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Research Article

Quantum Computing in the NISQ Era: A Scientometric Mapping of Research Trends, Hotspots, and Emerging Frontiers (2018-2025)

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ABSTRACT

In recent years, quantum computing has gained more and more of a research interest, especially with the emergence of Noisy Intermediate-Scale Quantum (NISQ) systems. This study is a bibliometric analysis of the publications related to NISQ quantum computing from 2018 to 2025. Publications were pulled from the OpenAlex database and narrowed down by the relevance of the records to NISQ related quantum computing. A total of 2,524 publications were selected for the final analysis. The study covers the growth of publications, citation characteristics, main research areas, research hotspots, leading contributors, geographic distribution and new research areas. The results indicate that the publishing activity has been significantly rising, peaking in 2022-2023. Based on the thematic analysis, the key directions for NISQ research are found to be quantum algorithms, variational quantum methods, quantum machine learning, quantum hardware, optimization, and error control. The analysis also indicates that there is greater thematic variety, indicating that NISQ research has diversified to a number of related fields. The United States is the primary source, followed by China, the United Kingdom and various major universities and research institutions. The citation maturity indicates that more mature citation is seen in the older publications, while newer publications are still building up their level of citations. The 2025 research snapshot also shows that there are strong linkages between the fields of quantum computing, computer science, physics, mathematics, optimization, and AI. The study gives a structured insight into the development and evolution of the research interest in NISQ quantum computing, and identifies areas that will likely continue to be the focus of research.

Keywords: Bibliometric Analysis, Emerging Research Frontiers, NISQ, Quantum Algorithms, Quantum Computing, Research Trends.

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INTRODUCTION

Quantum computing is one of the areas where research in the 21st century has shown to be the most promising and fruitful. Based on the counterintuitive principles of quantum physics: superposition, entanglement and quantum interference, quantum computing holds the potential to shift the computational paradigm for a range of applications, including optimization, cryptography, materials science, drug discovery and artificial intelligence. The field has developed since that seminal theoretical work of Feynman, Deutsch, Shor and Grover, from theoretical demonstration to near-term practical hardware.

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The last decade has witnessed an unprecedented acceleration in both theoretical and experimental quantum research. Google's landmark 2019 demonstration of quantum supremacy using a 53-qubit Sycamore processor (Arute *et al.*, 2019), the rise of Variational Quantum Algorithms (VQAs) for near-term Noisy Intermediate-Scale Quantum (NISQ) devices (Preskill, 2018; Cerezo *et al.*, 2021), and concurrent advances in quantum error correction, quantum networking, and quantum sensing have collectively redefined the boundaries of the field. Significant amounts of money have been invested in quantum research and development by major technology companies, such as Google, IBM, Microsoft and IonQ, along with national research programs in the United States, China, Germany, and the United Kingdom, forming a global ecosystem of quantum research of unprecedented dynamism.

With this expansion, a quantitative and systematic survey of the worldwide quantum computing research field has been inaccessible. Bibliometric and scientometric analysis is

an objective, data-driven approach to mapping intellectual infrastructure of a scientific discipline: which papers, authors, institutions, countries, journals have had the greatest impact; which papers, authors, institutions, countries, journals have co-authored and collaborated; how research topics have evolved over time (Donthu *et al*., 2021; Aria & Cuccurullo, 2017). Such analyses are becoming more common to inform research strategy development, fund granting decisions, and establish frontiers before they are mainstream. A closely related bibliometric study was published during the preparation of this manuscript: Conde-Torres *et al*. (EPJ Quantum Technology, 2026) analyzed 31,662 Scopus-indexed publications spanning 1980-2025, with emphasis on co-citation topology, funding agency sponsorship networks, and institutional collaboration across the full history of quantum computing. The present study is complementary but distinct.

