutionary role in this context. The idea is that quantum computing could enable us to derive the properties of a solar cell directly from the chemical structure of the materials used. This would enable a

	more precise prediction and could help to further increase efficiency. However, I also emphasise certain difficulties. Accurately predicting the overall efficiency of a solar cell remains complex as different scales (micro, meso and macro) need to be considered. One challenge is to transfer the findings on the microscale to the entire solar cell. Efficiency claims of 40%, for example, come up against fundamental limits. A perfect material can theoretically achieve a maximum efficiency of around 33%. However, it remains exciting to see how new technologies and possibly quantum computing will continue to drive research in this area. In this context, articles from the Jülich Research Centre, which mention efficiency claims of up to 40%, have certainly attracted attention. However, it turns out that there are fundamental limits that cannot simply be overcome by higher efficiency claims. In my research over the last six years, I have come across these challenges and remain excited about future developments.
Interviewer	Of the applications in the energy sector, what are you most convinced will bring the biggest change?
Interviewee	I like to be surprised when it comes to the use of quantum computing. It's obvious that there are certain problems that can be solved efficiently with this technology. However, nutrition-related issues and the scalability of the algorithms used today are still unresolved. The existing algorithms may already deliver impressive results today, but their long-term applicability and scalability are uncertain. In terms of chemistry, however, there are some fundamental reasons to suggest that quantum computers could be particularly effective here compared to classical computers.
Interviewer	How important would you rate quantum computing for sustainability?
Interviewee	My overall idea of computing is that it is a new tool that will not immediately solve all existing problems. It is not a magical solution to all challenges, but rather a new way of looking at existing problems. The key is to select the problems that can be solved more efficiently with quantum computing compared to classical methods. I ask myself which long-term problems we still want to solve at all. In the area of sustainability, there are things that we can already tackle with existing technologies without having to wait for further developments. For example, we have efficient solar cells that we can use as systems. Germany is building several nuclear power plant equivalents per year by utilising solar energy, which helps to reduce dependence on coal and gas. The question now is which technologies we use today and which aspects we want to improve in the future. The focus is on energy efficiency, building management and similar areas. Quantum computing could enable significant advances, especially in chemistry and materials science, but I remain cautious and emphasise that it is difficult to predict in advance exactly what progress can be made. My attitude is open to surprises, but I also recognise the uncertainties and challenges associated with this emerging technology.

	In terms of energy expenditure for quantum computers, I see this as less of a problem. The energy consumption is not that great once the system is cooled down, and the energy cost per computing operation could potentially be more efficient than with classical computers. I wonder what long-term problems we still want to solve. In the area of sustainability, there are things that we can already tackle with existing technologies without having to wait for further developments. For example, we have efficient solar cells that we can use as systems. Germany is building several nuclear power plant equivalents per year by utilising solar energy, which helps to reduce dependence on coal and gas. The question now is which technologies we use today and which aspects we want to improve in the future. The focus is on energy efficiency, building management and similar areas. Quantum computing could enable significant advances, especially in chemistry and materials science, but I remain cautious and emphasise that it is difficult to predict in advance exactly what progress can be made. My attitude is open to surprises, but I also recognise the uncertainties and challenges associated with this emerging technology. In terms of energy expenditure for quantum computers, I see this as less of a problem. The energy consumption is not as great once the system is cooled down, and the energy cost per computing operation could potentially be more efficient than with classical computers. As for opinions on the future of quantum computing, it's fascinating to see how widely opinions differ, even among people with similar backgrounds and studies. Some see quantum computing as the next big thing in the next two years, while others doubt that it will play a relevant role at all. The diversity of opinions shows the uncertainty and range of expectations around this emerging technology."

Interview Dialogue 23

Interviewer	Hi, I hope it's OK that my colleague Vicky is also here. We're writing our master's thesis together, exactly, maybe I'll start right in with a short round of introductions, Wiki and I are currently writing our master's thesis together, as I've already written, on the subject of quantum computing and we're trying to simulate a day in the future with full quantum computing capacity, we've thought about a few scenarios of what the whole thing could look like, how people could be affected.
Interviewee	Yes, OK, I have a chair for theoretical physics at the EU in Erlangen and we're looking at quantum computers in two aspects. One is that we develop algorithms, and that's our focus right now. I don't know how far this is known,

	i.e. on algorithms that could run on quantum computers in the near future, so to speak. Yes, so perhaps I can say a bit more precisely later on what I mean by the near future and the second aspect of our work is actually that we. Theoretical modeling and concepts for superconducting cubits, so to speak. We are also involved in the development of specific hardware platforms together with experimenters. Yes, so I'm basically a software and hardware developer somewhere, so to speak.
Interviewer	Cool here, exciting exactly, so maybe a quick word about me. I'm Victori and I'm writing the paper together with Hannah, maybe before we go into deeper industry areas, because we've also picked out 5 categories in the process. As a general question, where do you think we will find the fastest application areas in the future? In other words, in which industry or with which industrial partners are you perhaps working together to develop the algorithms?
Interviewee	I think I would expect the earliest applications to be in the materials, development and chemical industries. Materials, development and the chemical industry, yes. I can tell you a bit about the vision or development that I see. So I think what generated a lot of attention was the fact that there were, they are now perhaps called beyond classical experiments, yes, that this originally became known under the name Quantum Supremacy, which is a very unfortunate choice because of. It was used in a different context. That's why it's actually better to say Beyond Classical now, and I was also a guest scientist at Google, where it was successful. Yes, so you experienced it first-hand, so to speak, and it's there. If you run a randomly selected gata sequence on the quantum computer and you. You can show that it cannot be simulated classically. In this respect, the quantum computer has done what a classical computer cannot do. But as things stand now. No application in one class in which a quantum computer would be better than a classical computer. So we simply haven't gotten that far. Yes, and some people might say something, but I don't think that's really true. Yes, that means that, in your opinion, it's all just dreams of the future so far and none of it is actually tangible. So, there are currently no applications that computers would do better than a classic computer. Yes, and for most things, I would say that you can't use applications that are so incredibly powerful on a conventional computer. Or calculate much better. So that's that and that. That's simply because at this current, at this current stage, you have to pick out very precisely where a quantum computer is better and these random gate sequences are one example. And the next thing, which I think is the next big milestone for the field, is to simulate or calculate the dynamics of the large, quantum mechanical, many-particle system. It's simple. That's because we know that it's extremely difficult to calculate with classical computers and it's well suited to a quantum computer, so to speak, because it's quantum mechanical dynamics. Yes, so that's more or less it.
Interviewee	You could say it has an advantage, no, and that's the next step. So then these quantum mechanical dynamics, I think that's now something that's ne. So the interesting scientific question is, I would hope that we would then be able to answer scientific questions that we couldn't answer with classical computers with quantum computers. Yes, then the question of whether someone will make money with it is more uncertain, but I think the next step, so to speak, is

	because the calculations that you have to do in the chemical industry to predict reactions or something like that are ultimately mechanisms that run quantum mechanically and, so to speak, that is then. Going one step further, then you can't perhaps choose the quantum mechanical dynamics that run as well as possible on the quantum computer, but also one that is interesting for a large chemical company or doesn't necessarily have to be, but a chemical company. Yes, and I think that's what I see as the next step. The next big development stages, in other words, in the application. And something like why optimization problems and so on, that's even further in the future.
Interviewer	Yes, what, what time frame are we talking about?
Interviewee	O that's extremely difficult to say and therefore one reason why it's too difficult to say. And that's perhaps where I come to what I meant by the near future and what it means for quantum computers. We can't expect to get the individual gate operations, i.e. the individual computational steps, to a level of precision that we have with classical computers, so to speak. The error, which is the probability that a classical computer makes errors in the calculation steps, is something like 10 to the power of -1410 to the power of -15. I don't know how familiar you are with these stories, so 10 to the power of -6 would be a millionth, so it would go wrong once in a 1000000 executions. 10 to the power of -9 would be in a billion executions. If it goes wrong once, yes, and then it's 6 orders of magnitude less, so the classical computers are simply very precise, so the current status of quantum computers is about 1 in a hundred goes wrong. Yes, that's still and you don't think you can push it into the range where it's 1 in a million or something, so that's just not, so there's no evidence that that would be feasible, so now you choose the other way, it's called quantum error correction and that's also a very essential story to develop because of that. Roughly speaking, the concept is that instead of one, you can build a physical cupid, which is different depending on which technology you use. And you want to store units of logical information in there, so to speak, and instead of taking a Q for a unit of information, in this quantum error correction concept you then take several cubits for a logical cubit, so to speak, yes, for a logical 1 of information and what I meant before with algorithms for the near future are algorithms that don't need these errors, corrections. So yes, and now I think there's a question exactly, so I wanted to explain that now, because it's an open question where we don't know. What we can't predict is whether there will be an application for quantum computers. That runs better than on a classical computer and does not require quantum error correction. Yes, so I would say yes, I think that's the one, but you can't make any reliable predictions, so to speak. And it depends very much on when, for example, it will be possible to use it in chemistry. Yes, if it can now work without quantum error correction, then I could imagine that it will work within the next 10 years, but if it absolutely needs quantum error correction. Then I think I'm skeptical as to whether this will work within the next 10 years. But it's, well, of course it makes the future so interesting that nobody knows, yes, but to give an example in comparison, so at Google, it's more or less the roadmap that they want to develop an error-corrected quantum computer, so. I think you could say that they're banking on simply correcting errors, developing them, because there's not much else to do. And I think this roadmap says that they want to have it in

	10 years. If not 10 years is relatively tangible. Actually. Difficult to say. I think so. So somewhere optimistic will certainly be, yes, because that's always a plan with which you want to convince investors, not too conservative and also try to make it so that it doesn't fall on its feet.
Interviewer	But now, according to Google, I first need to work on things because they naturally want to seize the positive opportunities and possibilities. When you look at Google, you always hear a lot about the many risks and potential dangers that can come with quantum computing, and in terms of security, Google is already doing something in the direction of making itself quantum-ready, right?
Interviewee	To be honest, I don't know, but I'm relatively sure. An application that is also one of the biggest drivers for the development of quantum computing, of course. This so-called short algorithm, which needs an error-corrected quantum computer, so to speak. When I said that earlier, my expectation was that it would. But well, I can't predict it, but let's put it this way, I would be surprised if in less than 10 years someone gets something like this working on a scale that you have to worry about whether it could crack my emails, for example. Yes, because they can crack them, they'll be able to do the RSA encryption that we currently use in all kinds of things, i.e. break up these letters, very quickly. And then you have to think about other encryption methods, because of course these methods then become insecure. So if we succeed in developing this quantum computer to such an extent, then these procedures will become insecure and we will have to do something else. That's OK. I think that makes a difference, of course. I wouldn't say that it somehow makes our world fundamentally unsafe or anything like that. So of course someone who then has this quantum computer, that already has an influence and makes a difference, because then you're basically forcing people to change and we're no longer able to change. Yes, it just has problems keeping information secure. Of course, you have to prepare for it, so I would say it's negligent if you don't do that. I think it's very difficult to predict in the stadium we're in now when and if there will be a quantum computer capable of doing this in the foreseeable future. But, so to speak, I think the effort you have to put in to prepare for it, at least at the moment. This means have a thourough look at your existing cybersecurity framework and evaluate, maybe also with an expert, what needs to be done to be really for when this happens. It is important to include experts as soon as possible. Best case would be to recruit cybersecurity talents that have this as a skill or at least as an interest already.
Interviewer	R 1 scenarios I can think of something similar to stealing an e-mail address, because it's precisely things like online shopping or online banking accounts that have been stolen. And yes, it's a bit absurd, but because the person wakes up one day and the account has been emptied, simply because the bank wasn't on an infrastructure that was quantum secure.
Interviewee	Well, yes, exactly like that. I don't expect that to be some kind of story. Overnight happens, so to speak. So in order to develop quantum error correction, you have to do these things, that you store one unit of information on more cupids. Yes, now it was the 2 experiments or the 2 decisive

	experiments that were done there or or leading ones. Last year there was one from the team at the ETH in Zurich, which made 17 Q Cells, and then there was another one from Google, which made 50 and. You can see relatively precisely whether they bring an improvement in terms of how well the information can be stored. And that's not really the case yet. I think it's still very, very easy to track at the moment. How the development of this hardware performance is approaching the point where you could then run such algorithms, yes, and so there is still a long way to go at the moment. Of course, there is no guarantee that this will happen. It is currently being played so openly that the companies are at least openly showing what they can do, of course they don't necessarily show exactly how they do it on the hardware because they naturally want to protect their IP, but they do say in a publication, for example, "We've done it, yes, it's quite clear that the university team can do it. The crucial question is, of course, how long this will continue to be done. Yes, that's OK, I can't look into the strategists. But at least it sounds as if it will be until it actually happens. That's the kind of thing that would happen if the bank had been thinking about it for a long time. So from what you've just said, I'd say it's very negligent of the bank not to have thought about it 5 years before point k. Maybe we should think about it anyway.
Interviewee	OK, that means everything is actually evolving. Together, when certain developments are no longer so publicly visible. So I'm not talking about the technology now, but the fact that what you've achieved is always made public, I think that's what happens because. Perhaps the companies don't yet see it that way, that you're close to the breakthrough or close to it and that's why it's still very much used for public image. What you can do, yes, so to speak. IBM and Google use this as their presentation. The high-tech companies are then OK. We are quantum computers so far or so far and currently have no interest in keeping their achievements secret. L yes, perhaps, can perhaps also say, is perhaps also an indicator that there is still a long way to go.
Interviewer	Maybe still on a national level, because I mean Google m are American companies, what's the situation in Europe, are we somewhere there too or are we missing out again?
Interviewee	But I would, OK, so to speak. I don't want to now, so the danger is definitely there, I think we are, we have already woken up, so to speak, especially in Germany, the investment that is now being made in it, so I would definitely say now, for public funding, so both the federal government and OK, so I can say several federal states, I can definitely say it for Bavaria, are investing there each time. For example, the program at Google. I'm a bit more familiar with that from my own history, but in the end, I think it was 2014, they more or less simply bought up the university research group, so yes, and now in Germany these programs started about 2 years ago, so yes, in any case. That's a considerable delay of 7 years. And then? I would say so. University research in this direction was also more developed in the USA than in Germany, which in my opinion is simply due to the fact that among researchers. Too many people in Germany thought that it simply wouldn't work. So to speak. If you like, they thought more conservatively, yes. Exactly, so we are investing a lot at university and research institute level in Germany, and OK, of course, I don't

