A Systematic Review of Information Quality and Cybersecurity Challenges in Quantum-Enabled Financial Systems for Sustainable Economic Growth

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ABSTRACT

This paper systematically analyses the challenges and opportunities associated with info quality and cybersecurity in quantum financial systems up to 2020 and their implications for sustainable economic growth. Quantum computing promises significant advancements in risk assessment, portfolio optimization, and fraud detection with its superior computational power. The paper extracted 200 peer-reviewed articles and used the ASReview tool to analyze the need to improve information quality and data integrity and address quantum systems' new challenges in financial data management. The review also explores the economic benefits of quantum technologies, emphasizing the need for equitable access and energy efficiency for sustainable growth. Key research gaps were identified, including the need for empirical studies on quantum security measures and the development of practical frameworks for quantum technology deployment in diverse financial markets. The paper concludes by offering recommendations for policy and practice to help financial institutions transition toward quantum secure systems while contributing to long-term economic sustainability.

Keywords: Information Quality, Cybersecurity, Quantum Computing, Financial Systems, Economic Growth.

I. INTRODUCTION

Background and Motivation

The rapid evolution of quantum computing has garnered significant attention from both academic and industrial sectors. The financial systems and technology realm presents unprecedented opportunities and substantial risks [1-2]. Quantum computers are quantum bits (qubits) and promise exponentially faster computations than classical computers, which could revolutionize portfolio optimization, risk assessment, fraud detection, and cryptocurrency analysis [3]. The same computational power that quantum systems are so promising also introduces critical challenges in cybersecurity. In 2020, researchers were deeply concerned about the potential of quantum computers to disrupt the standard encryption procedures of RSA and ECC (Elliptic-Curve-Cryptography), which are foundational to the security of financial data and transactions globally. The financial institutions were more digitized and interconnected, and the issue of information quality was also a pivotal concern. Financial systems rely on accurate and timely data and face the challenge of maintaining data quality while integrating new quantum technologies [4-5]. The ability to handle large amounts of financial data, verify transactions, and manage real-time analytics could be significantly enhanced with quantum computing. The introduction of quantum technology into financial systems necessitates new frameworks for data integrity, auditability, and accuracy, which were still under development in 2020 [6].

From the cybersecurity standpoint, the potential of quantum computing to undermine traditional encryption methods posed a clear threat to the confidentiality and integrity of financial transactions. Cryptographic systems, the backbone of safe statement and file defense in financial systems, were expected to be vulnerable to quantum attacks within the next few decades [2-7]. These financial institutions were increasingly focusing on the quantum crypto graph, a division of cryptography that aims to grow the encryption methods that are resilient to quantum attacks. In 2020, many of these methods were still in the early stages of development and had not been widely adopted in real-world financial systems. The broader goal of sustainable economic growth adds another layer of complexity to the issue [8]. Quantum computing, while promising major advancements, also introduced concerns about energy consumption, equitable access, and the cost of implementing quantum-resistant systems. Financial systems are central to any economy, and their resilience in the face

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of quantum threats is essential to protecting the stability and sustainability of global economic growth [9]. In 2020, the financial sector was at a critical juncture while quantum computing held the potential to revolutionize operations, and failure to address the associated cybersecurity risks could result in catastrophic breaches and the loss of trust in financial markets.

II. OBJECTIVES OF THE REVIEW

The main objective of this Analysis is to systematically assess the existing literature up to 2020 on the challenges and solutions related to data quality and cybersecurity in quantum financial systems with their implications for sustainable economic growth. In analyzing research from 2010 to 2020, this review seeks to identify the key cybersecurity risks posed by quantum computing to financial systems and the methods proposed to mitigate these risks: post-quantum cryptography and quantum key distribution [8]. It aims to explore the impact of quantum technologies on the quality and integrity of financial data and highlight both opportunities for improvement and the challenges introduced by the complexities of quantum systems. This review will deliver a complete understanding of quantum cybersecurity and information quality up to 2020 while also identifying research gaps and resting the basis for upcoming training directed at the security and reliability of financial schemes in the quantum time.