During the preparation of this manuscript, a closely related bibliometric study was published, in which Conde-Torres *et al*. (EPJ Quantum Technology, 2026) analysed 31,662 publications in Scopus, covering the period from 1980 to 2025, focusing on the overall evolution of quantum computing research, co-citation structure, funding agency sponsorship, and institutional collaboration. The present study complements this study and does not replace it as it focuses on the NISQ era (2018-25). Using an OpenAlex-derived corpus of 2,524 NISQ-relevant publications, the present study examines publication growth, citation maturity, thematic diversification, NISQ challenges, keyword co-occurrence, research-domain transitions, country and institutional structure, emerging research frontiers, and the 2025 research snapshot. This narrow focus helps to shed light on the shifting priorities and new trajectories of near-term quantum-computing studies.

While there have been a few bibliometric studies that have examined the evolution of quantum computing, certain studies have been limited to general historical periods, publication growth, citation performance, or the broader quantum-technology arena. Thus, a targeted scientometric analysis of the NISQ era is needed to understand the changes in research priorities over a time when near-term quantum computing is a key research focus. This study relies on a collection of 2,524 publications relevant to NISQ that were published from 2018 to 2025, gathered via OpenAlex.

The study includes the publication trend analysis, citation assessment, author and institutional productivity, country-level collaboration analysis, keyword co-occurrence analysis, thematic evolution, research-domain transitions, thematic diversification, NISQ challenge analysis, emerging-frontier analysis, and a 2025 research snapshot.

The study utilizes a publication trend analysis, citation assessment, productivity analysis of authors and institutions, analysis of collaboration between countries, keyword co-occurrence analysis, analysis of the evolution of themes, conceptual structure mapping, and analysis of the participation of industry and academia to give a complete picture of the intellectual growth of quantum computing research. The results also pinpoint influential contributors and new research areas, as well as changing trends in collaboration and research interests which could help researchers, funding bodies and policymakers understand the state of quantum computing research and its future direction.

The present study concentrates on the scientific and information research on the quantum computer era in the years 2018-2025, as a way of filling the gap in this research. After removing duplicates, cleaning metadata, filtering by study period, and screening relevance, 2,524 NISQ-relevant publications were retrieved from OpenAlex. The analysis covers research growth, citation trends, collaboration networks, thematic development, research challenges, new research frontiers, and the evolving conceptual evolution of NISQ quantum computing.

This study has four major contributions. First, it offers a focused scientometric mapping of the NISQ-era quantum computing with an OpenAlex-derived corpus of 2,524 publications between 2018-2025. Second, it combines publication growth analysis, citation-maturity analysis, thematic diversification, research-domain transitions, keyword co-occurrence, analysis of NISQ challenges, collaboration structure, identification of emerging frontier and a research snapshot for 2025. Third, it decodes the evolution of research priorities in the context of the practical NISQ limitations such as noise, decoherence, limited number of qubits, circuit depth and error control. Fourth, it outlines the shift of focus from basic NISQ concepts to algorithms, hardware, optimization, quantum machine learning, error mitigation, and application-driven research. These contributions are complementary to other bibliometric research that offers a more general perspective on current quantum-computing studies.

We have the following research questions upon which our analysis is based:

RQ1: Who are the most productive authors, journals, organizations, and countries involved in quantum computing research and what are their citation impact profiles?

RQ2: What are the most common research themes in quantum computing? What are the changes in these themes between 2017 and 2025 and what are the keywords defining the conceptual vocabulary used in the field?

RQ3: What are the emerging research frontiers and future research directions of NISQ quantum computing by thematic evolution, research-domain transitions, keyword co-occurrence, hotspot analysis and emerging-frontier analysis?

The rest of this paper is organized in the following way. Section 2 outlines the methodology and data collection. Section 3 provides the findings in a division by analytical dimension. Section 4

summarizes major results and comments on implications. Section 5 provides future research directions. Section 6 ends with restrictions.