	want to complain about that, I'm also benefiting from it. I'm not quite sure whether this is a real problem at the moment. I think that would be desirable, but I wouldn't rule out the possibility that many of the start-ups that have been around so far will fall by the wayside at some point, because I think it's still a long way to go before it becomes conventionally relevant. Yes, and then there's always the question of how, how long is the type of investor, so in this case it can be that. I don't know how it's handled at IBM or Google, but OK, there's extreme financial substance behind it, at least as long as they can develop like this, I think. In other words, a program should definitely run for 10 years and be supported substantially. I don't know if that's interesting for you now. It's not yet clear on the hardware and technology side what will really win the race. And then what? If the investments in Germany and Europe hadn't been made in recent years, then I think it would have been very tight at some point. So whether we've missed it or not, I think it will be clear in 10 years' time, no. But has the rethink now come about? Yes, and and. And. Of course, we also have to see. Computing wasn't a big industry in Germany even before that, so we just, we just don't have a computer, there's nothing that's somehow. Like IBM or Google or Apple. Who could say, OK here in Germany, we do that, so. At the end of the day, Infineon is perhaps the only one of the big players that could have made the decision now
Interviewer	OK, it's cool to look at it from that angle, somehow. If you read a lot or talk to a lot of people, it's always very optimistic and very visionary, but it's also easy to realize what is still needed, also in terms of awareness.
Interviewee	The whole issue has also had a problem in recent years in that it has become a problem at all. Well, I think we're making pretty good progress with development, so the expectation was that it would make even better progress.
Interviewer	A new drug for Alzheimer's, great new batteries that are much more powerful. If you think along these lines, what do you think could be possible?
Interviewee	I would think that these are the directions in which we can expect the greatest impact. Yes, simply because you can. I would compare it to electrical engineering or engineering fields. Yes, today you can, if you have an electronic device or or. So the development of a car, something mechanical or something like that. You can simulate everything very well before the first parts are built and you see if it works. With chemical development, it's completely different, you can't simulate most of it and you just have to try out what works. And OK. So I don't want to say that there's no understanding of chemistry, but it's just a very large wealth of experience that you have there. OK, but ultimately it's all trial and error. So if you take it exactly and because these are all quantum mechanical processes. And they are classically extremely difficult to simulate. And if you now have a very powerful quantum computer. Then there is simply the hope that you can develop these materials, i.e. videos in the battery or chemistry. The Lindy can be raised to the same level as it is today in electrical engineering or engineering, where you can simply run through a few hundred or a few thousand scenarios in the simulation before you have the first one in the computer. And things are OK if you then marry them with some AI tools, so that the trial and error is automated, yes, because ultimately AI does that and

	learns from it. It's already conceivable that this could be taken to a whole new level. Yes, well. I'm not yet sure when that will happen. Because the number of gates that can be performed on a quantum computer today is many, many orders of magnitude away from what such calculations would need.
Interviewer	Yes, yes, but these are precisely the scenarios that are conceivable if the development is successful. Yes, exactly.
Interviewee	What is less conceivable. There is a lot of speculation that machine learning and big data problems, that quantum computing is important. There's actually not much evidence for this at the moment. There is, so to speak. So we know that quantum computers, the individual computing steps, are slower than on conventional computers. It's more due to the quantum mechanical way in which the information is stored, that there are many, many computing steps in parallel, but these highly parallelized computing steps are slow and that's why, because you have this parallelization that quantum computers have, you can't use it for input and output, because you have to communicate with classical data, so these steps are very slow. So yes, quantum computers have to read in enormous data sets, enormous data sets. In all likelihood, it won't be any better than classical computers. Yes, so you have to look for problems where the input is simple and the output is simple. And in between is something highly complex.
Interviewer	Exciting. OK, I think that was really interesting. To get a bit more critical perspective on the whole thing, because of course that also extends a bit of work, to bring in a different perspective if it's okay, we would include the things you mentioned here, anonymously if you like, or if you are also your name, your name, we would also take the name.
Interviewee	This regulation with such a, so it may well be that they are public, that they are at least in the university, library or something. So what would be important to me is, if it's public somewhere, whether I take another look at things where I'm quoted.

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Interviewee	Yes, I'm happy to do that. So first of all, I haven't had much contact with quantum computing so far, because it's now integrated into our teaching. Of course, I've taken this as an opportunity not to deal with it a bit, because I find it fundamentally exciting, but sometimes it just gets lost a bit in day-to-day business, so I don't know if I can take it that much further, but I'll give you my opinion and how I see it overall, but I'm not totally super deep into the topic, which I do here as part of my teaching and there are definitely points of contact.
Interviewee	Yes, basically it's very, very exciting what I've found now. I originally come from the Lemgo area of the university, I studied here, so maybe I started my CV here sometime in 2000, at that time still a graduate engineer in electrical engineering and then continued with a Master's degree in Information Technology, which still exists, dates just this year the 20th anniversary of the international Master, I was in Denmark and Sweden, studied there and in the

	end, when I landed at Phönix, wrote my math thesis there and then. I continued as a research assistant here, also at Image, and did my doctorate there. I then went into industry for 6 years and that's when I got into cyber security, so to speak. So then I got involved with the topic, but from a consulting perspective, which means I'm still a bit active, helping large companies, often DAX 30 companies that need support in various areas, these are often process topics, especially in the security sector, it's often not cryptography broken down to the last bit, but often processes that need to be optimized.
Interviewee	I continued to work as a research assistant here, including at Image, and completed my doctorate there. I then went into industry for 6 years and that's when I got into cyber security, so to speak. So then I got involved with the topic, but from a consulting perspective, which means I'm still a bit active in this area, helping large companies, often DAX 30 companies, that need support in various areas, these are often process issues, especially in the security area, it's often not cryptography broken down to the last bit, but often processes that need to be optimized.
Interviewee	But first you have to set them up, which is quite exciting because you have points of contact with many units in the company and don't just look at things from a very narrow technical perspective. I always found that very exciting and at some point the opportunity arose to return here via this current IB endowed professorship, because in a slightly different role, and I then took advantage of that and have been back here at the university since 2019, representing the field of networked automation systems and there is also a clear focus on cyber security and all topics that play a role in this context in the research area.
Interviewee	So far, not so much in the direction of post-quantum cryptography, there are games every now and then, then I would like to deal with it, but that is also a topic that is not so common now, you have to be really interested in it, so I think that's a bit further away
Interviewee	I'd be interested to know, if we're talking about the day in the future, what do you think the day in the future will be in 2026 or is it more likely to be 2036 or even further?
Interviewer	Yes, thank you very much for now. I'm Victoria and I'm delighted to be here today. In fact, it's a few years more, we're in the year 2040 approximately, we have of course taken into account that the different industries, the real entry of the account possibilities is super different. This means that cyber security is actually a bit closer than something like the pharmaceutical industry or the mobility sector, but it might also be interesting to hear who.
Interviewer	Even if you've only just dealt with it on the Internet, there's not much in the department yet. Why do you think this will be relevant for your area or your department at the university?

Interviewee	And I do the calculations in the lectures I just mentioned. organizations, the first two lectures are more of a historical outline, that's always the case with the students who have grown up in the department.
Interviewee	I then tell them that I started sometime in 1650 with his first mechanical calculating machine and, by the way, if you're interested, you can have a relatively nice look at it in Paderborn, if you think the museum forum is all set up there, then they're always a bit bored and what I actually want to get across is this development and what has happened in the last 20 years in particular.
Interviewee	The development has happened, because once you've crossed that threshold where these technologies are out of their infancy, and that took quite a long time, now in the field of classic computers, because things are taking off and at this point in brand computing, we are now where we might be with classic classic computers.
Interviewee	I can't say exactly. Maybe the 1950s, where the first transistor-based computers were created, not yet transistors, but it all developed and the dimensions were a bit bigger back then, we had whole rooms that were filled, but also always central computers and we have the same thing now with computing, where we also have to say that at the moment we have computers that are still quite manageable in terms of performance and they can't yet fulfill what the technology promises at some point in the future, but I think if you look at the technological progress in this area over the last three years or so.
Interviewee	A lot has already happened and I believe that this will simply continue and the potential that lies behind it will be realized at some point.
Interviewee	I also believe that it can be exploited because technological development will continue, and I'm pretty sure that will definitely become an issue.
Interviewer	Mhm, maybe on that point. What are the major breakthroughs or developments that will or must happen in the field of quantum computing in order for a cyber security space to have a real impact?
Interviewee	At the moment, I think one of the bigger problems is the susceptibility to errors that this topic still has at the moment and I think that will have to be solved at some point so that it can be scaled up. At the end of the day, I think it's still the case and this has shown me once again that you have to deal with the topic from the company's point of view at an early stage in order to be able to develop this creativity in the end. What can I actually do with it? Of course, you can look at the optimization problems that are primarily solved with these systems.
Interviewee	They should be in the future, but you have to understand that first, so I think you first have to understand the status quo that you have there today in order to be able to develop creativity on the company side, what you can do with it in the future, so that new business models and completely new approaches can perhaps emerge.
Interviewee	Again, there's the comparison between the classic area, where 50 years ago we somehow had room-filling computers, which then somehow took over central

	tasks, which now had vanishingly low computing power compared to what these things can do today. And today, everyone has such a system in their cell phone and can do really great things with it, it's actually ubiquitous, as usual.
Interviewee	If you look at Google Maps navigation today, for example, because if you no longer have that and you're supposed to drive somewhere and I think this development, i.e. what will perhaps happen in this, in this area of application with the functioning quantum computer, i.e. usable for everyone, that's very difficult to estimate, so you can't say now, in theB60: B67sem, so in 2014 we'll have exactly this and that, nobody can really say today, no, that's why it's interesting to carry out work like this, where you can perhaps think a bit freely in this direction, that's good, I'm not talking.
Interviewer	Our scenario also goes something like this, in that we have really thought about some of the most absurd things and are trying to validate whether this could actually be the case, i.e. whether experts' opinions could also be used, or whether this is actually much further in the future than we thought, for example in the area of security is even more different, because it is not about technological progress to cure some disease or somehow achieve route optimization, but also have individual radios where it is about the fact that. This means that national security could be affected, for example that the topic of cyber wars could somehow increase much more, because there is also this phenomenon, this Harbest Now and Later, or that some governments may not yet be up to the Post Quantum Standard and do not yet have Quantum Safe Communications Channels. And that's where we go again. OK, then somehow that will now be the way to attack a nationality, to attack a nation. Would you perhaps say that this is somehow going in the right direction? So even if you've only read this briefly, it could actually work.
Interviewee	This can actually happen at any time and I don't think the attackers will have to wait until they rake them. So we have the capacity for quantum computers to migrate. In principle, it's always a constant race in the security sector. So somehow there are new attack possibilities at the moment that are really strong in the area of attacks, some of which are also supported by AI, and then the companies or the targets, which are not just companies, are also national economies, clearly we have to upgrade again and say, how can we defend ourselves now and that is sometimes not really a dynamic environment if you currently look into security operations centers in companies at larger companies, which they have to deal with, they really have a big task, but even that has not yet reached all companies. I was just at Siemens in Munich yesterday and they're already relatively advanced in terms of security, production sites and so on, but there are still quite a few areas where you have to say that otherwise there really is potential for optimization and that's a company that I think is relatively well positioned and other companies or even public authorities, there are currently a lot of big loopholes everywhere where you can get in. If you really want to do that, then of course the quantum computer will increase that dimension.
Interviewee	It's not a huge danger if you're not yet chest-wall ready when it comes to encryption and so on. I think you just have to continuously deal with the topic,

	but otherwise to open up the scenario and say that with these capabilities the attackers have completely different possibilities, that is quite valid, so they can definitely do that, although they shouldn't forget that the defense mechanisms can of course also be raised to another level with the possibilities that are available to both the attackers and the defenders.
Interviewer	Yes, and also that hopefully by that point you have created an environment. That was actually also the case with this technology, with which and that doesn't happen from one day to the next. Maybe a question about how X prepared for this, did they somehow get an insight or how authorities should do this?
Interviewee	No, I can't, then I can't say anything at all, which I'm sorry about X. So even if I knew, it would probably be covered somehow by the NDA, so I would probably talk about it, but I don't have any points of contact yet, it's more of a classic sicuri area at the moment. What I do know though is that X has a culture of learning. Continous learning development is crucial is you want your employees to stay on top of the next thing. I guess though for organizations but any institution really it is very important to have the right partnerships in this matter. The more knowledge you can share the easier it will be to know what is coming and how to prepare. This can be good team work and a source of a new alliance for countries.
Interviewer	We also have the issue of authentication in the area of finance and banking, where this area is sometimes to be greatly improved by computers or now there are already agreed attempts at portfolio optimization and the like. We also have a small interjection from cybersecurity that we say the person was up one day and their bank account is emptied because the bank is not on the infrastructure. which is quantum ready. What is your opinion on this is that actually, what could happen is already close today, perhaps on the computer, but in a different way.
Interviewee	Absolutely. So that's definitely a scenario. So I think the attackers will get to the point relatively quickly where they say, well, we'll use the computing capacities available to us now, perhaps even earlier than the defenders. That is security. As such, it is always a continuous process, so in principle, if you have a reasonable security management system, you actually have to continuously look as a company or as an authority to see where I actually have to become active. It's not the case that I say I'm going to do security once and then I'll have all the measures in place and everything will be fine, but in principle you have to continuously examine how the threat situation is changing, and that's a very big issue at the moment. Because these landscapes are an area of intelligence, where you look at what attacks are currently underway, there are also pools from large companies such as IBM headquarters. Pools where incidence is collected, where you can register as a company, so to speak, and where you can get information on current attacks in order to be able to deduce what I need to do as a company to be better positioned. And that's exactly how I would see it if these opportunities are used and I as a company, as a financial institution, as a bank, say where and not so much now, whereby a relatively large amount is

	also specified by Bafin in regulatory terms, then that is definitely a valid scenario if you try to keep pace with technological developments as an institution, because. It shouldn't actually happen, because at some point you get to that point. So now we have the risk that our previous encryption or authentication or something like that can be cracked by quantum computers. That's so high now, we have to do something and then it has to happen at the latest, if it doesn't happen, if nobody looks at it, then it's clear, so then it will happen.
Interviewer	Yes OK, very exciting. We also had the suggestion from an expert the other day that ultimately the bank doesn't really have to take care of it, because the infrastructure isn't set up by any bank itself, but is used by the big computers and they actually have to set themselves up and the bank just has to go along with them, so to speak.
Interviewee	They at least have to keep an eye on it. So if it involves any large external data centers, then they at least have to look there and see if they are certified or if they have implemented measures for this or not? I don't think you can just delegate that away.
Interviewer	Yes, either point is now apart from cyber security or the finance sector, we have also delved a little into the topic of pharmaceuticals, because that is also a super exciting topic in terms of what would be possible there. That's why Hannah, if you still. Exactly. So I'm allowed to deal with the healthcare sector at work, so I'll just ask you in advance whether you've ever had any points of contact with it or not.
Interviewee	Lene So we also have a department here that deals with medicine and health technology at the university, which is a combination of more technical topics that come from our side, so we have a degree program called Medicine, Health Technology and Pharmacy, which we also have a little bit about the Department of Food Technology, or easily be Technologies has now recently been renamed, and we are also active in research there, but it's not so much about this topic yet, but more about how medicines might be printed in the future. So we now have Amazi itself as part of this. Of course, you can see this everywhere, as existing computing will also be the next big step due to the complex processes that today can often only be represented in elaborate laboratory experiments, which can then be simulated, because we actually have a similar situation, I haven't even found that myself, in the area of food production, i.e. food. Apple production processes are often so complex that they are measured with standard sensor technology, any temperatures and so on, but with these standard sensors, such sensor technology is not really able to predict the current process status. This means that you often have to spend a lot of time in the laboratory extracting samples and trying to examine them here in the laboratory to see if they really are the quality I was hoping for and then, of course, this also becomes a very big accelerator in this area, so that you can really improve during production, so to speak in layman's terms in the production line. New quantum computer-based sensor technology, for example, and the computing capacity behind it, will allow us to establish that we are much better at this. Or in predicting the current quality or where we currently stand in the process. I'm not enough of an

	expert when it comes to the process and what's behind it, but I think there's great potential there too, and I think it's similar in the pharmaceutical sector.
Interviewer	Yes OK, cool, if I haven't actually dealt with the food industry at all. I had more of the classic cases that come to mind, like new drugs. Based on simulation or quantum sensors. So thank you for that. Maybe I'll just give it a try with a scenario.
Interviewee	Maybe I could give you another hint or maybe I could try to convey this to you again. We have 2 very active professors in this area and one of them is a bit at the interface between math, physics and the real process topics in this area, which might make for interesting interviews.
Interviewer	OK, then I would like to present a scenario from the health care sector, simply as an insurance policy, and it's about a particularly high-resolution screen that can recognize cancer cells in the lungs, for example, much earlier than computers or screens can do in hospitals today, so it's mainly about pattern recognition, which can somehow recognize computers faster and can then be used to create an NDNA-specific chemotherapy plan. Maybe just with regard to that. With current computers, they see something like this as possible or an advance and will quantum computers play a major role at all?
Interviewee	So I can't really judge these, these imaging processes, not so much. As a first reflex, I would say that with today's graphics processors, we already have GPUS chips that can do a lot of things in parallel, because these are very common tasks, so the same operations have to be performed on identical pixels, and today's graphics processors have already done that relatively well, I don't know what else would be needed from a more banking computing point of view to make it work even better. But I'm not familiar enough with this medical technology topic for that.
Interviewer	There is no, no issue, all good. Ultimately, that's also the problem in the healthcare sector, that it's all very much based on what can be further developed and researched from a medical perspective. That's why it's always difficult to make a statement, I've heard that more often, so it would be really great if you could somehow contact your contacts again, so that I can go into the exchange again, exactly, but otherwise the tasks were the answers from us really very helpful.
Interviewer	Thank you for that. Perhaps we can ask a final question. Now that you've only recently started to read in depth, what are the possibilities or even wishes and dreams for using quantum computers in the future?
Interviewee	As I said, one point will certainly be to differentiate, without me being able to open this up as a senario, to differentiate in which areas is it used and where is a classic computer still good to use? I don't think anything has really been highlighted yet, at least that I've found. What influence can the whole thing actually have on the AI world? I believe that this is exactly when the thing fits, i.e. the main problems here in my office opposite the mathematician are always relative to all his models. It's also difficult to assess the direction of development. And I believe that if quantum computing is introduced in this area

	and it can be improved, then I think it will become a really big area. In addition to classical mathematical problems that cannot be calculated today, which can then be calculated and which of course have consequences, I have to say that I find it difficult to come up with a real scenario.