Research Questions

There are few questions in this research are being explored and identified are given below:

- What were the key cybersecurity risks associated with quantum computing in financial systems before 2020?
- What were the major solutions and strategies proposed to address cybersecurity challenges?
- How were these solutions linked to the broader goal of sustainable economic growth?

III. METHODOLOGY

This chapter presents the systematic methodology used to conduct the literature review on the intersection of **quantum computing**, **cybersecurity,** and **information quality** in financial systems on studies published up to **2020**. The structured search strategy was employed in all databases, including Google Scholar, IEEE Xplore Springer, and ScienceDirect, utilizing specific keywords to gather relevant literature [9]. The methodology contains clear inclusion and exclusion criteria for selecting high-quality and peer-reviewed articles addressing the challenges and advancements in quantum cybersecurity. This approach aims to provide the implications of quantum technologies for financial systems with their potential contributions to **sustainable economic growth**.

2.1 Search Strategy

- **Databases used**: Google Scholar, IEEE Xplore, and Springer plus ScienceDirect.
- **Keywords**: "quantum computing in finance (up to 2020)" and "cybersecurity in financial systems (2020)" plus "information quality in quantum systems" then "quantum cryptography up to 2020."
- **Boolean operators and search combinations**: Use combinations that are "AND," plus "OR," and "NOT" to refine search results. These are "quantum computing AND finance AND cybersecurity," "quantum cryptography OR post-quantum cryptography," and "information quality AND quantum systems NOT theoretical."

2.2 Inclusion and Exclusion Criteria

Here are a few criteria for including and excluding the study of past papers, detailed in Table 1 below.

Table 1: Excluding the study of past papers

Criteria	Inclusion	Exclusion
Timeframe	Studies published between 2010–2020	Studies outside the 2010–2020 timeframe
Focus on Financial Systems	Research focused on financial applications of quantum computing	Studies not focused on financial systems
Cybersecurity and Information Quality	Papers addressing cybersecurity risks and information quality challenges	Papers focusing solely on theoretical quantum computing without discussing financial or security implications

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Type of Publication	Peer-reviewed studies	Non-peer-reviewed sources (e.g., opinion articles, blogs)
Language	Studies published in English	Papers published in languages other than English

2.3 Study Selection Process

The learning choice course for this systematic literature review was designed for the methodical and relevant collection of studies about quantum-enabled financial systems up to 2020. The titles and abstracts of articles were screened to assess their relevance to the research questions on cybersecurity and information quality challenges. Following this preliminary screening, a full-text review was conducted on selected papers to evaluate their alignment with the research objectives [23]. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) strategies were employed to maintain transparency and consistency in the selection process, and the organized framework for documenting each selection process was delivered.

2.4 Data Extraction

Data is gathering key information from the selected studies, from extracting the 200 papers' data, counting the author, the year of publication plus focus, methods plus findings, and their relevance to cybersecurity challenges, and then information quality in 2020. The 200 papers extracted files are organized into specific categories: cybersecurity threats, information quality challenges, and proposed solutions [9]. This structured categorization facilitates a clearer literature analysis and helps identify trends, gaps, and significant contributions within the field.

2.5 Quality Assessment

The quality assessment of the study is conducted to evaluate its methodological rigor and the soundness of its results. The study was reviewed against the established criteria to determine its contributions to quantum computing, cybersecurity, and information quality in financial systems and adhere to standards prevalent in 2020 [15]. This assessment only includes high-quality and credible research, which is comprised in the review, strengthening the overall validity and reliability of the findings derived from the literature.

IV. CYBERSECURITY QUANTUM ENABLED FINANCIAL SYSTEM

3.1 Common Threats Identified (Up to 2020)

In 2020, the advent of quantum computing posed a significant danger to outdated encryption procedures and widely used algorithms like RSA and Elliptic-Curve-Cryptography (ECC) [8]. These methods are based on the effort of factoring the great integers or resolving the separate logarithm complications and chores that are computationally infeasible for classical computers [9-10]. These quantum procedures, like Shor's-algorithm quantum computers, resolve these glitches efficiently and make interpreting outdated encryptions susceptible. In the financial sector, which heavily relies on encryption to secure transactions, communications, and sensitive data, the potential for quantum computing to break encryption has raised concerns about the integrity of financial systems [11]. Cybercriminals with access to quantum-computing capabilities could exploit this power to decrypt sensitive information and data breaches with identity theft, fraud, and disruption of financial markets.