Related Work

Quantum computing has developed into a wide research area involving computer science, physics, mathematics, engineering, machine learning, optimization, and information security. Because the research output is increasing rapidly, bibliometric studies are useful for understanding the growth of the field and the areas receiving more attention. Wang *et al.* studied quantum computing literature from 2016 to 2020 and analysed publication trends, research hotspots, technological trends, authors, institutions, and countries. They found that the United States and China were the major contributors during this period (Wang *et al.*, 2021). Scheidsteger *et al.* studied the wider quantum technology field using 54,598 publications from 1980 to 2018 and showed how quantum research developed from early work towards a more mature research field (Scheidsteger *et al.*, 2021). These studies provide a good base for understanding quantum research, but they cover either general quantum computing or the wider quantum technology field. A focused study on the NISQ period from 2018 to 2025 is therefore useful to understand the recent change in research priorities and the areas receiving greater attention.

Evolution and Growth of Quantum Research

The earlier bibliometric studies show a continuous increase in quantum computing research. Wang *et al.* reported that quantum computing was still developing during 2016-2020, with strong contributions from the United States and China. Dhawan *et al.* studied quantum machine learning from 1999 to 2020 and found that the United States and China were also the leading contributors in this specialised area (Gupta & Mamdapur, 2021). Jang *et al.* compared the knowledge production patterns of China and the United States in quantum technology and found differences in their collaboration patterns and research focus (Jang *et al.*, 2022). More recent studies show that the research field has expanded further. Sood and Pooja analysed a decade of quantum computing research and reported important research domains, country collaboration, citation patterns, research fronts, and challenges (Sood, 2023). Sood and Monika also mapped quantum engineering research from 2008 to 2022 and found that quantum algorithms form an important base of the field, while quantum machine learning has become a highly active area (Bornmann *et al.*, 2019). These findings indicate that the growth of quantum research is not only seen in publication numbers but also in the number of topics being studied.

Bibliometric Approaches and Research Mapping

Different methods have been used in the previous studies to understand the structure of quantum research. Wang *et al.* used bibliometric indicators to study research hotspots, technological trends, authors, institutions, countries, and journals (Wang *et al.*, 2021). Scheidsteger *et al.* used publication and citation indicators together with keyword mapping to study the development of different quantum technology areas (Scheidsteger *et al.*, 2021). Sood and Pooja used article and author co-citation analysis to identify important research relationships and research directions (Sood, 2023). Sood and Monika used CiteSpace, citation analysis, and keyword co-occurrence networks to identify emerging areas in quantum engineering (Bornmann *et al.*, 2019). Rawat and Sharma further used scientometric analysis, collaboration analysis, author co-citation, keyword co-occurrence, and thematic analysis to study quantum computing from 2010 to 2023 (Rawat & Sharma, 2024). Garcia-Buendia *et al.* used SciMAT and science mapping to study the relationship between quantum computing and high-performance computing and identified major themes such as quantum computing, quantum machine learning, cryptography, and quantum communication (Garcia-Buendia *et al.*, 2024).

These studies demonstrate that the integrated approach of publication analysis, network and thematic mapping is more effective than pure publication counts in providing an overview of the research field.

Key Research Themes and Clusters

As quantum computing evolves, the research themes have also been changed as identified in the literature. Initial studies were closely related to quantum algorithms, qubits and physical implementation.

Later studies show stronger attention towards quantum machine learning, quantum algorithms, quantum engineering, optimization, cryptography, quantum hardware, and hybrid quantum-classical methods. Arora and Gupta analysed 3,067 publications on quantum computational intelligence from 2014 to 2023 and identified quantum machine learning, quantum neural networks, quantum particle swarm optimization, quantum variational Monte Carlo, and quantum-inspired evolutionary algorithms as major research groups (Arora & Gupta, 2025). Dupouët *et al.* approached the field from the community perspective and studied how research communities form, grow, split, merge, and disappear over time (Dupouët *et al.*, 2024). Their work is useful because it shows that changes in research themes are also connected with changes in the research communities producing the knowledge. These findings support the need to study the NISQ-specific themes, particularly variational quantum algorithms, error correction, error mitigation, quantum machine learning, optimization, hardware, and simulation.