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Interviewer	Use the conversation today to address this in particular? Exactly. But we will perhaps start with a few general questions beforehand, as far as the procedure is concerned. Would you like to introduce yourself briefly and if you have any questions?
Interviewee	I'm Amelie, I hope it's okay that I've brought my colleague with me, because we're writing the Master's thesis together. First of all, thank you very much for your time and I'm glad it worked out.
Interviewer	So we've set up our scenario, which is a day in the future with full quantum computing capacity. We have considered real-life applications in 5 areas, namely finance, energy, healthcare, mobility and cybersecurity. As part of our master's thesis, we then held interviews with experts to validate this, so to speak, because we also tended to find that a few things are more positive and, above all, that opinions on the time frame differ greatly.
Interviewer	How did you come to write the article and what exactly do you do at Quantum Link?
Interviewee	At Quantum Links, we are the link, so to speak, hence the word between companies and their interests, so to speak, in the field of quantum. So what we do a lot is that we also assess Startups and so on, simply look at the market situation and also look at and assess the technology, then just look, OK, what does that mean for a technology strategy of different companies. Mhm, exactly and for which topics are there any cooperation partners? What we have a bit of an outreach topic and what also comes from the fact that you realize in the topic, so there are still a lot of, let's say, on the algorithm development side and on the getting as much as possible out of the hardware side and even the use cases that are often made. Do we often not have that much to do with actual use cases? I have, simply because the people who don't speak the language somehow, because they don't know the problems and so n kind of bridge this gap, so to speak, we have launched this planned challenge. To do this in the area of technologies or problems that are always relevant. To say, OK, every year we look at what's available in this area. The climate-relevant problems are now bleeding. We've done optimization once, then this year we've done optimization of materials for Director and next year will be disaster prediction.
Interviewer	Will and exactly. And then we say OK are the problem and try to solve problems as realistically as possible.

	Solving quantum computers is a two-stage process, so the problem is always broken down very much and then, if the participants are encouraged to develop concepts on how to escalate it. Active technology, scouting a bit. Exactly from this direction, because I was personally interested, I looked into it, I thought, hey, it would be really cool to somehow write a current report, other consultancies have already written reports about it perianal what should the World Economic Forum write about it, but even if I now have a technical scientific background, I was interested in it and then we wrote this report.
Interviewee	So my overall idea of quantum computing is a bit like this, it's just a new tool, so to speak. It won't immediately solve any problems that we've always had, so it's not the magic pill that somehow solves everything. But it's definitely a new tool that allows you to take a look at things and see if you can solve them. Of course, the time scale always plays a decisive role. So which problems can we really solve with near term? Which can we do better with quantum than with classical? And which problems do we still want to solve in the long term, so to speak? In this sustainability, I think it's more about things that we simply have to do now with the technologies we have. Where we don't have to develop anything else, where we say, OK, we have solar cells that are sufficiently efficient, we have them as systems, we can build them, great, we are currently building several nuclear power plants equivalent to solar power plants per year in Germany. This will enable us to reduce our dependence on coal and gas. What are the technologies that we use today and the other question is what are the things that we want to improve in the future. Everything that has something to do with energy efficiency, including building management and so on. What about the fact that you need so much energy to keep the quantum computer running at minus. 30 degrees is absolutely zero, that's just what we need.
Interviewer	Do you also mean that power cuts are avoided?
Interviewee	Exactly, so there are two problems. Firstly, we have the challenge that local energy production is sometimes insufficient or there is too much at peak times. The aim here is to achieve better distribution throughout the day. That is one problem. On the other hand, when we talk about storage, we tend to have a scenario that you may have heard about in the intraday sector. The other problem relates to longer-term energy consumption, so to speak. In Germany, we are producing more electricity overall, but unfortunately often at the wrong time. The existing energy storage systems can only cope with this for a few hours or a maximum of 2-3 days. For a longer period, for example for the next 3 weeks, we would need both advanced storage technologies and technologies that can better predict energy demand in the future.
Interviewer	And do you think that wouldn't be as possible without quantum computing?
Interviewee	Yes, it's already being done, and it's possible without quantum computing. It seems that there are many optimisation problems that do not necessarily require

	the power of quantum computers. The strength lies more in finding better solutions. In areas such as energy efficiency or finance, a solution that is 10% better can already bring significant benefits.
Interviewer	A brief digression, because you just mentioned optimisation. What do you personally think the most of, simulation, optimisation or machine learning? Where do you see the greatest potential?
Interviewee	It's difficult to predict, but the greatest potential for quantum computers probably lies in chemistry. In chemistry, simulations and property calculations of molecules often rely on approximations, and certain simplifications do not apply to all molecules. A quantum algorithm called Quantum Phase Estimation could help to perfectly calculate all properties of a molecule, which would enable enormous progress in chemistry. This could be used in the pharmaceutical industry, for example, to speed up the development of new drugs by testing a large number of candidates in the laboratory. This would significantly speed up development cycles in chemistry.
Interviewer	OK, proposing quantum chemistry, I have another scenario for batteries, which was also mentioned in the article. It's just kind of spun around now, but I once read in an article that it could be possible, for example, to charge a mobile phone or electric car within 5 minutes.
Interviewee	Well, I'm a bit critical when it comes to predicting exactly what advances in materials science can be achieved through the use of new tools such as quantum computers. It seems difficult to assess what fundamental laws of physics might militate against the idea of charging an entire car in minutes. I doubt that such advances can be easily predicted. Especially in the context of new batteries that can be simulated by quantum computing, it is pointed out that batteries are complex systems. The interactions between electrolyte and electrode material are difficult to model classically. Although the calculation of material and system properties could be improved by quantum computing, the accurate prediction of advances in materials science remains a challenge. In my reflections on the use of quantum computing in materials science, I draw a comparison with the introduction of microscopes. In doing so, I emphasise that quantum computing could hold potential in previously unforeseeable areas, similar to the development of transistors. Despite these potential opportunities, I remain sceptical and point out that it is difficult to predict in advance exactly what advances in materials science can be achieved through the use of quantum computing.
Interviewer	When can we expect to see these applications?
Interviewee	I personally believe that applications need to be developed first to realise the full power of quantum computing, and many advances, such as the Quantum Utility introduced by IBM, are already showing a big push. However, especially in areas such as chemistry and machine learning, thousands of logical or physical qubits are already required. Scaling is not linear, and various technologies, such as neutral atoms, still face challenges, but their solution

	could enable the scaling of quantum computing. However, it remains unclear when exactly these problems will be solved and the technology will be available on a larger scale.
Interviewer	What's your opinion on quantum computing and the scaling up of quantum computing?
Interviewee	During my studies, I gained extensive experience with solar cells, including practical work in the laboratory where I produced solar cells myself. In particular, I have worked with crystalline materials such as perovskites. With such materials, the challenge is to find the optimal combination of ions that have certain optical properties. Simulations can be used to predict both the optical and electrical properties. A precise simulation makes it possible to optimise these properties and thus increase the efficiency of the solar cell. A central concern in research is also the search for alternative materials for solar cells that are not dependent on rare or environmentally harmful substances. Simulation plays a decisive role here in identifying suitable substitute materials. We need solar cells to further reduce our dependence on other sources. Quantum computing could play a revolutionary role in this context. The idea is that quantum computing could enable us to derive the properties of a solar cell directly from the chemical structure of the materials used. This would enable a more precise prediction and could help to further increase efficiency. However, I also emphasise certain difficulties. Accurately predicting the overall efficiency of a solar cell remains complex as different scales (micro, meso and macro) need to be considered. One challenge is to transfer the findings on the microscale to the entire solar cell. Efficiency claims of 40%, for example, come up against fundamental limits. A perfect material can theoretically achieve a maximum efficiency of around 33%. However, it remains exciting to see how new technologies and possibly quantum computing will continue to drive research in this area. In this context, articles from the Jülich Research Centre, which mention efficiency claims of up to 40%, have certainly attracted attention. However, it turns out that there are fundamental limits that cannot simply be overcome by higher efficiency claims. In my research over the last six years, I have come across these challenges and remain excited about future developments.
Interviewer	Of the applications in the energy sector, what are you most convinced will bring the biggest change?
Interviewee	I like to be surprised when it comes to the use of quantum computing. It's obvious that there are certain problems that can be solved efficiently with this technology. However, nutrition-related issues and the scalability of the algorithms used today are still unresolved. The existing algorithms may already deliver impressive results today, but their long-term applicability and scalability are uncertain. In terms of chemistry, however, there are some fundamental

	reasons to suggest that quantum computers could be particularly effective here compared to classical computers.
Interviewer	How important would you rate quantum computing for sustainability?
Interviewee	My overall idea of computing is that it is a new tool that will not immediately solve all existing problems. It is not a magical solution to all challenges, but rather a new way of looking at existing problems. The key is to select the problems that can be solved more efficiently with quantum computing compared to classical methods. I ask myself which long-term problems we still want to solve at all. In the area of sustainability, there are things that we can already tackle with existing technologies without having to wait for further developments. For example, we have efficient solar cells that we can use as systems. Germany is building several nuclear power plant equivalents per year by utilising solar energy, which helps to reduce dependence on coal and gas. The question now is which technologies we use today and which aspects we want to improve in the future. The focus is on energy efficiency, building management and similar areas. Quantum computing could enable significant advances, especially in chemistry and materials science, but I remain cautious and emphasise that it is difficult to predict in advance exactly what progress can be made. My attitude is open to surprises, but I also recognise the uncertainties and challenges associated with this emerging technology. In terms of energy expenditure for quantum computers, I see this as less of a problem. The energy consumption is not that great once the system is cooled down, and the energy cost per computing operation could potentially be more efficient than with classical computers. I wonder what long-term problems we still want to solve. In the area of sustainability, there are things that we can already tackle with existing technologies without having to wait for further developments. For example, we have efficient solar cells that we can use as systems. Germany is building several nuclear power plant equivalents per year by utilising solar energy, which helps to reduce dependence on coal and gas. The question now is which technologies we use today and which aspects we want to improve in the future. The focus is on energy efficiency, building management and similar areas. Quantum computing could enable significant advances, especially in chemistry and materials science, but I remain cautious and emphasise that it is difficult to predict in advance exactly what progress can be made. My attitude is open to surprises, but I also recognise the uncertainties and challenges associated with this emerging technology. In terms of energy expenditure for quantum computers, I see this as less of a problem. The energy consumption is not as great once the system is cooled down, and the energy cost per computing operation could potentially be more efficient than with classical computers. As for opinions on the future of quantum computing, it's fascinating to see how

	widely opinions differ, even among people with similar backgrounds and studies. Some see quantum computing as the next big thing in the next two years, while others doubt that it will play a relevant role at all. The diversity of opinions shows the uncertainty and range of expectations around this emerging technology."

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Interviewee	Yes, with pleasure. Yes. I can briefly introduce myself, my name is XXX exactly, I come from computer science, I only learned the basics of physics and so on after or towards the end of my master's degree, so to speak, and yes, I mainly deal with hardware software co-design, i.e. I try to look at OK what quantum hardware should look like so that we can already solve problems that we have in industry today, for example in the area of optimization problems. Machine learning is another area that we want to look at next. Simulation is of course very interesting for us, but at the same time I'm also looking at, OK, what kind of hardware do we have today? So we are really looking at the various platforms, both annealing and gate-based. And of course we also look at: how can we reformulate the problems we have today? How can we formulate our algorithms in such a way that they are better suited to the hardware we have, so that we can get the most out of the limited resources we have, so to speak, a bit like the beginnings of classical programming when the first quantum computers were started in 1950/60. I don't know if I've heard a bit of C programming, where you really allocate the memory and the bits you need. Assign them individually. That's how you can imagine it a bit with quantum computers today, so that you really use every qubit. Let's take a look: how can I reformulate my problems so that they simply fit better and I might already have a benefit in the NISQ era, which we are currently in, and not have to wait until the quantum computers are error-free and have a certain size. Of course, like with us at XXX, we have special use cases where it would make sense and where not. And it's also okay if you get out. Hey, you could also solve this in the classic way, where my background in computer science helps, so that you know what is already available in the classic way, what is optimal or good enough. It's still a bit different in research than in industry. Industry doesn't always have to be the perfect solution, it can also be a better solution or a faster solution in research, of course you always want to find the right solution.
Interviewer	Yes, perhaps I can start directly with a question because I am also interested in what you have already found out about what actually works classically at the moment or will always work better than on a quantum computer. Are there any specific use cases?
Interviewee	In other words, the problems we are looking at are the MP complete problems. Do you know what MP complete problems are? No, unfortunately not. OK, it's easy to explain, so you have a classic development in the field of computer science, at some point computer scientists started thinking about problem solutions in the 1970s, for example graph coloring or traveling sales man is a very simple problem. The problem of the traveling salesman. I have to visit x