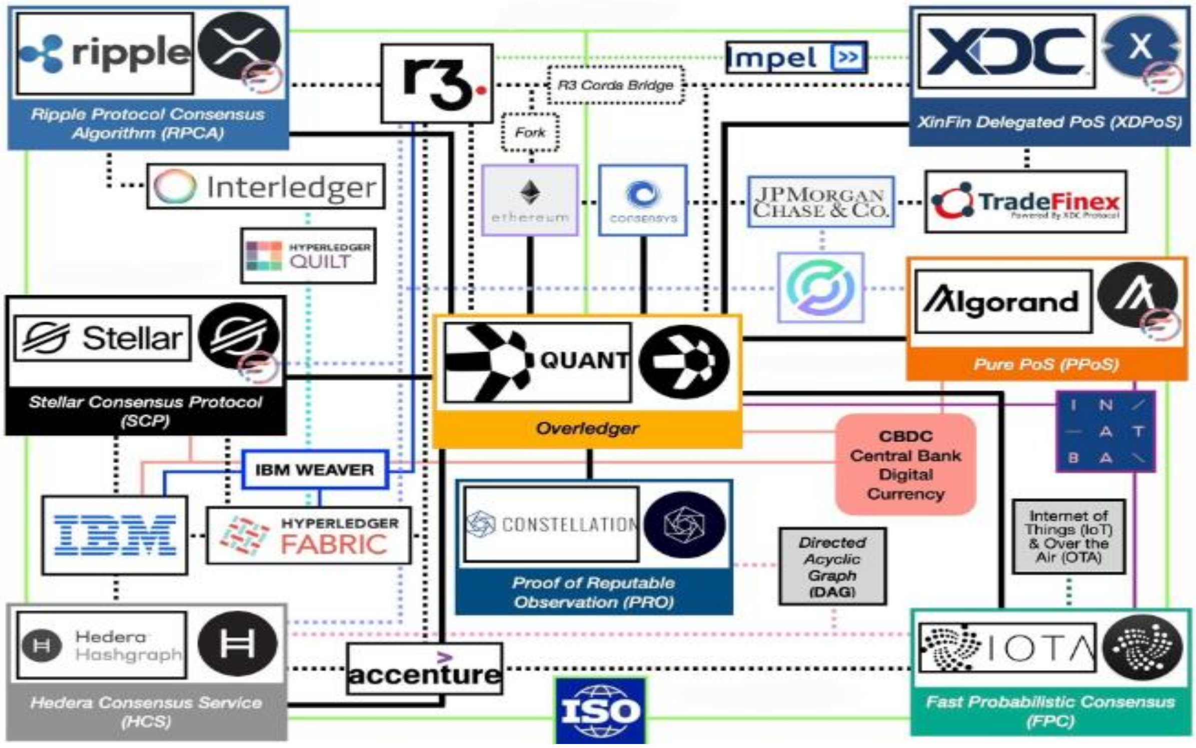

Figure 1:Cybersecurity Quantum Enabled Financial System Framework

Figure 1 illustrates the interconnections and collaborations among the various blockchain technologies, financial institutions, and consensus protocols, highlighting the role of quantum-enabled financial systems and cybersecurity in the evolving digital economy [12]. Here is the breakdown of the key components:

1. Consensus Algorithms and Protocols:

- **Ripple Protocol Consensus Algorithm (RPCA)**: Ripple (XRP) uses this algorithm to validate transactions and prevent double-spending in the Ripple network.
- **Stellar Consensus Protocol (SCP)**: Stellar (XLM) relies on this protocol to achieve decentralized consensus efficiently [13].
- **Hedera Consensus Service (HCS)**: Hedera Hashgraph employs its consensus mechanism to offer faster, secure, and scalable solutions for distributed ledgers.
- **XinFin Delegated Proof of Stake (XDPoS)**: Used in XinFin (XDC) for scalable blockchain performance, XDPoS is a highly competent accord mechanism combining elements of proof of stake and delegation [14].
- **Proof of Reputable Observation (PRO)**: Constellation's protocol offers scalability and security through a directed acyclic graph (DAG).
- **Fast Probabilistic Consensus (FPC)**: IOTA employs this lightweight, decentralized consensus algorithm suited for IoT.