Comparison with Recent Bibliometric Studies

Bibliometric studies have been done recently on the history and themes of quantum computing. In contrast, Conde-Torres *et al.*

used a much larger corpus from Scopus that covers the entire period from 1980 to 2025 to gain deeper insights into the evolution of quantum computing and highlight structural relationships like co-citation, funding, and institutional collaboration. The present study, however, aims to narrowly focus on the research that has been carried out during the NISQ era (2018-2025) and to select OpenAlex as its bibliographic source. The analytical focus is also different with an emphasis on publication growth, citation maturity, thematic diversification, NISQ challenges, research domain transition, keyword co-occurrence, emerging frontiers and the research snapshot for 2025. It is, therefore, not an alternative to the wider historical bibliometric analyses of the subject, but rather complementary.

METHODOLOGY

The paper is written in a rigorous bibliometric analysis framework, based on well-established scientometric methodologies and a general structure is shown in the Figure 1.

Database Selection

The OpenAlex database was selected as the primary source of bibliographic information for this study. OpenAlex provides structured metadata covering scholarly publications, authors, institutions, countries, journals, topics, and citation information. The database was considered suitable for the present study because the objective was to examine the development of quantum-computing research across multiple dimensions rather than relying only on publication counts.

The analysis was restricted to the period 2018-2025, corresponding to the selected NISQ-era study window.

The bibliographic records for this were obtained from OpenAlex on April 2026. The publication and citation indicators included in this study are based on the last update of the OpenAlex database on this retrieval date, as this database is updated regularly.

Records outside this period were excluded from the analysis. The final dataset obtained after retrieval, duplicate removal, and NISQ relevance filtering contained 2,524 publications. The study is therefore based on an OpenAlex-derived NISQ-related quantum-computing dataset, rather than claiming to represent the complete universe of publications in quantum computing. The process of data selection is shown in Figure 2.

Search Query Formulation

The bibliographic information was obtained from OpenAlex on April 2026. Only publications made during 2018-2025 were searched. As the search strategy was deliberately more general than "NISQ" alone, publications that discuss near-term algorithms, hardware, error mitigation, optimization, simulation, and related concepts for quantum computing may be considered relevant.

A structured search strategy was developed to retrieve publications associated with quantum computing in the NISQ era. The search terms were formulated to cover both the fundamental terminology of quantum computing and the major research areas that characterize NISQ research.