	cities, what is the shortest and best route and I go to visit them once and then return to the starting point, and at some point, of course, people tried to make the algorithms more and more performant, i.e. they were simply solved faster, took less time to be solved or required less memory, and at some point they realized with a few algorithms, OK, we're not getting anywhere here and then they started to classify them. So you thought about it: We have different complexity classes that are sorted according to how long it takes to get a result from the algorithm at infinity. So if we remember this from school mathematics, you always look at the infinite range in analysis and how much memory I need and there is a class called MP complete, which includes all problems, i.e. MP complete and MP hard is another level above, for example chess belongs to the MP hard problems. Where it is said that there is still no known classical algorithm that can solve these problems in a reasonable time. For example, the decryption of our encryption systems also falls into this category, and these are the problems we are looking at, where there is no classical solution in a high range that can solve it well, no algorithm that can solve it well. There are solutions that can approximate it well. Yes, the ones that approximate quite well, where you have no idea. Problems the size of 1000 2000 cities, such as traveling salesmen, can be solved.But to really give you the exact solution or the best move in chess. Of all the solutions that exist, there is simply nothing, these are the problems we are looking at, that is, we already know that there is actually no way to solve them exactly classically and we have the theoretical and proven hope that precisely these problems are very well suited for quantum computers. Something like the traveling salesman or graph coloring. Mathematically or MP complete problems are all reducible to each other, i.e. if you have the solution to one of the problems, you automatically have the solution to all problems. This is the $1 million question to find out if there is a solution at all, classically. Exactly and that makes it classical, there isn't, but with quantum computing you have hope and that's simply because quantum computers have completely different properties than classical ones. I don't know if you know a bit about it by now, the one superposition, we have entanglement, exactly, tell you what, because of these conditions, it is said that quantum computers can probably solve combinatorial optimization problems better, because you simply look at a larger search space in parallel at once.
Interviewee	But the problem we have today is that we can only test this for small problem sizes because the hardware is still too small, but that's enough to be able to make a few predictions for the future. We can also simulate something a little. So that you can see, OK, what would it be like if we had completely error-free quantum hardware later on, and you mustn't forget, for example, the problem of the traveling salesman, which sounds like this at first: what's the point? But there are lots of industrial use cases, for example job store scheduling, maybe you've heard of it, you're in production, you have x orders and you need to process them. And what is the best order in which to process them? Or let's think of one of the biggest problems we have in Germany, the car industry, if you order a new car today, you can modify everything and then you have to imagine that the places from which you get the materials, the goods, where parts of the car are produced, are also distributed all over the world. It's a very

	complex problem where you have. millions and many millions more variations. To work out today what.
Interviewee	The ideal way would be to assemble the car and where. The algorithm runs for about 8 hours for one car. And you still don't know with 1000% certainty whether it's optimal. And this is also a use case, for example: traffic, whether traffic optimization. Portfolio management in the financial sector, yes, making better investments has already been proven. It is also practical in applications for short-term investments to make better forecasts, which would be a smart investment for the short term because, again, the hardware is still very limited and that is why there is hope that it can also be used later for long-term investments.
Interviewer	With full-scale quantum in finance, do you think that there could also be a zero-risk portfolio at some point?
Interviewee	No, but I generally don't believe that finance will ever be zero risk, because one thing you always have to take into account is people themselves and their emotions, which often lead them to make irrational decisions rather than logical ones. And that's why I believe you can never do something like this with zero risk, but you can optimize it better.
Interviewer	We did our scenario in 5 industries and we were just talking about cars and I think it would be mobility, so maybe I would come back to that and one of the applications we found through the literature is autonomous driving, which is not only good optimization, but also a lot of machine learning. Do you think quantum computing will help achieve a breakthrough there, or is it not so dependent on quantum computers?
Interviewee	It could definitely help there, so quantum computing with machine learning is being looked at in two directions, one direction is you use machine learning to improve quantum computing, you do that because quantum computers have errors and the hope is that you could use machine learning to reduce these errors. Both are probabilistic, so they could fit. The other direction is, and this is now the case in autonomous driving. People are thinking, OK, quantum computers could help improve machine learning algorithms. Why? 2 reasons the first is I can speed up the training, I think that's a bit self-explanatory information that you also have the other is but I can look at a larger search space everything around us they are actually quantum systems and quantum computers can simulate quantum systems better.Because you can simply look at more at once.Also through this superposition.And if I can look at more and have more information and more data, then I can also make better decisions and that makes sense, especially in something as complex as autonomous driving, where I have a lot to consider and where a lot can happen that I haven't trained beforehand.Another area that is also very much looked at in machine learning.I haven't done any experiments on this myself, but I would like to.Reinforcement learning by reinforcement learning works like this. I have an environment a bit like Pavlov's dog and have a function, that's where I want to go is my objective function and I like to use rewards and punishments to determine what the right

	behavior is, so to speak. That means I don't need a lot of data, there are many quantum algorithms that work on the same principle. I have a function, I get penalties, depending on whether I do what is desired or things that are not desired, not feasible and then calibrate my parameters so that I get the optimal solution and that's why you think that it would fit together very well. Machine learning and quantum computing and that could speed up the training and help to look at a larger search space and then get more optimal results.
Interviewer	And do you think this could be spun further and then somehow transferred to the airspace so that the drones could somehow be optimized and controlled by quantum computing? Or is there a limit somewhere where computing could no longer absorb this entire mass of data?
Interviewee	I think it is certainly possible. The only thing you have to imagine is that many algorithms are hybrid algorithms, i.e. you use a quantum computer underneath a classical computer and the algorithms are also structured in such a way that you have the exchange between classical computer and quantum computer and clearly at the present time everything that is done technically in terms of data processing, a lot of it is also done on a classical computer, yes, that you have this exchange and I can also imagine that we will have quantum computers for a long time, for example in high performing computer centers with federations as accelerators for classical computers. And where exactly the part, i.e. when it comes to this combinatorial optimization, that is also done by quantum computers, but the whole pre-filtering of the data and so on is still done classically, we already have some good methods and it can certainly be used there as well. I don't see the problem with quantum hardware as being about solving even bigger problems from machine learning, cyber security and so on, but getting the hardware there first, because getting quantum particles under control, making sure that the error rates are low, we haven't figured out how to do that yet. So the bigger problem is actually just the hardware and the hardware development and getting the qubits under control, making sure that the information doesn't get lost, making sure that the error rates are low enough and that the qubits can all communicate well with each other, because theoretically if you have data stable systems, what's possible.
Interviewer	Perhaps the question is, when do you see the time period? When such hardware could be really solid and ready.
Interviewee	I think that depends entirely on the use cases. So I think we can really improve optimization a lot in 3 to 5 years. As I said, so everything that requires optimization, better approximation and so on, I think it will take 3 to 5 years for everything that really needs pre-tolerant hardware, so something like decryption of the RSA encryption systems we have or topics such as simulation of chemical reactions, simulation of materials, manufacturing, finding new materials, All of this requires full-tolerant hardware and we are still very much at the beginning of development and I think we will probably have that in 10 years, or that is unfortunately the honest answer that many people often don't want to hear, but full-tolerant will still be a while before we have that in a size that is really useful, but I think we will learn how to use it in 3 to 5 years.

Interviewer	You've just talked a lot about optimization.One of the applications that we heard a lot about from the experts was actually simulation and especially in materials design or drug design.Do you see that as slower, but is that later on considered optimization or how would you classify that?
Interviewee	Well, I think that's definitely where we'll get the biggest or one of the biggest and best benefits, because we also have really good approximations in the classical sense.Yes, of course you can still get a bit more out of it, but especially in the medical field, you can find new drugs, make better simulations of how they react to the human body.You could be much, much faster.We could carry out drug tests and also find new materials.So you have to imagine that if you're looking for a new material, you have to think about building it, testing it or the simulation takes forever.So this process, which normally takes 6 months and upwards, could then really be reduced to 3 weeks to test a new material, because you can really simulate everything.Fantastic.The problem is that we don't have the hardware for this yet. And that's why, that's the only reason why it takes longer, not because we don't know how to write the algorithms, not because we have no idea how to use the quantum computers for it, we know all that mathematically no problem, algorithmically no problem, but the hardware is missing and that's the only reason why I think it will take longer in these areas, but why you can't go wrong in these areas if you invest a lot in research and continue and find out what the best algorithms actually are. The thing is that these areas don't even have a classical approximate solution. So there really is no solution. Here and there we also have an exponential speed and in optimization problems we only have a quadratic speed up. That's a huge difference, especially in the medical field, material simulation field now with the metaverse and industrial metaversum I know some people say that consumer metavers is already. Burying death has no future, but in industry metaverse is actually a bigger issue. Yes, it makes perfect sense there.
Interviewer	Do you think there will be different hardware systems and again different computer quantum algorithms and be happy to answer that.
Interviewee	Yes, definitely in the meantime. We have a lot of different manufacturers and there are also, so you can imagine such a tree, we have quantum annealing and we have gate-based, quantum annealing is you practically let physics run free, because in natural physics everything looks for the minimum energy, that means quantum annealers mainly process functions where it is a matter of minimizing energy, such as how do I find the route, which costs me at least energy, then you have gate base. The quantum computers work more like our classical computers, you have your qubits, bits, and from these you also make operators such as I add something. Even if you have different operators than classical and there are different manufacturers, so you have IBM, you have Google, you also have a lot of small European companies like AQT Kontinuum, a lot of companies. These companies don't all build the same quantum computer. There are companies that build quantum computers with super conductors, some with atoms, some with ions, some with diamonds and each of these designs has different advantages and disadvantages, some have fewer errors, it is super difficult to get many qubits together, with the super conductors, for example, you get too many qubits together, but that is the

	communication with each other is difficult and you need temperatures that are as cold as the universe. So depending on the use case you need something different and that's what we're trying to figure out, for some use cases it's super important that every qubit communicates with every qubit.
Interviewee	For others, it doesn't really matter, but it's super important that you have fewer errors. So yes, I do believe that there will be different hardware for different use cases. But I don't think the end user will have to worry about this in the future, because the end user will then send their problem and there will be an intermediate layer, so to speak. Everything else for which knows exactly what the problem is how to solve it and that with the right hardware and improved.
Interviewer	OK, interesting. I also have a small question, because you also mentioned the topic of encryption and co. I'm in the cybersecurity space and many people appreciate that this is a game changer in encryption.And that there are enormous opportunities to make the whole thing more secure, but that there are also a lot of risks involved in simply destroying our current encryption completely.How do you see this as a real danger, that we should prepare ourselves with post-quantum algorithms?Or is there currently no chance?
Interviewee	I generally see technologies as opportunities, it always depends on who uses it and who does it, and I also see encryption as an opportunity, for example key exchange is already being done today with quantum computers.Quantum computers have this one property that they only break the superposition once and look inside.The information that you look at is then broken and you can't jump back when you exchange keys, which is much more secure because the person who receives the key knows with greater certainty whether someone has already looked into the experiment setup.
Interviewee	And with quantum computers you also have new encryption methods and there has been research on this for a very, very long time and there are already theories and possibilities to encrypt this better and also to protect it against bank decryption encryption.That's why I'm not so worried.The only thing I would say that worries me is this trend with the Save Now decrypt later, that people are already picking up data and saving it and so on, but then our security systems are already failing. So if someone has the opportunity to download important government data or otherwise very strongly secured data, we already have another problem anyway, whether encrypted or not, I would say, so there are always dangers, there are always cyber security issues, there are always vulnerabilities even without quantum computers and there are always hackers who find their way out and it's a cat and mouse game and I think that will go on forever but I hope that there are simply more people who are committed to protecting everything.
Interviewer	And you're in Germany now, I think, because Europe is now trying to catch up, but as with IBM Google, these are all US companies that are actually the pioneers, you have the feeling that this could somehow also be a national advantage if you're the first to develop the hardware.
Interviewee	develop the hardware. Yes, if you look at publications in general, Germany and Europe are very far ahead. We have a super, super amount of basic research in

	this area and we are very well positioned and we also invest a lot. For example, a quantum school is now opening in Hamburg, Cambridge University in England has actually been involved in quantum computing for the longest time in the world, we have made a very, very good start, the problem with us in Europe, and not only there, has also been observed and observed in topics such as generative AI and so on, is that the leap into industry does not always work for us. Because our industry always starts until the technology is about to come out, yes, and then it's really ready or where you can say, in 2-3 years we'll make a profit with it and I find that problematic with technologies like quantum computing, because it's just fundamentally different from everything we've had so far and needs a certain amount of preparation time. In the USA, for example, it's the other way around. You have very little public funding in these areas, but you have a super, super large number of private companies that invest a lot of money and don't mind investing millions and billions 10-15 years in advance and then immediately have the industrial use cases. There are a few calls in Germany, I think there was a bit of a wake-up call, and also in Europe, so there are also European funding projects that focus more on applications. But unfortunately, I see that many companies are not investing much and not enough. Because it takes people too long. The start-ups actually give me hope, there are very, very many quantum start-ups, also due to the government, I know many are always upset about the governments. Especially when it comes to digitalization issues and so on, I'm not innocent either, but I can see that they are doing a lot and have also supported startups very strongly in the quantum area, which still came from Merkel. She is a physicist herself.I think the topic was close to our hearts here, it gave us another push, which is precisely why there is still hope that we can really swim with it, but we really have to make sure that our industry invests and has a stake in basic research, we are already doing a lot.
Interviewer	Yes, unfortunately we are already overdue. May I ask one more question, Amelie, who has just written in, and that is about energy and she wanted to know your opinion on how computing can have an impact on sustainability.
Interviewee	Oh really, really big, for example in the area of building optimization. You can take a look at a few figures. I haven't done much research, but the latest official figures I have are actually from Siemens: energy consumption in buildings is 30 to 40% too high.But also worldwide.I think that exemplifies the total energy consumption and you could really use quantum computing to optimize that better. There are also other ways that have not yet gotten everything out, even classically, but there is a lot there.You can reduce things like training times for machine learning algorithms or need fewer computing resources because you simply have the option of calculating more in less time and doing it in parallel.Well, if the computer no longer has to run for 12 hours, but only for one hour, that's great.You'll also save all that energy. Simulations are very energy-consuming, I'd say. So you really have a lot of potential to improve things. That's exactly why it will play a very big role.

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Interviewee	OK, so yeah, my background is in mathematics. I'm originally from Spain and I first started working in IBM with classical computers. So the computers that are using high performance computing, but also to train the models that we use in artificial intelligence. And after that I started to learn about quantum and my first contact was in a team of evangelist inside of IBM. So I was trained by the researchers because we were helping them bring the message out to the world because they were busy doing the research.
Interviewee	And I liked it so much that I decided I wanted to change my field to Quantum. And yeah, and so that's why I moved to Switzerland, because the IBM Research Lab that works in Quantum in Europe is mainly based in Switzerland. And I was there for two years working in outreach, education and community building. But also I had a small project with the application group on Quantum Finance and that's how I first got into finance and one year ago I changed companies and I started working for moodys and I don't know how much you know about it about.
Interviewer	Not that much.
Interviewee	So, OK, I can send you some information, but to summarize, you have to think that when some company wants to do business with another company, they need to make their estimations beforehand on what's the risk associated with that decision. So the companies like Moody's provide the role of providing insights based in data and analytics so that they bring transparency to this kind of transactions. So that whenever a company wants to get in business with others, they can rely on our opinions about this third party to ensure and to have a aggregated view of the risk associated with that decision. Because there are different kind of risk associated with making business with other companies. Ones can be financial risk but they can also be service security risk.
Interviewee	If you are for example an insurance company and maybe what you are evaluating is a certain profile of a client depending on where they live and you need to establish a price for the policy, right. So and maybe there there's also a component of climate risk because people that live in areas where there are more natural disasters need higher insurance and coverage. So and and we don't normally provide isolated overview of each kind of risk, but the value that we bring is that we also give like an aggregated view of how each kind of risk influences each other. OK. So as as you can imagine in this kind of company, our first step is let's represent reality as a mathematical problem and then let's make operations on it to get information about forecast, what's gonna happen in the future, etcetera.
Interviewee	So whenever there's a new technology, we need to understand if any of these problems that we solve today can be solved more efficiently with the new technology. So that's what my team is doing, is evaluating how quantum will affect all these simulation and optimization problems that we're solving. Can we do it better with quantum in the future? And that's what I'm doing right now, OK?
	That's very great, really interesting, yeah.