2. Blockchain Frameworks:

- **Hyperledger Fabric**: the open-source blockchain structure held in the Linux Foundation, then plug-and-play solutions for different industries [15].
- **IBM Weaver**: A solution by IBM that provides blockchain integration services and connects different blockchain networks.
- **R3 Corda**: Enterprise-focused DLT (Distributed Ledger Technology) for recording, managing, and synchronizing agreements between financial institutions [15-16].
- **Quorum (Consensys)**: JPMorgan Chase & Co.'s enterprise-grade variant of Ethereum for private blockchains.

3. Overledger (Quant): This project is central to the image and provides the **Overledger** operating system that connects the different Distributed-Ledger-Technologies (DLTs). Overledger facilitates communication in all blockchains and interoperability among platforms like Ethereum, XRP, and Stellar [17].

4. Integration of Technologies: the open protocol suite for payment networks to provide seamless transactions in all different ledgers and blockchains. ISO symbols suggest adherence to standardized financial protocols in all systems to ensure security and consistency.

5. Digital Financial Innovations: Indicating the importance of state-backed digital currencies (CBDCs) in the evolving financial landscape [18]. Constellation, IOTA, and Algorand use this technology for faster transaction processing and scalability than traditional blockchain structures.

6. Collaboration Between Financial Entities: Entities like JPMorgan Chase, R3, and Consensys play significant roles in collaborating in blockchain technologies for implementing secure, scalable, and interoperable financial systems [19].

8. Quantum Security Implications:

- **Cybersecurity**: Quantum technologies (highlighted by "quantum enabled" and the central role of Quant's Overledger) may be geared toward securing financial systems against quantum computing threats by integrating the various consensus algorithms and DLTs.

This image represents the complex and interconnected network of blockchain technologies with financial systems and cutting-edge cybersecurity measures to create a secure, interoperable, and scalable quantum-enabled financial ecosystem [19].

3.2 Proposed Solutions (2020)

Researchers and technologists have proposed several solutions to alleviate the dangers of quantum computing. One of the most prominent approaches was the development of Quantum-Key-Distribution (QKD), a technique that quantum mechanics uses to firmly convert encryption keys among the parties [20]. In QKD, any effort to interrupt the key exchange process would be detectable, and communication channels would be secure even in the presence of quantum threats. The other key solution was the exploration of post-quantum cryptography, which contains the evolving fresh crypto-graphic procedures that can withstand quantum attacks. Unlike QKD, post-quantum cryptography can be implemented on existing systems and does not require quantum technologies [21]. These procedures are designed to be safe against classical and quantum computers, providing a future-proof solution to protect financial systems.

3.3 Cyber Key Challenges

The promise of these proposed solutions is hindered by several challenges hindered by their widespread adoption in 2020.

- The most notable challenge was the lack of large-scale deployment of quantum-resistant technologies [22].
- Implementing new cryptographic standards and integrating QKD or post-quantum algorithms into existing financial infrastructure required substantial research, development, and investment in testing.
- Many financial institutions hesitated to adopt these measures prematurely, given the uncertainty about when quantum computers would become a practical threat.
- Moreover, significant cost concerns were associated with adopting quantum-resistant security solutions [23].
- Implementing these technologies required substantial resources, and financial entities were often reluctant to allocate funds without clear, immediate risks.

Many financial institutions were already dealing with **tight profit margins** and **legacy infrastructures,** and it was difficult to justify the expense without immediate and tangible threats. There were concerns about the **scalability** and **compatibility** of these quantum solutions with existing technologies, which further complicated their adoption [24].