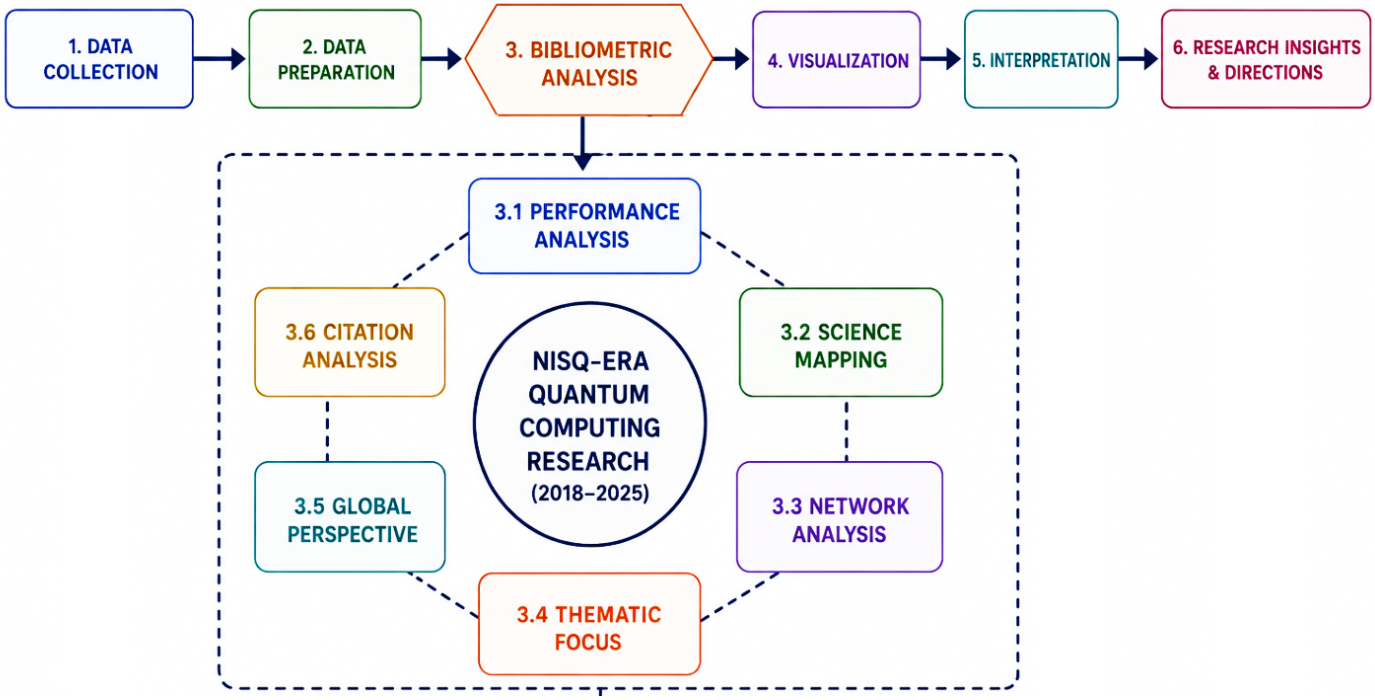


Figure 1: Overview of the bibliometric analysis framework adopted in this study.



Figure 2: Data selection and filtering process for the quantum computing bibliometric corpus.

The search terms used were: quantum computing, quantum computation, quantum computer, quantum processor, quantum circuit and quantum algorithms. These were complemented by the NISQ-specific terms: NISQ, noisy intermediate-scale quantum, variational quantum algorithms, QAOA, VQE, quantum error mitigation, quantum error correction, quantum machine learning, quantum optimization, quantum simulation, quantum advantage, quantum hardware, quantum architecture, and quantum compilation.

It was a conscious decision to not just search for NISQ, but to search for a wider scope of relevant publications, as many publications tackle near-term quantum-computing problems without the NISQ terminology in their title or key words. The final search strategy thus involved the key quantum computing vocabulary and algorithms, hardware, software, error mitigation, error correction, and near-term quantum computing ideas.

The search strategy was restricted to publications between 2018 and 2025, which allowed for consistency between the search strategy and the defined study period.

Data Preprocessing

The bibliographic records were retrieved from OpenAlex, and then were combined into a single dataset for analysis. Duplicate publications were detected mainly based on the DOIs. If DOI information was not available, the duplicate was identified by the publication title and publication year. Duplicate records were deleted, to ensure that every publication appeared only once in the final corpus.

The data was then processed for consistency in the publication year, formatting citations for easy counting, consistent keyword normalization, and consistency of bibliographic metadata. Common abbreviations and synonymous terms were grouped together when possible, unnecessary spaces were eliminated, and all words were standardized for capitalization.

Author and institutional metadata were preserved based on OpenAlex data. Advanced author-name disambiguation and normalization of institutional affiliation beyond the metadata provided by OpenAlex were not done independently. This limitation is recognized since there are some inconsistencies in author and institutional identities that might affect productivity and collaboration analyses.

Dataset Screening and Selection Workflow

The screening was divided into four major steps. First, records outside the pre-defined study time (2018-2025) were purged. Second, duplicate records were eliminated through the use of DOI

matching and title and year matching, when DOI information was not available. Third, records with insufficient bibliographic information for analysis were excluded. Fourth, relevance screening was done to differentiate the publications related to NISQ from the publications that were not primarily focused on other areas of quantum technologies.

When the available title, abstract, keywords, or metadata did not contain enough evidence of relevance to quantum computing, publications were excluded that were primarily associated with quantum communication, quantum sensing, quantum metrology, or cryptography. After following these procedures, 2,524 publications relevant to NISQ were retained for the final analysis.