Interviewer	Maybe we can then start directly into one of our first questions that is what do you believe which area of our daily lives will be affected by quantum computing the soonest? But you mean in finance or in general?
Interviewer	It's up to you actually, either in finance or in general.
Interviewee	If you have expertise in finance, then maybe in finance, OK, yeah. Because actually I don't think the first applications will be in finance. So when you think about quantum computers, when you think about how to use this new computing parallel, you think you need to think about three different paradigms. So the first one is what we call quantum inspired, OK. And we call it quantum inspired because this is a set of techniques that enable us to solve problems, but they are run in classical hardware.
Interviewee	That means that all the variations that need to be done, they are done in classical computers. But why do we call them quantum inspired? Because these techniques have been used by physicists to study properties of quantum systems for many years. So that's why they were developed and that's why we say they are quantum inspired, because they are inspired from the field of quantum physics, but they are not purely quantum because they are run in classical hardware. So these are probably the more near term applications relying on these kind of techniques because the hardware already exists is the classical high performance computing that we have today.
Interviewee	So for this kind of techniques, quantum inspired techniques there are different potential applications. So for example, in simulation, but also in optimization, there's some potential for it. And then in these problem categories we can find more concrete applications. So you want me to go one by one with the applications or should I first talk about the three and then the three paradigms and the general applications would be preferred? Yeah, first the three paradigms.
Interviewee	OK, so we have quantum inspired techniques on one side. Then there's no problem in the hardware, the hardware is already there, we just need to find the applications. OK, The second way to think about quantum computing is analog quantum computing. So this is the original idea that came from Richard Feynman. And the idea was, OK, so we want to study quantum systems in nature, so some kind of system that behaves under the rules of quantum mechanics.
Interviewee	Let's build a machine that behaves exactly that, the system that we want to study. But with this machine, we have a control environment and we can kind of tune the system so that we can measure what we are interested in, right? So this is more like maybe just you understand it better with an example. Let's say that there's a biologist that wants to study the movement of snakes. They are not going to go to the jungle and study them because in the jungle you don't have cameras, you don't have sensors.
Interviewee	So what they are going to do is they're going to use a snake, but they are going to build the lab where they have all the sensors they need to measure every movement of the snake. OK. So it's the same kind of idea. So we are mimicking

	something that is in nature, but we are building on a machine that behaves that nature so that we can understand the system in nature. And this is the second one.
Interviewee	So here, for example, we can be talking. This is called analog computing, analog quantum computing. So this is where quantum anealers or other kind of computers, like the ones based in neutral atoms for example, they can be used as this to mimic some systems that there are in the nature. And the third one is digital quantum computers. So this is the most similar theme to the computers that we have today.
Interviewee	OK. So we have some operations that we can do. We represent information in a digital way and then we make operations, OK. And this is for example the one that you see in IBM, in Microsoft, in Google. These are digital quantum computers where you can represent information and make operations and this way use of problems.
Interviewee	OK, so whenever you think about applications, you need to think about these three ways that you have available, right And then intensive networks and the potential first applications for those have to do with simulation and with optimization. In the second paradigm, the analog quantum computing as far as it concerns finance, one of the most promising use cases is all of the the use cases that we have in the area of optimization like for example the area of optimization of portfolios, portfolio optimization. So anything that has to do with asset management more completely for insurers, it can be asset liability management. But in the end, essentially they are all optimization problems. So we have the program I'm talking about portfolio optimization is when you are an asset manager and you have different assets where you can invest and you have a client that you have to advise how to invest the money so that you optimize the return and minimize the risk, right.
Interviewee	So this kind of a problem can be formulated as something that you can put in this analog quantum computing parallel. The third one with digital quantum computers we need to think about two moments more short term and more long term because currently the devices that we have are noisy so they are not perfect. In the classical computers errors get corrected before they happen. So this means that whenever we use the computers as end users, we don't experiment any errors because they get corrected before they happen. But with the current quantum computers that we have that are called, we are in the noisy intermediate scale era and we cannot trust a lot the results that we are getting, OK, because they have noise. So there are some techniques to mitigate the effects of the noise.
Interviewee	So we are trying to look for applications where we can use these devices with noise but we can mitigate it so that the results are good enough to trust them there. And is this still an open question. For example, IBM has opened their system so that we can start using looking for these first useful applications in the NISC era. But our main goal could be to arrive to the possibility of having error correction. So quantum computers where the errors are corrected before they happen and this in this regime of quantum error corrected quantum

	computers that are called fault tolerant quantum computers and then that's when the highest improvements will happen, right?
Interviewee	So there for example in the case of a finance, there is the promise of a quadratic speed up for Monte Carlo simulation methods. Monte Carlo methods are a method of simulation that we use very often in in finance. So you we create a lot of scenarios whenever we want to understand how one scenario what's going to happen in the future or something about a certain scenario. And what we do is we simulate many instances of this scenario and then we compute the metrics that we are interested based on these simulations. But this is a very computationally expensive methods because in practice you need to do a lot of iterations and a lot of simulations so that you can simulate as many scenarios as possible and it's more realistic.
Interviewee	And therefore this is an example where we are very excited because Monte Carlo can be done in at a number of iterations that is quadratically smaller than what we are using today. So this will be the main application for the long term these fault tolerant quantum computers. But there are also in this regime we can think about the speeding up optimization problems and we can think about enhancing some machine learning methods that we use for example for a prediction tasks. OK, sorry, maybe I didn't exactly answer your question but yeah so the more near term will rely on a quantum inspired techniques and there we expect to have a optimization and simulation as some of the first applications.
Interviewer	Thank you. Maybe let's deep dive into Monte Carlo simulation because that's also one major point in our scenario. So I think I already heard that you believe that quantum computing can optimize the Monte Carlo simulation and help to minimize overall risk. But can you maybe explain a bit how? Because for me it's very difficult to understand because there's still a human factor and a human behaviour and I don't know, financial crisis that can happen.
Interviewer	Can you explain how quantum computing can really predict all that?
Interviewee	Yes, actually I'm going to share with you a resource for this because I think it's a very good one that explains how quantum speed this kind of process. But I would say that what quantum does is a providing a result with a very good accuracy so that you can be confident that this is a realistic result, right. What we call accuracy and accurate result and it can be done faster than with the classical method that we use today. But the method is not going to change. So in in this case you are.
Interviewee	I think you are more wondering about how this Monte Carlo methods work in general, right?
Interviewer	And how it can really be optimized or forecasted?
Interviewee	OK, so yeah, the problem today, these are very successful methods to predict the kind of metrics to do simulation and if they are widely used, not just in finance but also in other fields. And why these methods are successful, it's a different question on how will quantum help. So the methods are very

	successful and we know we can rely on them. So for example, we use them whenever we have a system that cannot be solved like with other methods. And then the only thing left to do is simulate a lot of instances and then make estimations based on your simulations, right.
Interviewee	So this is like the idea behind a Monte Carlo. So to give you an example, it helps you, for example, to understand how well the experiment of tossing is going in there. And if you wanted to understand what's the probability of having heads and tails, what you can do is tossing it many times and then measure how many times you have heads and how many times you have tails. But you are not thinking, OK, how does this experiment work? What's the probability distribution between the two possible events, heads or tails?
Interviewee	What you are doing is OK, let's try a lot of times. Let's simulate. Let's write down how many times we had heads, how many times we had tails, and then based on the data that we are observing, let's assume what's the probability of having tails or heads. This is the same process as in Monte Carlo. What you are going to do is produce an experiment many times and then make assumptions on the model that covers this experiment based on what you have seen with empirical data.
Interviewee	But the of course the case of the coin is very simple, but you can also think about it with more complex games like in the casino like the roulette. This is a good example. For quantum Monte Carlo you simulate both the for example the European and the American roulette and you see that there are differences because in the American one they have two zeros. And in the European one they don't. So you can make assumptions.
Interviewee	So what's the probability of each of the events, red or black or each of the numbers? Here what you will have to do is simulate a lot of terms rotating the wheel right And if this is when you said that thinking about OK or the possibilities or the numbers, how does it rotate it set up. So in finance we use the same but also in other fields and whenever the model that we have used to represent some event in reality is too complex to be solved with other mathematical techniques, then what we do is use Monte Carlo simulation. And of course the better your model the better the results you will get. But these realize on how you model reality.
Interviewee	So that's the problem of a mathematical modeling, how do you represent reality, for example the economy and all the factors that influence each other. How do you represent that? And this for example my company Moody's, it's expert and they have been working on this for years and they have quants that are expressing quantitative finance, thinking about how to model reality. But then the method is another question, What's the problem with this method? The problem with this method is that for simulating a coin, the experiment of a coin, this is very simple.
Interviewee	But if we want to to simulate a very complex model, each time you simulate a different version of the of the scenario, it takes a lot of time. And if you have to do it for many input variables that are different to consider different scenarios in economy and then it gets very computationally expensive. And you want to put

	as many different data as possible to come up with every possible different scenario. So this is where is the problem. It's a very successful method, but it's very computationally expensive because if you want to be realistic and consider all possible scenarios, then it will take a long time.
Interviewee	So the excitement about quantum is that this same process of simulation can be done faster. And sometimes this is very important for our clients because maybe they need to compute some metrics more often that they do today and the limitation today is the time it takes to come up with these metrics.
Interviewer	OK, so quantum computing can help there because it's much faster and can, yeah, simulate much more scenarios in in the amount of time, yes.
Interviewee	OK, for that concrete case.
Interviewer	And then another topic that we have in our scenario is everything that is related to fraud detection. Because yeah, banks right now they lose some revenue because they disqualify suitable candidates due to a lack of information and vice versa. And we read that quantum computing can help to better detect potential customers. Do you think that, quantum computing can help with that? I think it's a bit similar to what your firm is doing right now.
Interviewee	Yes, yes, absolutely. That's another one of the cases that we're considering. So the three categories, not the ones that I told you before, but the three categories of problem areas where it can help is a simulation optimization and machine learning. Yeah, so the use case you are talking about right now is a anomaly detection. So fraud detection is usually all the transactions that happen are not fraudulent, but there are some that are an anomaly when someone is trying to commit fraud, right.
Interviewee	So this is an example of where the current algorithms that we have in machine learning in order to build good models that are good at detecting these anomalies. This process of training the model is also very computationally expensive. And in some of these algorithms there are parts of the of the part of the computation that are also computationally expensive can be enhanced if you use like a hybrid approach where some parts of the training of your model are done in quantum and some are done in in in the classical GPU's or well or classical machines that we have today. But yeah, the idea with machine learning is that quantum can enhance the models that we have today by providing some some computations that maybe today are only done approximately or that are very heavily expensive and giving a better a better result for but but it's always some sub process inside the creation of the machine learning model that can quantum can help with mm hmm and in the case of a normal detection.
Interviewer	Yeah. And what do you think is the time horizon for that so? What do you think, does it take, I don't know, five years or 10 years till it like, works perfectly and quantum computing can really help?
Interviewee	OK, yeah. So this is a little bit more difficult to predict because this is a use case that we see for the long term. Quantum machine learning is still a little bit

	immature as a field. And there are like several open questions that they still need to be answered. So we consider this to be a more long term use case.
Interviewer	OK. Then maybe one last question to our scenario. So we read that right now customers of banks complain about the lack of individualized offerings and do you believe that quantum computing could help to resolve this problem? So maybe through personalized chat bots, personalized portfolio creation that is like automatically and you don't have to go to your bank supervisor anymore.
Interviewee	So I think that the way you have to think about Quantum is like it's a new accelerator that you have available for any computation you have to do. So in this use case that you're defining about customizing more the experience for a customer. And I would say that it should be a combination of factors, because a chat bot is classical technology, it's AI based, right. But there's no need for quantum. But coming up with a better recommendation for a portfolio, that's something that can be enhanced with quantum computing.
Interviewee	So and you need to think about it like this new accelerator that you have in the data center or that you have available to to solve the problems you need. And then for certain task it will help. So in the case it will coexist with classical computing. So in the case you are describing, it will be a joint effort. The bank will need to be innovative and will need to monitor the new trends on the AI.
Interviewee	But also we'll need to look about where Quantum can help in this process of customizing. And all these technologies working together will help give some more customized experience for the customer of the bank. But we have to understand that quantum can help for very specific tasks. The good thing about quantum is that it can help in concrete tasks that aren't intractable for classical computers. So a good method for that I like is you have to think like you know you are exploring the world, right?
Interviewee	And what tools do you have to do that? So right now, let's say that classical computers are cars, right? In the past we could only walk, so we could only see the village where we are born. But then we build cars, planes, etcetera. But let's say that a, classical computers are cars, quantum computers are not faster cars.
Interviewee	They are not the Ferrari, they are a submarine. So you know, it's like a new tool that will enable us to access problems that for now we knew it where they were there, but we had no way to get there in a very precise way. And now we are able to explore these and explore areas. So in the case of financial problems and what we are have been doing until now is simplifying reality because otherwise if we wanted to be more accurate and we make these assumptions to simplify and we could not solve the problems that we ended up with. But now, with quantum computing for many of these problems, we can consider more complex scenarios and then forget better information about what's going to happen in the future, about how to better invest the clients money, about how to better detect fraud, and being able to consider more complex models to make better predictions and provide better insights.

Interviewer	No. A bit maybe in comparison if like machine learning has the same effect that AI had before on our like economy.

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So for now, it looks doesn't nothing very special, right? But what becomes special? If you think about it, at this point, it may not be in the zero state and can be any point in this sphere. And then, when you apply multiple rotations, you change the state of this qubit. This manipulation allows you to perform calculations. So now we have the qubits, we have the gates, and we know how to perform calculations.
Then, how does a quantum computer physically look for real? You can touch it. Well, this is what a quantum computer, or I would say a quantum chip, looks like. If you use a qubit as ions, so ions are just atoms from the periodic table, and you extract one electron from them, they become positively charged. And the magic happens exactly at the center of this chip, where you can find all these atoms suspended by a magnetic field, staying in place there. So, these beautiful 23 qubits are all aligned together in the cavity we see before.
Now that we have the qubit, let's see how a program in a quantum computer works. Our beautiful program starts from running the initialization, so the states of these qubits are initialized as you see here. Then, the actual magic happens, because now we manipulate the state of these qubits by running several gates. For instance, in this case, this case involves 2 qubits at the same time, so we modify 2 qubits at the same time. This is, for instance, a 1 qubit gate, and so on and so forth. The idea is that at the final step of the program, when you perform all these manipulations, so when you have modified all the states of the qubits, you can read out what is your final quantum state. And this final quantum state, once the readout happens, should inform you about the solution to your problem.
By the way, I would like to thank IQ, one of our partners, and in this particular case, this is how an IonQ device works. So we have the QV, we have the game, we know how to build a machine. What the heck prevents us from already having in our pocket a quantum device ready? And this is one of the big drawbacks of nowadays quantum computers. And probably you have already heard that, and it is error. So whenever you compute your X gate, the gate that we saw before, for each gate there is actually associated an error. And in this particular case, you don't really need to remember the name, but it's a coherent error. And this is what's happening: Instead of going from zero to 1, what you actually do is you perform a slightly larger rotation and you end up in a place on this Bloch sphere that is not exactly where you want your qubit to go. It's like a little bit of a cheeky qubit because you never get exactly the state that you want.
OK, well these are small rotations. It's really like small rotations, a big problem. Well, the point is that actually you do not add all these extra rotations around 1 axis, but you have extra rotations a little bit around all the three axes of the sphere. And in particular, when you apply it multiple times, these gates, your error amplifies and compounds. So at the end, if you apply, for instance in this video, five times your series of gates, your final state is very, very different with respect to what you would like it to be. And this is a big drawback because, as a counterpart, it has the fact that now our circuit, so the number of operations that we can perform on our qubit, becomes very, very small. Just to give you an example, this is just an equation, but it's the equation to calculate the amount of operations that you can perform on a

quantum computer given a certain error, the number of quantum operations. So the end times that you perform this operation, it's just 68.