V. INFORMATION QUALITY IN QUANTUM FINANCIAL SYSTEMS

Quantum computing is poised to revolutionize financial systems by significantly enhancing file processing capabilities and improving the quality of information used in decision-making processes. Its ability to perform complex calculations at unprecedented speeds and quantum computing offers promising benefits for financial institutions, such as more accurate risk assessments with faster transaction processing and improved fraud detection [8-25]. The introduction of quantum technologies also brings new challenges in managing data quality, as shown in Figure 2. The probabilistic nature of quantum systems, coupled with the complexities of handling large-scale quantum data, raises concerns about maintaining accuracy, integrity, and reliability [26]. This overview explores the effect of quantum computing on data quality, the methods proposed to high standards of information, and the key challenges facing integrating quantum technologies into financial systems as of 2020.

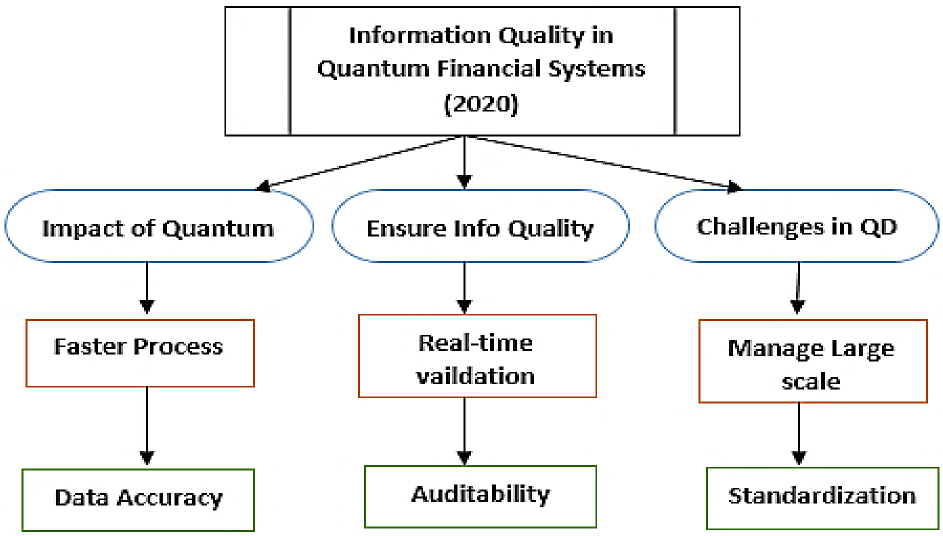

Figure 2:Information Quality in Quantum Financial Systems diagram

4.1 Impact of Quantum Computing on Data Quality

Quantum computing can process and analyze enormous amounts of data faster than classical computers [27]. In financial systems, this can directly improve data quality by:

- Enhancing processing speeds: Quantum computers can solve complex problems faster, such as risk modeling or market simulations.
- Increasing data accuracy: The precision of quantum algorithms can reduce the error margins in large datasets and make more accurate financial predictions [28].
- The probabilistic nature of quantum computing: Quantum systems rely on probabilities, meaning they may not always produce deterministic results. This introduces the challenge of managing output uncertainty, affecting data reliability [29].
- The need for specialized quantum algorithms and hardware: Existing data management tools are not designed for quantum data, so new systems must be developed, adding complexity to financial data management [27-29].

Ensuring Information Quality (2020)

Several methods have been proposed for the info quality in quantum-computing environments:

- **Real-time data validation**: Quantum systems could perform rapid validation checks to verify data accuracy instantly. This reduces the chances of data discrepancies in transactions and calculations. Stock trading and quantum systems can continuously validate data inputs to correct pricing and reduce errors in financial transactions [30].
- **Auditability and Transparency**: Quantum systems can enhance the audit processes to maintain traceability in all data transformations [31]. The ability to audit quantum computations is critical for compliance with financial regulations. Quantum blockchains could be used for transparent and auditable financial records.

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- **Data Integrity through Quantum Encryption**: Quantum-cryptography provides secure methods for the reliability and confidentiality of subtle financial files. Using Quantum-key-Distribution (QKD), sensitive financial transactions can be encrypted with high security, and data remains protected against cyberattacks.