Data Retrieval and Refinement

OpenAlex was used to retrieve the bibliographic records that were then exported for further processing. The metadata retrieved consisted of: publication title, authors, publication year, journal, keywords, affiliations, countries, citation information, DOI, and other related bibliographic fields. This first set was then refined throughout a number of steps. Firstly, the records were limited to the specified 2018-2025 timeframe. Secondly, duplicate records were eliminated to avoid double counting of the same publication. Third, the authors, institutions, countries, and keywords were standardized as needed for the subsequent network and thematic analysis.

The final corpus was refined by relevance to focus on quantum computing research in the NISQ space and not the quantum technology space as a whole. Records were kept if they had titles, abstracts, keywords, or other metadata related to quantum computing, NISQ systems, quantum algorithms, quantum hardware, quantum error mitigation/correction, quantum optimization, quantum simulation, or quantum machine learning. When not enough quantum-computing relevance could be drawn, records were excluded, mostly those on quantum communication, sensing, metrology, or quantum-technology applications unrelated to quantum computing.

Bibliometric Analysis

A combination of performance analysis, science mapping, network analysis, thematic analysis and citation analysis was used to analyse the refined dataset. This multi-dimensional approach was used to gain insight into not only the amount of research but also the structural and thematic evolution of NISQ-era quantum computing. A performance analysis was employed to analyze the number of publications and research activity changes. The number of publications increased from 142 in 2018 to 380 in 2021, followed by 410 publications in 2022 and 425 in 2023. The data then shows 327 articles published in 2024 and 386 in 2025.

The dataset was analyzed using science mapping to explore the main domains of research. The analysis included quantum algorithms, quantum machine learning, quantum optimization, quantum simulation, error mitigation, error correction, quantum hardware and quantum software. Collaboration structure between researchers and countries was analyzed using network analysis. The author collaboration networks were employed to determine the shape of the research communities that are connected to each other, and country-level analysis employed to gain insight into the geographical distribution and international collaboration structure of the field. The effect of publications and the

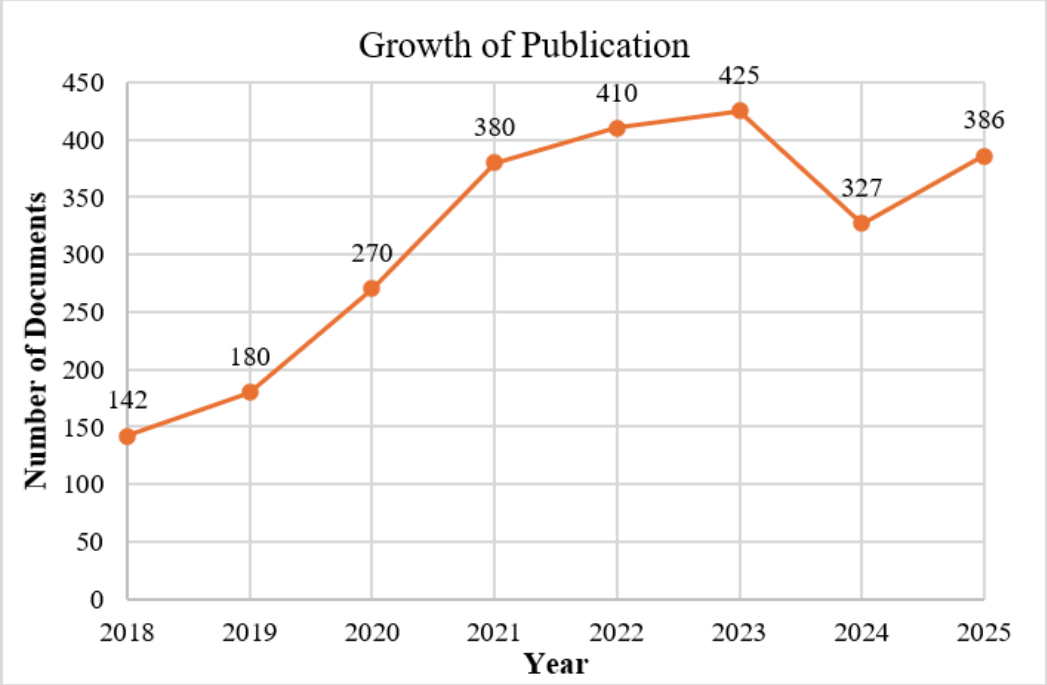


Figure 3: Evolution of Published documents.