OK, so what? Small circuit, right? So it is very, very little manipulation. In a classical computer, nowadays, you can reach 10 to the 17 operations without committing a single error. This means that a single CPU can work without error for three days and you can perform a lot of operations, and therefore your code is free of any error whatsoever. So the take-home message is that, as Jasper said before, quantum technologies offer exponential advantages not only in terms of the solution space that you can reach but also the timing of which the algorithm runs, where you can run algorithms that are extremely complex using a classical computer very, very fast. However, we are not really yet there because there is still some engineering problem to overcome, and this error problem of this gate is one of them. I'm sure we will improve and there is a really strategy to make this

happen, but we are not really yet there. We cannot really tackle incredibly complex problems yet, but if I remember where Jasper, I think there are lots of problems that we can tackle. Can you tell us a little bit more about some insight?

Jasper: "Sure, sure. Of course. I mean, that's why we are here. So quantum computing is really this potentially disruptive computational power, as Manila was just pointing out. We don't really know where this journey is going to go, but the potential is there to be a really large, big, and huge disruption. So, of course, we can now think about where can we use a quantum computer. Let's say, for example, we can use it for a scientific problem which is too hard to solve on a classical computer. There are many problems, new problems, which probably nobody has thought to solve because they are just so difficult, so hard that there's anyway no chance to do so. There might be new problems which we can solve. What is done today quite often is, for example, in the industrial sector, what we are doing at Airbus, looking into industrial problems for us in aerospace. And there, we find a lot of applications for the quantum computer. But it's not only others looking into quantum computing—energy sectors, automotive, finance, pharmaceuticals. So just to name a few, there are really many industries exploring how quantum computing will help them in the future.

There's one thing we always have to keep in mind when we think about what should we use a quantum computer for? It's very likely that when we achieve this fully-fledged quantum computer with all its power, there will not be many resources. The resources will be scarce. Maybe there's only one machine or a few in the initially. So it will take time to grow this capability. And that's why we have to make sure that we use a quantum computer for something which is really driving a challenge for our society. So one of the challenges we all know, and which is also a big topic here at the summit, is of course global warming. So to give you an example of how we at Airbus investigate quantum computing in this context is that we are using quantum computing to accelerate the decarbonization of aviation. And this is what we'd like to show you, what we have been doing here.

So Airbus sees hydrogen as one of the key important technologies for the decarbonization of aviation. We have a program where we develop technology bricks, we investigate different concepts, and the ambition is to bring the product, the first commercial hydrogen-powered aircraft, into the market by 2035. This is, of course, ambitious, with many challenges. What you see here is the drawing of the engine, one of the options to power such a hydrogen-powered aircraft. In the center of this engine is a stack of fuel cells. The fuel cell is converting hydrogen into electricity, so it's providing the power to lift off this aircraft, to take off this

aircraft, and then let it travel for a few hundred kilometers. So, I think it's obvious that this device needs to be extremely efficient.
So, Manila, can you tell us how we used the quantum computer to assess that?
Manila: "Yes, of course. I hope you are very interested because this is one of my topics that I am more keen on studying and this is how it works. A fuel cell. OK, I'm a chemist and a fuels cell works very sketchy like this. OK, so there is an anode on top where the hydrogen is oxidized. OK, so you react arrive at the top of the anode and as you see, it releases some electrons. On the opposite side, we have a cathode where now the oxygen that is in the air, OK, is reduced, so it absorbs the electron that the hydrogen releases, OK, and in reaction forms water. So the outcome, the final outcome of this reaction is twofold. First, it's clean water, so no problem of CO_2 or anything in the atmosphere. And the second is that they create a certain voltage between the cathode and the anode, and this voltage is what actually powers the engine of the aircraft.
But there is a 'but'. There is a 'but', okay? It's not that easy because for powering an aircraft—and I hope everyone here in the room agrees—we need safety and we need a lot of power, okay? And these reactions have to occur very, very efficiently to be applied for an engine on an aircraft, okay?
And the biggest problem here is the oxygen reduction reaction that occurs here because these are very difficult to make it happen efficiently, so very quickly, okay? And in fact, you see, I hear a lot of balls, and these balls are basically a catalyst. So it's some methods or some particular alloy of methods that allow this reaction to occur much more quickly than without it.
So it's clear that if we want to make this reaction occur as best as we can, we really need to understand how this reaction occurs, to understand how the catalyst functions. And this can be done in two ways. The first one is to spend a lot of money, a lot of time, and a lot of effort in a lot, and you try a lot of different experiments in a lab, and you take out, or you deduce some results.
But there is a much better way of doing it, and that is doing simulation. Therefore, perform calculations on a computer and extract information from the simulation. And this is a much smarter way of doing it because your comprehension is much larger, so you comprehend more details of the reaction. And therefore, you can increase your capability of modifying the reaction to make it occur faster.
And how do you do this simulation? Well, this is the nice quantum chemistry world where I come from. And quantum chemistry is basically solving the Schrödinger equation that is a very complex equation. It was what Feynman was mentioning before—the mechanics of quantum particles that are very hard to solve on a classical machine. It's basically impossible to solve on a classical machine.
And why quantum? Well, because molecules are composed of electrons and nuclei, and especially electrons are very much quantum particles, and you have to treat them quantum mechanically. And this is basically how the simulation looks like, right? So you can explore how these oxygen attach to the platinum layer. Here you arrive, and you break your bond to form these two atoms of oxygen attached to different spaces of the platinum catalyst. And these two atoms are what actually produce water afterward, okay, what we said before.

I want to also mention another tricky thing you see here behind. Actually, this is another method, and we study how changing the metal behind, underneath the platinum layer, can influence this reaction and, in case, what kind of metal is the best to make this reaction occur faster.
So quantum chemistry is my bread and butter, but it's not the only thing that we do in our labs. And in fact, I'm very interested also in other topics, and I will show you some other use cases that we have in mind where quantum computers can excel and can outperform classical machines.
One is optimization. So let's say you want to optimize your production line to reduce costs—that is how we do it on a quantum computer. Or maybe flight management or satellite mission planning, all things that a quantum computer is very good at.
Then we have also algebra, or in other words, solving equations, and our acoustics and aerodynamics. For instance, how sound waves propagate on this road could be one of these applications, or even if you are brave enough, going into the more complex aerodynamics, so how a flow of air or a fluid moves when there is an object around.
And I'm sure you didn't hear anything about machine learning at this web summit, so I will throw it in as well. And this is quantum machine learning, and more particularly, also quantum neural networks that I'm very interested in because it's been shown that the quantum version of a neural network—so when instead of neurons you have quantum systems—are outperforming classical neural networks and classical machine learning approaches to describe entangled data.
Entangled data means data that are correlated, that there is some structure, and this, for instance, is possible in image processing. And I know you have a much more broad overview of what quantum machine learning can do, but this is all quantum computing.
I think, Jasper, if I remember well, you mentioned before that there is also some... How is quantum communication and quantum sensing, right? Perfect, yeah. So that's something we would like to, of course, share with you as well, so...
Quantum computing is really exciting and offers lots of opportunities. Nevertheless, it is also a very challenging technology and not yet at the stage that it can clearly outperform a classical computer. So there's something where we have to wait, and we rely on hardware developments.
Nevertheless, other quantum technologies are further developed,
and of course, here, Airbus is more interested, or more active, let's say. I mean, interest we have in all of them, but here we have a more concrete way of activities. For example, in quantum communication...
So when we talk about quantum communication, then we have to go back to the quantum computer. Sorry. So the quantum computer is potentially so powerful that in the future, it might also be a threat, not only an opportunity. So it might be able to attack our cryptography, and the algorithms we have today may not be safe against an attack of a quantum computer. And that's actually a huge problem because today, our society—how we work, how we live—relies on the capability to have secure communication.

This is in our daily life, if we transfer money, it's our job, at the professional life when we have video meetings, etcetera. So there's a big need for secure communication, and in fact, quantum communication is one very promising opportunity to provide this.
And in Europe, for example, the European Commission has identified this, and they started in 2019 the Euro QCI, maybe some of you know it's a European Quantum Communication Infrastructure initiative, which is a new communication infrastructure based on quantum technologies. And this is accelerating very fast. We hope that the first operational system will be available within this decade, and Albus is very active here in this concept, for example, to develop the corresponding satellite system.
But it's not only quantum communication; we are also mentioning quantum sensing. So quantum sensing provides sensors which are very accurate but also which have a very low or even no drift. This is very interesting for many sectors. In particular for us, because no drift means you do not need to calibrate, or you reduce the need to calibrate your sensors. And there's a variety of applications in the aerospace sector. Just think about navigation.
Today, if you're aboard an aircraft or if you fly with a helicopter, you have a navigation system which is built from an inertial navigation system, so measuring acceleration, rotation, but also measuring, for example, magnetic fields, having satellite positioning connections. In the future, a quantum navigation or quantum-enhanced navigation system is likely independent of satellite navigation. So this is changing the way of mobility of tomorrow.
So this is a very nice application on the ground and in the air, but let's take one step further, let's go to space. So Airbus is also a large satellite manufacturer, actually Europe's largest satellite manufacturer. We are building a lot of Earth observation satellites. So in our teams, we are working to build quantum sensing technology for space.
So bringing those quantum sensors into orbit and measure, provide data for our societies. And one of the really nice projects at the moment we are having is the development of a quantum satellite which will measure the gravity field of the Earth with unprecedented accuracy. So this is currently under development. We hope that the first Pathfinder mission will be launched in 2023.
So also here, you see, this is nothing which is playground and only in the future. There are some very concrete technologies coming. And this is also, we have talked about quantum computing, quantum communication, quantum sensing, so a large variety of technologies, and this is the take-home message for you that quantum really matters. So quantum technology will have a huge impact, most likely in many sectors on all of us.
We at Airbus, we are working on this. We are preparing for it, exploring the opportunities. If you're interested in joining, have a look. And in any case, we are very happy to connect and to follow up with the discussion or answer your questions. Thank you very much. Thank you.
Q&A after Presenation
Hello. Howare you

Yeah, okay, Benjamin. I'm a master's student in data science, and my question is about your simulation on the fuel cell. How can you do this with only 68 qubits, with the limit of 68 qubits?
Good question. There exists a possibility, and quantum chemists are very good at doing that, or simplifying part of the problem so that simulation had not been performed completely on a quantum computer, but only some part, especially the one where the oxygen attaches. So adhere to the platinum surface and along that reaction, only some atoms. So part of the system has been treated on a quantum computer, while the other part was treated in a more complicated way on a classical machine.
The idea is, of course, the more qubits and more accurate qubits you use, the more the core system is enlarged, and you simplify the problem a lot in the sense that now we are limited on the amount of gates, so operation that you can perform. If these gates become larger, you can enlarge the system much more, and this part becomes much more efficient than the classical counterpart. So the total speed of the simulation decreases potentially. Thank you
Katya (Product Director)
Hello. Hi, I'm Katya. I am a Product director for e-commerce and SaaS companies. I'm not in tech, so I've understood half of what you said, but it's really interesting. I have a curiosity question. You mentioned something about quantum sensing being able to measure the gravity field of the Earth to an unprecedented extent. I'm wondering about the benefits of that and possible application cases.
Presenter's Response
That's a very good question. For several decades, we've had satellites in orbit measuring the Earth's gravity field. This is operational monitoring of our gravity, and the main interest, among many, is the scientific interest, particularly for climate modeling. For accurate climate models, certain parameters need to be measured, and gravity is a crucial one for our scientists.
Roberto (Developer)
My name is Roberto. I'm a developer, not an engineer. I'm curious about the sensors you mentioned. There are many applications, but what about noise on sensing? Can you expand the sensors beyond a certain barrier?
Presenter's Response
Quantum sensing is complex, with a plethora of applications, especially in aerospace and medical industries. Noise is indeed a problem, as with quantum computers, but it's somewhat easier to manage in sensors. Quantum sensors are quite advanced and can outperform classical sensors. The challenge lies in integrating new technologies into systems and getting them certified, which is a long process.
Veronica (A-Level Student in Physics and Chemistry)
Hi, I'm Veronica. You talked about using hydrogen as a fuel. Although it produces only water, which is good for the environment, its production involves CO_2 and carbon monoxide, which

are harmful. Plus, storing hydrogen is complicated. What's your perspective on solving these problems?
Presenter's Response
I appreciate this question. Hydrogen is a clean source when produced cleanly. Most hydrogen used now is from hydrocarbons, which isn't ideal. However, hydrogen can also be produced from water splitting using electricity. This could be viable if we harness surplus energy from renewable sources. Integrating hydrogen produced by renewable sources into our society is an exciting prospect, though we aren't there yet. Like electric cars, this technology could significantly change our lifestyle.
Hosapina (Physical Student)
Hi, I'm Hosapina. Could you tell us more about the teams involved in this part of Airbus? Are they all scientists, physicists, PhDs, or others?
Presenter's Response
Happy to answer. This is a challenge with quantum technologies. We're scaling up engineers and growing expertise in quantum technologies. Compared to AI or electrification, quantum technology is still a small community but is growing fast. We're preparing our workforce to utilize quantum computing effectively in the future.
David (Audience Member)
Hi, I'm David. Thank you for the accessible talk. Regarding noise reduction in quantum computing, what are the easy wins? Is improving light sources a good start?
Presenter's Response
We're in an exciting phase of quantum computing. There are various approaches, like photonic quantum computers or superconducting quantum computers. Each has its pros and cons. Continuous improvements are being made. Just as AI evolved over decades, quantum computing is in a phase of rapid development and exploration. We don't know what future quantum computers will look like, but engineering will find a way.
"My name is Bella. I work in a bank. My question is related to security and its challenges. Considering that our private keys nowadays are far from being quantum-resilient, what would be your advice to design a strategy, or to think about how to tackle these threats in the future? Thank you."
"Yeah. So, I think right now it's really important for all the major companies, the big players, and for the field in general, to work on their strategy. It's really important because there is a risk that these technologies come faster than anticipated. And if this is the case, then there might be a disruption, which is going to really change a lot on our side. This is also why we are active in the field now, and that's why we have developed our strategy. We are growing this field.
I can maybe speak also from other companies in the finance sector where I know there was a lot of excitement on the quantum computing side, let's say for portfolio management, etcetera.

But recently, I have observed, at least from the finance industry perspective, a strong focus on the security aspect.
What we didn't tell you today is in quantum communication. We were showing you guys this real exchange of quantum keys, which is theoretically secure. This is something which is most likely not applicable, let's say for many operations, because you cannot have an optical transmitter and receiver, and then you need to send it to a satellite. So, it's pretty unlikely that this will happen on our scale here.
But the other technologies, which help you for example to mitigate the risk of a quantum computer breaking encryptions, are called post-quantum cryptography. That's one of the paths which I see recently very often also in the finance industry because they are really concerned.