2. Challenges

The promising benefits of quantum-computing and several key challenges exist in maintaining information quality:

- **Managing large-scale quantum data processing**: Quantum systems and classical computers require different protocols for managing large datasets. Data consistency in quantum and classical systems is difficult to achieve. Current data governance frameworks cannot handle quantum data and interoperability challenges when integrating quantum systems with existing financial technologies [32].
- **Standardization**: The lack of standards for quantum data processing presents the challenge of maintaining information quality in all different financial institutions. Each financial institution may develop its quantum protocols, and it is not easy to establish a universal approach to managing quantum data.
- **Error rates and stability**: Quantum computers in 2020 were prone to high error rates due to the fragile nature of qubits [33]. The reliable outputs while minimizing these errors are essential for maintaining data integrity. The quantum system running and financial model may yield errors due to qubit instability and difficulty trusting the output without additional error correction.

VI. ECONOMIC SUSTAINABILITY AND QUANTUM TECHNOLOGIES

5.1 Quantum Computing for Economic Growth (2020)

Quantum computing has been projected to significantly drive economic growth by transforming industries and finance [34]. In 2020, there are key areas where quantum technologies are expected to improve operational efficiency:

- **Cost reduction**: Quantum computing can process and analyze data more efficiently than classical systems, reducing costs in financial services [35]. This is useful in risk management, fraud detection, and portfolio optimization, where quantum algorithms could deliver faster, more accurate solutions.
- **Risk management**: Financial institutions face complex risks, from credit risk to market volatility. Quantum computing's ability to simulate numerous financial scenarios simultaneously provides more robust risk modeling and better-informed decision-making. This can reduce economic losses during crises and improve long-term financial stability [36].
- **Operational efficiency**: Solving optimization problems at a scale unachievable in classical computers and quantum technologies can streamline operations in industries such as logistics, manufacturing, and finance. These efficiency improvements increase productivity and boost **economic growth** globally [37].

5.2 Challenges to Sustainability

Its potential for fostering economic growth and the adoption of quantum technologies are facing several challenges to sustainability:

- **Access disparities in developing countries**: Quantum technologies' high cost and technical complexity present significant barriers for developing countries [37]. The gap between advanced economies and developing nations could widen if access to quantum computing is not democratized. Developing countries may lack the infrastructure and investment needed to fully participate in the quantum revolution and potentially global economic inequality.
- **Cost barriers**: Quantum computers are still in their early stages, and the cost of developing and maintaining these systems is extremely high. Quantum data centers require specialized equipment, skilled personnel, and massive capital investment. The numerous industries are small and medium-sized enterprises (SMEs), and these charge barriers could limit the economic benefits of quantum technologies [38].
- **Energy consumption concerns**: Quantum computers and their supporting infrastructure consume substantial energy. The quantum-technologies scale and their energy demands are likely to increase. This raises concerns about the sustainability of quantum data centers in light of global efforts to reduce carbon emissions and achieve energy efficiency. Quantum technologies contribute positively to economic sustainability, and addressing their environmental impact is crucial [39].

In summary, while quantum technologies hold great promise for driving economic growth through improved efficiency, cost reduction, and enhanced risk management, challenges related to access plus cost and energy consumption must be addressed to ensure these benefits are realized sustainably globally [40].

VII. FINDINGS AND RESULTS

The systematic review provides in-depth findings and highlights key trends in quantum-enabled financial systems. Citations are concentrated in a few highly cited papers, suggesting influential research. Springer and IEEE dominate as top publishers, driving much of the work in this field. The economic comparison across regions shows that Central and Eastern Europe (CEE) outperforms the EU and Euro area, offering insights into the broader economic impacts of quantum technologies. These findings emphasize the importance of quantum advancements in financial system security and sustainability.

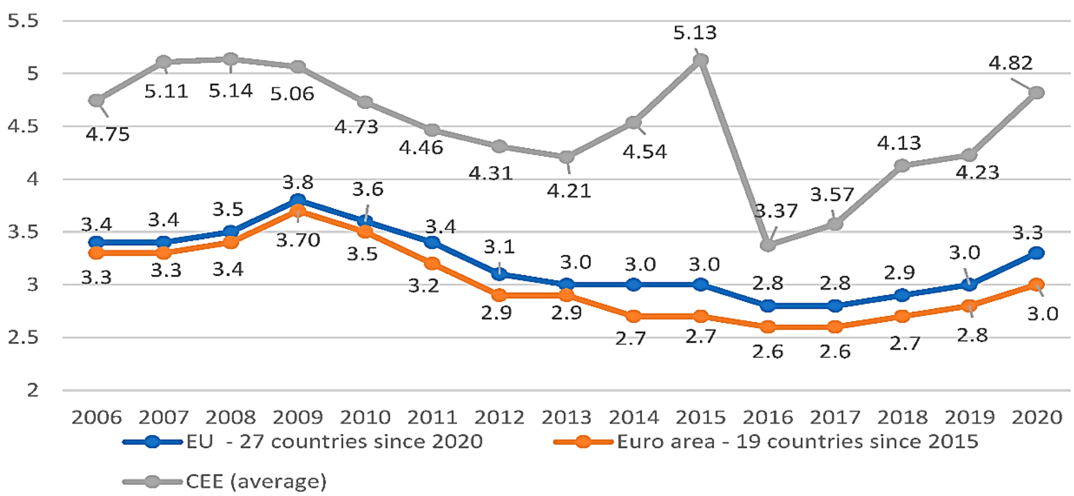

Figure 3: Economic Growth Yearly Analysis

This Figure 3 line chart compares the economic performance (likely average GDP growth or a similar indicator) of three regions: the EU (27 countries), the Euro area (19 countries), and Central and Eastern Europe (CEE). The CEE region (gray line) consistently outperforms the EU and the Euro area, though it shows some volatility, with a steep drop in 2013 and a sharp rise in 2020. The EU and Euro area follow similar trends, with gradual improvements and stabilization, but at a lower performance level than the CEE region. This chart could reflect how advancements in quantum-enabled financial systems or other economic factors impact various regions economically.

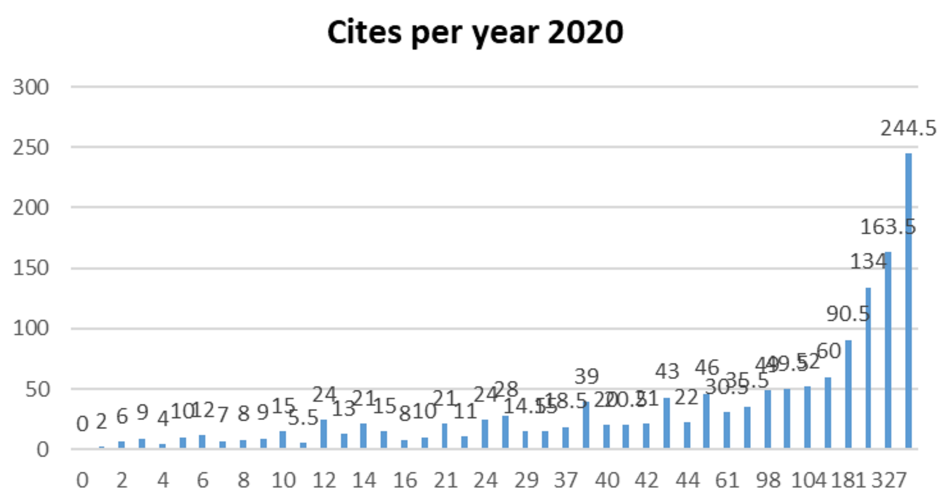

Figure 4: Cites per year

The Figure 4 bar graph shows the distribution of citations received yearly in 2020. The values on the x-axis range from low to high citation counts. Most publications have lower citation numbers (ranging from 0 to around 40), but a few have significantly higher citation counts (peaking at 244.5). This demonstrates that while many papers receive modest attention,

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a few publications are highly cited, indicating possible groundbreaking research.