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Interviewer	It's OK if you don't have the expert deep dive knowledge in all of these because it's obviously a big broad scenery, but one of the the industries that we focused on was energy. And we started to talk about energy grids. I don't know if you've been in touch with this at at any point, but what do you see is the biggest challenge when it comes to energy grids. And we have in this scenario of energy grids, the idea that with everyone having solar panels and the energy being consumed back into the the general energy stream. People could get money back from it. Do you think that's a realistic way our future could look like and a realistic way to pay for?
Interviewee	Absolutely, yeah. So you're lucky that we've done a lot of work on in the intersection between quantum and and energy. So, so I I'll say a couple of things for a while and then you can, you know, stop me. So I think firstly like we always think about it from what where the industry is going, where the where it is transitioning, OK. And where we're transitioning is towards greater sustainability and renewable energy across the grid, OK. So what does that mean? That means that the whole value chain of energy is is changing all the way from generation to transmission and distribution to the usage and consumption of things.
Interviewee	Now as these things actually translate, OK, you have very challenging problems that come across that are very complex and and could benefit from quantum technologies from solving that. I've actually done like a number of projects across the whole value chain and I can tell exactly what those problems are, then give you some examples Okay. So firstly like I'll pick some examples out Okay and then you can ask me more questions on them. So firstly in the generation side of things, one problem that is really good is unit commitment. A unit commitment is a problem where you basically need to commit a certain number of generation units to maintain base load power, OK for the economy to run stably.
Interviewee	OK unit commitment is a problem. I work with actually Microsoft on that one with the quantum inspired optimization for enhancing the way you do unit commitment considering that you need to include both coal and also new

	renewable generation assets into the mix. One really, really good problem, good commitment. The second problem is very much in the center of the energy value chain. It's around balancing mechanism and optimal powerful dynamics, OK, balancing mechanism and optimal powerful dynamics.
Interviewee	It's just making sure that you know you can certainly have a stable grid that is resilient, very, very important and this is very challenging because of the level of intermittency that you have with renewable supply. OK that you need to balance the grid. So the balancing mechanism problem or the economic dispatch problem. OK, very specifically, OK. You can find the definition to what these are as well are NPR problems.
Interviewee	And so they benefit a lot from complex optimization techniques and also CUBO based model from a quantum perspective. OK. That's the second bucket. The third bucket is very much on the on the side which I'll give you a very relatable example, right. So you know solar power, right?
Interviewee	So PV power. Well, I have a paper actually coming out. It's also an archive as well, so you can find it. I can send you a link to it on a photovoltaic power prediction. OK, Like, it's very hard to predict using data from just the previous two days.
Interviewee	What is going to happen in the next hour or the next 24 hours? It's very challenging to predict that. If we could predict that accurately like we're doing with hybrid quantum neural networks and hybrid quantum models, it automatically helps you use greater solar power capacity and also you know, maximize the use of those solutions. Another very good use case is everything with social energy storage or battery dispatch strategy and optimization. So what's happening is that as the number of renewables in the grid increases, you need to store this capacity as well and you need to also use that capacity in the right way.
Interviewee	That's called battery storage and dispatch strategy organization. Okay again, MP hard problem, very, very complex, lots of benefits of solving it better because there's let's say monetary benefits of doing that as well where you use it for and free services or you use it for grid based services and stuff like that. So all the problems that I mentioned, OK, it is a little bit on the high level, but you can dig deep. I also have a set in mind. It has these nicely formulated, so I can share some content with you so you guys can see.
Interviewee	But it's really, they've got the same nature. They're highly complex, OK? They're highly valuable, so they've got money behind them. If you save money or you make money and there are problems that are not going anywhere, yeah, and they're going to be stable. They're going to be 50 years into the future, 100 years in the future.
Interviewee	We still need to balance the grid. We still need to commit units. We still need to, you know, predict photovoltaic power. We still need to, you know, optimize the storage capacity, so.

Interviewer	This is, this is very nice. It seems like they're with all these different types of technologies or types of ideas to have a technology. There's a different challenge always coming up. But from your point, so from what what I could could gather is that it is realistically that, you know, getting money back from having your own solar panels on top of your house could be a potential future scenario.
Interviewee	So that what you're talking about is actually the poster model, right. So you produce and you consume like the poster model. And the thing about that is though to be very honest, right, it's very much about the economics of it. It should economically make sense for somebody to, you know, have a solar panel on their loop, be able to generate power storage with their batteries, charge their car, right. And it's more the economics.
Interviewee	So if you take talk about the economics, the importance of Quantum in that dynamic is actually to make things more economically favorable, more economically attractive. And we could do that to enhance optimization, enhance performance, OK, on that level to improve the dynamics of attractiveness for the end consumer, which makes it 50 and the future more, more, more, more possible to do.
Interviewer	I think with that you just answered our next question. Also following up that How can quantum computing help to increase the efficiency of of solar panels? But like you just said
Interviewee	I've written, I've written an article about this is where you can find it online. It's called Quantum and climate. But I mean specifically with solar panels, there's there's a range of things, right? I mean there's firstly there's efficiency improvements, OK, in terms of how you can maximize your radiation angle and stuff like that. But the, the one we found that's most important is photovoltaic power prediction.
Interviewee	OK, if I was on the computer, I could show you a live demo because we have live demos of actually actually doing this, right. Photovoltaic power protection. Very, very important. Very, very important because it's linked to regulations, linked to actual penalties as well by, you know, bad kind of assortment of solar power. And also it links to kind of surprising during the day and stuff like that, right.
Interviewee	So there's another problem, which is called participant protection. So you know, we need to also understand how you can increase the lifetime of solar power panels. OK, solar panels. And those are like something called hot spots that are on these panels. Again, you can use quantum sensing to identify these parts of what's appropriate, everything about that as well.
Interviewee	You can find that online. And one last thing I would think about is quantum based materials for solar panels would be really interesting when nanotechnology is expected that will not explode yet. Like, something's many further into the future, but if you understand how solar patterns work, they simply take one photon of light and negligent electron, right? I mean, it's electron, photon of electrons, right. So if you have materials like on on the

	nanotechnology level that we can innovate on in a science perspective, then we could kind of move past a diary of, you know, one photon leading to multiple electrons, you know, and stuff like that.
Interviewee	So as there's innovation on the material science aspect to show the solar panel, yeah.
Interviewer	Thanks for that answer. Thank you so much. And maybe we can then hop directly on to our next topic, which is regarding finance. And one of our colleagues is writing her part about that and she is quite concerned about portfolio optimization as one of her scenarios. Have you gotten in touch with some sort of scenario like this?
Interviewee	A lot, a lot. So very deep in finance as well. I mean finance, I think it really depends upon which part of the, you know, again the value train you're in, right. So it all comes from kind of how you manage capital, how you trade it, how you also can allocate it, right. So I think there's, there's a range of, let's say problems there, but the most valuable ones, I'll highlight the couple for you, right.
Interviewee	So in in portfolio optimization, I mean that's very great on the high level, but you need to worry about which portfolio optimizing. A lot of work we've done is around the collateral portfolio optimization, OK, collateral allocation. So collateral is theyou know something that you need to hold on your balance sheet, OK, to ensure that you have sufficient liquidity that in case your your balance sheet has any distress that you have a sufficient you know buffer to to make sure that you survive. OK. Our collateral allocations has been very hard problems and we've done stuff with HSBC for example recently on that.
Interviewee	OK, collateral allocation optimization from a portfolio perspective, OK. So that's very much in the portfolio optimization standpoint of things. A lot in finance that is very much overlooked that we do a lot of work in IS is in you know replacing Monte Carlo based engines. And so you know we do a lot of work in tensor networks based simulations, tensor networks based simulations, OK to kind of speed up the way we do a couple of things, the way we price options, the way we do XVA, CVA calculations, reverse stress testing, you know and that domain would benefit a lot from bottom inspired content based methodology. OK.
Interviewee	So very much in finance you want to move the first adoption points are very much further away from regulation, right, because it's very hard to move closer to regulatory touching products and services, right. So those are two areas. Another area I would point out is quantitative trading, right. So we do a lot of stuff in quantitative trading as well, OK. Quantitative trading is trying to find arbitrage based opportunities in the market to find you know got trends using quantum machine learning and stuff like that.
Interviewee	So quarantative trading is another kind of pocket again financial services I can and get my team to send some use case and case studies for you as well. So it's

	good. So anything in financial services you're interested in, right, So I'll send you some stuff online that.
Interviewer	Thank you so much. Thank you. Yeah, because reading them afterwards always helps as well. Yeah. OK, maybe we can also jump into another industry that I'm actually writing about, which is cryptography in terms of cyber security with.
Interviewer	The whole quantum world comes also a challenge that our encryption might potentially be broken and. I've been reading a lot about post quantum algorithms being developed so that computers nowadays around infrastructure nowadays can be protected and be resistant against quantum quantum attacks. I just still haven't figured out quite yet what the probability is that quantum post quantum algorithms might also not work or might also not. So So what what are the like the the common thoughts on the on this topic? OK.
Interviewee	I mean, let's go back to first principles, right? I mean, security that we know it today depends upon three things, right? Depends upon all problems and algorithms that are computationally too hard for a machine to solve. A quantum of classical machines we have. The first thing is hard problems, second thing is keys.
Interviewee	OK, the keys that are using these problems, they need to be long enough and random enough. OK, size and randomness matters. And 3rd is distribution right? That means how do you get these things from A to B. You need to be able to do them in a quick way, speed and also do it over longest systems.
Interviewee	So anything you talk about on the, you know, the cryptographic backbone of security systems, confidentiality systems, privacy systems, you know, in these three fundamental things, quantum or classic, it doesn't matter. OK, so now what happens is with quantum computers actually maturing, right, the nature of the threat factors is changing. And so you know this is not only it's not only you know better machines or you know more computational capability but also it's a different kind of algorithmic technologies as well right. Algorithmic techniques and formulations that increased the timeline of this thread vector for example, right. You can see lots of papers from the Chinese using the as well in terms of breaking RSA.
Interviewee	Recently you can find another paper from MEM Computing on this as well. And so the threat is pretty well right. So you know you could use you know new types of formulations that help advantage of not only give this quantum computers but also quantum dealers to bring this thread further. So the conclusion of that it's not if quantum computing quantum technology yes they are. We understand that it is the end game for cryptography as we know it.
Interviewee	Symmetric and symmetric cryptography doesn't matter. It is the end game. The question is when. OK so now let's talk about the when right. It has different dimensions to it right.
Interviewee	Some people say that look you need to you are vulnerable already today because of the stone out decrypt later risk OK that people can take your data right now highly sensitive has a long timeline you should your data secure from

	today. OK that's a lot of the things. 2030 is the is the earliest timeline or 2027 is sometimes when people say Okay based on Homeland Security. Okay in the USA 2030 is the earliest time and they say the US federal government has already mandated a shift to post on cryptography for all the federal systems already today. I mean, it's already happening.
Interviewee	So I think that the timeline is very, very short. Now let's talk about the quantum security element of things. OK, you have two buckets of things. OK, You have classical things that you can do. You have quantum things that you can do.
Interviewee	There's a bunch of classical things, which is, I call them quantum resistance. It's a cat and mouse place. You're just making PQC and basically harder problems to solve that could be had at some point of time. If the computers get better, the algorithms get better. On the right hand side you have quantum where you're doing things for example chronic distribution and those are protected by the laws of physics, those are something that's listed in the US and NSA wouldn't want to happen because it puts them completely in the dark.
Interviewee	There's no black toes that it's not hackable. They won't prolong that from being adopted very, very long term, right. So they'll say go to PGC. PGC is already vulnerable and all of the five PGC algorithms that have been mandated are owned by IBM. So you know you can see with the direction of the tide very, very clearly. We do a lot of things in security as well.
Interviewee	I don't think we have time to go into that, but we have our own PPE protocol. We also have our own kind of applications and security space as well as we do systems that enable kind of PQC to be adopted as well. But that's a different story.
Interviewer	OK, well that gives me definitely a different structure to also recommend things in the short term and long term. Maybe one last question that I have concerning this is that I've also met read so many times where other experts have told me that yes, these are all things that everyone is talking about, but the hardware has not been developed yet. Thus we don't really know yet, like everything could still be completely different from what we think everything will be like. Is that something you would also agree with or from what perspective?
Interviewee	And it depends what perspective you want. There's a different perspective. So that's the that's the important thing, for example, right. So if you think of it from a researcher's perspective, it's different. They are looking for quantum advantage quantum hardware.
Interviewee	If you think of it from a hardware provider's perspective, they're going to say you can't do anything for another 30 years, another 10 years, right. You look at it from, you know. So it really depends on the perspective, right. So I think, I mean I can give you the practical picture, right. I mean quantum hardware today or keeping because we know it is very, very beautiful.
Interviewee	You know, we still live in this area. You know probably it's very, very noisy, but That doesn't mean we can't do some things with it. We can do some very small. The way we see the future is very much hybrid, right. We see a hybrid

	combination of things where today we already developed quantum software that can be harnessed on qubit based simulators, right.
Interviewee	So the simulators are quantum computers and we see the inflection point at which you know you have software today. There's new types of logics, new types of formulations, which is basically quantum circuits. OK. That can be one of these two bit bus simulators, OK. And secondly when these simulators get better, or get better new simulators, then we can actually use them.
Interviewee	Otherwise we don't need to, we can experiment with them, right. We can experiment them and we did a paper on this you can find online as well, it's called, it's a benchmarking paper that shows that you know that once we have more than 30 logical papers that will keep you makes sense to be used right and we'll be excited to use them as well. And so you know currently in the era that we're in, there's two paradigms, there's the existing performance enhancement for existing applications for hybrid approaches, OK, that you can do with this approach that I mentioned Quantum Software on simulators. We have a car tissue NVIDIA that enables that. But then we are talking about native hardware which is you know fault tolerant era which a lot of people talk about.
Interviewee	You know, that probably comes five to 10 years from from today, right, Which is awesome as well. And and that would be things that we need for them, hardware for like, you know, a lot of kind of material simulation. We really need it for for those places as well. So yeah, I think it's a, you know, you have like nuance to perspective, right, Because it depends on who you're talking to, what the agenda is. They're motivated by that.
Interviewee	You could take a picture of solved, right. So I mean, you know, my answer would be different to who I'm talking to.
Interviewer	Yeah, but that's also the interesting thing to have those different viewpoints. And since it is still very theoretical, everyone has their own opinion and it's kind of nice to see where the direction is going.
Interviewer	But yeah, I would say it's very practical. Yeah, it's very practical, but I'm very different, right? So I think you know we're using this system like we know.
Interviewee	And you you can't tell me, but I know, right. So it's different. So I think we can already we publish so much about it, but you can do so much with this system, publish, you know widely about it and I can send you 10 papers that showcase it. You know with the hybrid methodology you can do something today that is better than an existing methodology that you have in that is good enough for somebody in the industry. It's probably not good enough for somebody who's the, you know, academic, but they're not at all the audience for that.
Interviewee	No. And so it it really depends the academic. OK, great. You know, no worries, right. You know, we continue as soon as you have better heartbreak or doctor.
Interviewer	All right. Maybe looking at the time, do you have some some last quick thoughts maybe on the yeah, one more. Healthcare industry as well.