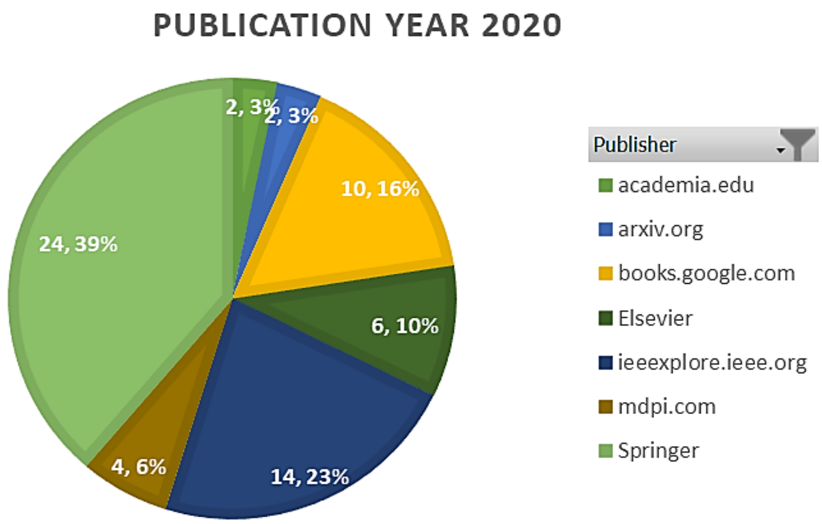

Figure 5: Publication year Distribution 2020

This Figure 5 Pie chart illustrates the number of publications from different publishers in 2020. Springer leads with the most publications (24), followed by ieee.org (14), books.google.com (10), Elsevier (6), and mdpi.com (4), with a few other sources like academia.edu and arxiv.org contributing only 2 each. This chart gives insight into the dominant publishers contributing to the body of literature in this area, with Springer being a key player.

VIII. CONCLUSION AND DISCUSSION

7.1 Summary of Key Findings

This review explored the challenges and potential solutions associated with information quality and cybersecurity in quantum-enabled financial systems up to 2020. Due to its unprecedented processing capabilities, Quantum computing offers significant risk modeling, fraud detection, and financial optimization advantages. These same capabilities pose cybersecurity risks and are the vulnerability of traditional cryptographic methods like RSA and ECC to quantum attacks. While post-quantum cryptography and Quantum-Key-Distribution (QKD) are promising countermeasures, their widespread adoption remains limited.

Information quality is critical as quantum systems introduce data integrity and auditability complexities. The ability to process vast amounts of financial data could improve accuracy and decision-making, but managing quantum data presented unique challenges. The review highlighted that while frameworks for addressing these issues were developing, empirical studies on large-scale applications of quantum technologies in financial systems remained scarce. These advancements have the potential to contribute to sustainable economic growth by improving operational efficiency and reducing costs, but equitable access and energy consumption have posed hurdles.

7.2 Final Thoughts on Economic Sustainability

Quantum computing showed immense potential to transform financial systems and drive economic growth through improved risk management, reduced operational costs, and enhanced decision-making. These challenges are equitable access, cost barriers, and energy demands that need urgent attention. If left unaddressed, these issues could exacerbate economic inequalities among developed and evolving nations. Sustainable finance practices should contain strategies to democratize access to quantum technologies and minimize their environmental impact to share benefits globally.

7.3 Recommendations for Policy and Practice

To facilitate the adoption of quantum security measures, financial institutions should:

- Begin exploring post-quantum cryptographic solutions to safeguard sensitive financial data from future quantum threats.
- Invest in pilot programs to test and integrate Quantum Key Distribution (QKD) into their cybersecurity frameworks.
- Establish collaborative initiatives with research institutions to develop practical quantum-resistant solutions.
- Address the potential environmental impact of quantum computing by adopting energy-efficient systems and ensuring that quantum technologies contribute positively to sustainability goals.

Further research should explore the economic implications of quantum computing in finance and whether these technologies can align with global sustainability objectives.

7.4 Research Gaps Identified

Several gaps in the research were identified in the empirical application of quantum technologies in financial systems:

- Few large-scale studies on implementing quantum security measures in real-world financial systems existed by 2020.
- There was a limited exploration of the intersection between quantum computing, information quality, and economic sustainability.
- Practical frameworks for deploying quantum technologies in diverse financial markets remained underdeveloped, signaling that more focused research was needed.

7.5 Future Research

Upcoming studies explore the long-term economic effects of integrating quantum computing into financial systems. This includes examining the viability of post-quantum cryptographic systems on a global scale, assessing the role of quantum technologies in enhancing economic sustainability, and developing standardized frameworks for managing quantum data in all financial institutions. Collaboration among governments, academic researchers, and industry stakeholders will be essential to ensure quantum-enabled financial systems are secure, equitable, and sustainable.

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