Interviewee	Yeah, lots. I think lots again. So I mean, healthcare in, 2 minutes, I go through in 2 minutes. I think there's a lot of opportunities in terms of the personalization based element of things, OK. Especially with kind of quantum biology.
Interviewee	We do a lot of things in that space as well. For example, drug response prediction, OK. Understanding what the drugs are and how they would potentially respond on different genomics of people, very kind of valuable. Important everybody talks about the drug discovery things. You don't need me to talk about it.
Interviewee	It's kind of like talk about. But a lot of the benefits will come also from kind of like you know, true personalization on, on a kind of a genomics level, right. A metabolomics, genomics, learning right. Think of Omics on quantum input which Omics. I just think that that would really make a difference.
Interviewee	Two things, right. And if you think about the healthcare in in general, you need to kind of break it down into app sites, it's pharma and healthcare, right. And synchronize. We have some content on that. I will share with you.

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Interviewer	Perfect. We thought it would be directly in German, it seems to be working well. Thank you very much for taking the time to talk to us today, we really appreciate it. Let's introduce ourselves briefly, this is Ameli and I'm Hanna and we're studying together in Lisbon, doing our masters in management and writing our masters thesis on the topic of quantum computing and we're simulating a day in the future and thinking about what it might look like with full quantum computing capacity. We have 5 different industries, energy, cybersecurity, healthcare, finance and mobility, and we have picked out various use cases based on the literature and are now trying to validate them with the help of experts, and that's exactly how we came up with them, we will proceed in such a way that we would perhaps first ask a few general questions on the subject of quantum computers and then perhaps even look into our scenarios. And we would really value your opinion. But perhaps you could also briefly introduce yourself and your relationship to the quantum computer thing.
Interviewee	Thomas Strohm is my name, Thomas if you like. I am Chief Expert Technologies at Robert Bosch GMBH. Specifically there, in the research department near Stuttgart. We do both quantum sensors and quantum computing, we don't build quantum computers, but we are involved in application research, I would say. So solving problems, making software and so on and I am also Vice President of the European Industry Consortium.
Interviewer	Cool. Then maybe I'll introduce myself briefly before I get into the first question. So exactly Ameli and I study with Hanna Management at Nova Lisbon and exactly next month we are going to finish our master's thesis. So the first question, so what kind of general area in our daily life or industry think?

Interviewee	So in my opinion, I think that's also the opinion of a large part of the community, is that materials research or quantum chemistry yes, so there is the task, you somehow imagine a new molecule or something, you don't know it yet or some crystal or something and you want to know what properties it has, yes, electrical conductivity, thermal properties, what it binds to and so on and then of course you can assemble the things, synthesize them and then you can do experiments to measure how good the electrical conductivity or something like that is. To measure how good the electrical conductivity is or something like that. But you can also try to calculate the properties directly with the computer, without having to produce the molecule crystal, which is now possible with conventional computers for some molecules and crystals, but not for many interesting ones and that's where the quantum computer would come in. And yes, there's a certain amount of hope in that. That would significantly accelerate the development of materials and chemistry, and also the development of pharmaceuticals.
Interviewer	Yes, we have now heard that confirmed by the majority opinion. Perhaps we can go straight into our scenarios and exactly.
Interviewer	Then I can get started. I work in the healthcare sector and one scenario that I would like to present as an example would be with the help of a quantum-controlled chip that is implanted in the body. The most precise data on the person's current health status and forecasts can be transferred to an app, which the person can then view tomorrow. For example. A precise life expectancy down to the month, for example, or the perfect vitamin ration for the day. What do you think of that? It's also a bit like quantum sensing.
Interviewee	For me, it's not only computing, but also quantum sensing. I have a sensor in my body, however great it works, it will detect some clever quantum effect from my biological state in some way. The transmission is a moot point, it has to somehow get out to the central computer, to my app, to whatever. The fact that we first need a sensing system, let's say in medicine, is a good market because there's money in it, but of course it also has to work well. Yes, so I have safety in there, I have certification in there, I have training in there, I have to get the doctors to the point where they understand it at all and can use the internet. Yes, and ultimately it has to be available on prescription, so to speak. Let me put it this way, it would certainly be nice if we could, but I don't see that as being in the short or medium term, it will take a while, because we simply want to detect different things. We don't just want to find out the electrical field of the heart, but then we'll probably derive and output 30 other parameters, plus we'll need to analyze what to do with the data. This is a classic part, it probably already exists. Someone has come up with it.
Interviewer	OK, and when you say that you don't see this in the short or medium term, what does the long term mean for you, perhaps in years? When you have your idea?
Interviewee	To be honest, it's mainly limited by all the medical factors, I'll call it that you have to have the whole stack completely certified afterwards and have put it all into practice. And that alone is what you ultimately need for any medical devices afterwards, I know that 10 years plus is really the case, that even if you

	already had the finished product now and threw in the whole certification machinery, it would still take a long time. Let's see. Mhm B don't even have the product yet, so that's still to come.
Interviewer	OK, all right, thank you very much. Then I'll move on to the next scenario. I've been doing a bit of work in the energy industry and I have a use case that solar panels can be built much more efficiently with the help of quantum simulations. Somehow, I once read an article at the Jülich Research Center that somehow solar panels can be built with an efficiency of up to 40%, do you have any opinion on that?
Interviewee	Another spontaneous question, I always remember my post from my physics studies back then, which said that there is simply a fundamental with how to build a solar cell, so it just won't work and now let's get really nasty, they're not that bad yet. So yes, there is still something in it, but the revolution through quanta. To be honest, I don't believe that if you add another 5% afterwards. That's nice, but not if I'm planning this on my roof. Fine for me, but if it then becomes much more complex in the planning beforehand or in the ND beforehand, it will also be more expensive. Doesn't pay off afterwards. In that case, I could just as well use poorer quality materials and simply lay out 5% more area. Then the result is the same again and it might be cheaper.
Interviewee	Ah, that's difficult. Well, my colleagues, they've already scanned hundreds of materials to see how well they can be used in a battery and so on and so that's not on the street either, yes, there may be a chance find or something, but like the previous activities, they haven't found any gold bars either, that doesn't mean that they don't exist. But you might find them somehow. Yes, but it's not that simple. Let's put it this way: the hope is that a quantum computer will make it much easier to scan these materials. But there's still a long way to go before we have a practical quantum computer that's good enough in some metric, whatever good means, that's good enough to be able to do that. And as long as I don't have that, I'll still be doing a bit of manual work when I do. Sure, then it's nice, because then I can start scanning through materials and see which one is good for which material. That can certainly be useful because I'm worth it faster, plain and simple. And then afterwards I have to take another look at what's stored in the development process to see if you have a material that stores energy really well and has great discharging and charging properties. But then the durability is totally miserable afterwards. Yes, so you have other factors that you simply have to work on during development, not research, but the development of your product. You also have to look at whether, for example. If you know it breaks due to vibration, it might not be in such good hands again. And in 10 years' time, you might be able to calculate a whole range of simple materials, quantum computers, and even we don't really know that yet, yes, some of the materials, Intel are also complex, and a computer will still be needed, so maybe it will be another 20 years before we can really do something really good or something, I don't think we know at the moment, but I think it's still overestimated at the moment. Yes, the impact will be huge. Small yes, but it won't come in 5 years or probably not even in 10 years. On the time

	scale, it's not a question of what will happen, but when, and I don't know one hundred percent, I'm just looking at a crystal ball.
Interviewer	That's right, cool. Then I have a question about the financial industry. Do you have an opinion on the extent to which this can help with portfolio optimization, i.e. to what extent it can somehow personalize portfolios without risk?
Interviewee	Without risk. This must now be financial questions, so ultimately it's a similar point, if I have the computing power, I can use it to calculate things, quite generically yes, and if the computing power therefore allows me to do this quickly. At some point, it will be easier for you to calculate something different than it is for me and it's a great thing for the banker. Same point, we just don't know when that will happen. That's the battle situation. In that sense, it's different, because I can of course optimize. I can calculate less precisely and still have an optimization, whereas with such a battery material. It has to be the exact molecule afterwards, otherwise it's no good, right. In this respect, it might be easier, but that's still at the end of the glass ball. That's why I can't say at the moment what the final result will be and how good it will be. For me, this is just one of the many examples where we hope that it will ultimately provide great added value for the normal population. The only thing that's a bit off about it is that the battery materials are behind the end customer, which doesn't bother anyone when the electric car goes out and says how fast it is. The most complicated question is asked by a portfolio if I can tell you that it's great for you, yes, taking everything into account, I can then suddenly use it as a product, as a banker I can of course win a flower pot again."
Interviewee	In principle, it's a bit like this, so say quantum computers are characterized by the number of QP, which has yes and then how good they are, the Q bits, that's very roughly speaking and in materials research, you don't actually need that many. Kubitzki have to be good and for such optimization problems as portfolio optimization or many other optimization problems, you often need a brutal number of cobits, i.e. hundreds of thousands or tens of thousands. According to the minister, the optimization results are not that good, but in both cases we are still a long way off. Yes, in one case because you just don't have enough hobbies and in the other case because they're just not good enough.
Interviewer	Thank you very much. Then maybe we'll go back to the automotive industry, our last one. That's exactly where we can imagine various things, from root optimization to autonomous driving, but perhaps independently of what we've been thinking about. What do you think could be the big thing in the mobility sector with quantum computing?
Interviewee	Well, first of all, the fact that you might be able to optimize materials and therefore have better sensors or batteries or something like that, keyword electrification and so on, that's one possibility and the other thing is certainly rapid coordination and so on. Well, automated driving will probably also have an impact, but that's a bit more difficult, because ultimately it's about making that happen, mainly on the basis of artificial intelligence, and you first have to show that a quantum computer has any advantages in terms of artificial intelligence. That could well be the case, but it's certainly not obvious, not even

	in terms of time. I don't see Asta at the moment, so perhaps more materials, batteries, sensors and so on, and indeed, rapid optimization, routes, planning, martinetz. Won't be in here either. I listen, will it go in that direction as well. I want so would differentiate in what says what pulls the end user who sees if his route is good. Yes, but even there, the quantum computer is not yet in the car in the first step in case of doubt, whether it will ever be at all is not yet known, but let's assume that it is out of the way and helps you at the beginning, but if you are now traveling in the deep valley somewhere in the Alps, where you are not so well connected, nothing helps you even if the computer would calculate totally well. No mobile phone reception is fine.Any railroad line, right? All right, exactly along any railroad line. So that's exactly what I would say, say, sure, who benefits if their car charges faster when all this stuff. But I almost would have. They are not even small factors, no, so how fast do I get or how well do I get optimized in the production of my vehicle, that the parts are delivered to the factory, how well do I get optimized so that when I cut out the metal parts, I don't have so much waste. So I would rather say that the user doesn't care afterwards, because he gets into his car anyway, it doesn't matter. But it might make the car cheaper if it runs well, or at least better from an ecological point of view. So that's where I would start.
Interviewer	Thank you!
Interviewee	I just thought of something else in general. So if you, if you want completely different points, so maybe we can then think of individualized medicine, before you have already discussed a bit in that direction, but if I now have a weird disease or something and there is no medicine there, but then because you can develop medicine more efficiently, it might be worthwhile to develop it only for my disease and that of a few others. I could well imagine developing special medicine, so to speak, but that will be in 30 or 50 years or so and I'll be there in 10 years, but that would somehow be a day in the future for me that
Interviewer	Definitely, one of my scenarios, also with regard to Drug Discovery, is that there will be medication for Alzheimer's, for example. But of course it's all the cooler that we can really work on a very individual basis, although I've already had a conversation with a researcher in this field, and she was also aware of the regulations, that pharmaceutical companies are always very keen to reach a broad mass.
Interviewee	Whereby we then of course also speculate, such legal circumstances have to adapt to reality, in the long run, no, so if the owners were to come, then the legal profession would have to follow suit and adapt the law accordingly, that certainly won't happen at the same time, but nobody will then say, no, individual Alzheimer's drugs don't work, because there's a law against that. Exactly. Ultimately, if society benefits from it, has a benefit from it, then I have to adapt the regulations. Yes, absolutely.
Interviewer	Yes, that's right. Good point, thank you in any case. Do you have any ideas for a truly future scenario in a different industry?
Interviewee	So what's floating around in the back of my mind right now is rather, if I could give you a tip on what to write, I would rather say, watch out when formulating

	how it comes up and don't say that things will come, but that they are just things that could come. They could come individually, each for themselves. With completely different time horizons and different probabilities of occurrence. I'm not just hanging on a bit, because they're just different things. And if I just look at the fact that the whole development of quantum technology is still in its infancy, maybe quantum sensing is much earlier, yes, so it could well be that there is a sensor that knows something, because I analyze my blood flow and the next time I have a cold, I go to the doctor and then he scans me and then it comes out whether it's in Mars or on my lungs or what do I know. It could be much closer than him sending it to a quantum computer and the quantum computer then carrying out some funny analysis. So just see from the presentation here that it's ready.
Interviewer	Yes, yes, we've definitely already noticed that we once started with the idea of mapping a day in 2040, but we didn't realize that that's not possible.
Interviewee	No, you actually have to write every single sentence, if that's the case then no and then maybe not. I don't think that can simply be written off afterwards - it's clear to everyone that there are simply many components that should work. Another thing is the energy industry. What did you mention before? I mean, it's being completely turned upside down. Yes, there used to be a few power plants that fed into the grid.
Interviewee	A lot of users and now there are a lot of producers and still a lot of users and it fluctuates back and forth throughout the day. Yes, it has become much more complex and. Somehow the system optimization, that you simply control all the consumers and the control base and configure the network accordingly, dynamically, so that everything works really well, so that's a huge optimization problem, just like with the railroads, for example, yes, I mean, a few trains are cancelled or something. You have to reconfigure the timetable relatively quickly, these are huge optimization problems and if you could somehow do something with quantum computers, I think that would be quite attractive. But again, so you shouldn't make any big promises, yes I mean there will be a lot of upheavals, but in terms of when.
Interviewer	No, yes, definitely. That was also a difficult topic. So we're glad that we've somehow dared to tackle it now, but we've also realized that if you don't come from a technical background, it's also more difficult to grasp what's still to come. Yes, and even those of us with a technical background. The whole community actually deserves that, it's hard to grasp. We're just starting out and it's such a complex technology that anything can happen. And yet it does. Everyone plans their technical development in advance to a certain extent. Yes, and then there's also a lot of PR. Yes, that's just part of it, let's be honest, everyone says that they'll be ready in five years and everyone knows behind closed doors, of course, that's probably not true.
Interviewee	Whereby some of them still have traces of realism in them. But no, if I'm someone who builds the computer myself, of course I say that tomorrow it will be world domination for everything. It's also about the ecological impact and so on, yes, I mean, saving the planet and so on, that's the absolute positive

	optimum tomorrow, yes, so we're not saving anything, but maybe we don't understand it, too deep into this right now, we're doing it at the moment, but on the other hand, it could also be that it will be cool in the future, quantum computers for whatever and things need so much energy, much like bitcoins. The fact that we are blowing our atmosphere even more full of CO 2 could also happen. Nobody even knows at the moment whether this has a positive trend for CO 2 or not. Anything can happen, it's completely open, imagine you're in your 20s, 100 years ago, there are cars driving around that we would hardly recognize as cars and then someone asks you to paint them. Imagine the future with automated driving. How? Yes, I mean, that's so far removed from the exhibition world at the moment. Back in the 1920s, people thought that in the 1950s we would somehow have floating cities and regularly fly to the moon and whatnot, and none of that happened, so you have to somehow keep those points in mind.