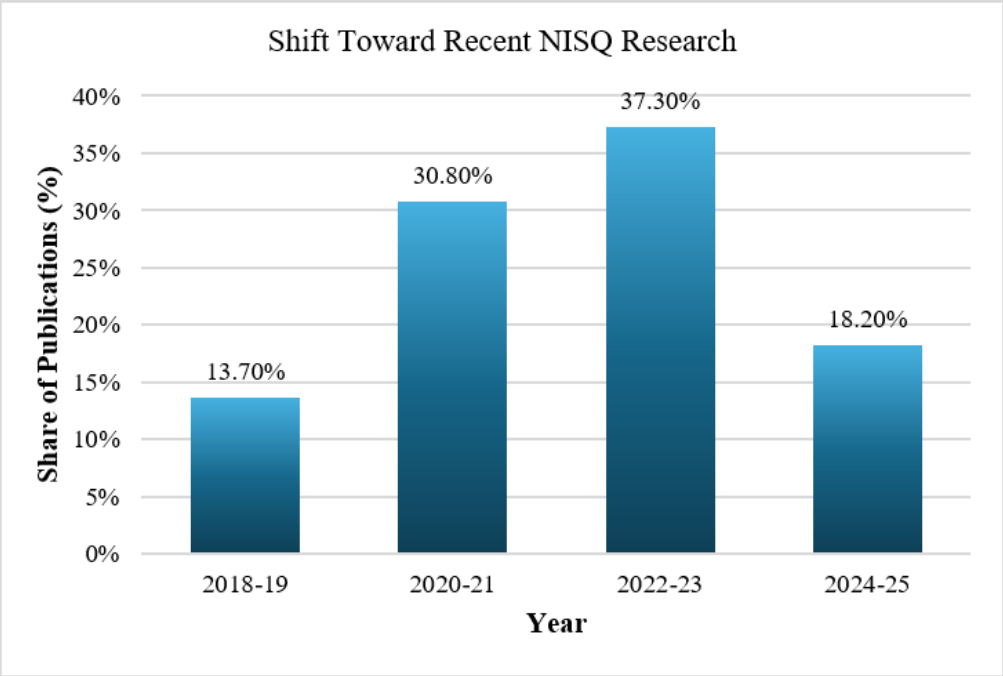


Figure 4: Shift Toward Recent NISQ Research.

connection between research growth and citation accumulation were analyzed via citation analysis. The development of the research field was assessed by taking into account the citation maturity, together with the growth in publications. The analysis also provided visual products on publication trends, research momentum, keyword trends, theme development, collaboration networks, hotspot shifts, new frontiers, and citation ripening.

Theme Identification and Interpretation

The identification of the themes was done to identify the major research areas and emerging areas in NISQ-era quantum computing. The information used in the thematic analysis comprised information from the titles, abstracts, keywords, topics and related bibliographic fields of the data set.

The themes identified were discussed with regard to the various periods to see how the priorities of research have evolved over time. A set of related terms were clustered into larger research areas, highlighting key elements of the NISQ ecosystem, instead of analyzing individual keywords. These encompassed quantum algorithms, variational quantum computing, quantum machine learning, quantum optimization, quantum simulation, error mitigation, error correction, quantum hardware, quantum architecture, quantum compilation, and quantum advantage.

These were then analysed in terms of temporal comparison and relatively established themes were differentiated from the areas with more recent growth.

Titles, abstracts, keywords, topics and related bibliographic metadata were used to identify themes. These terms were categorized as broader NISQ research areas such as quantum algorithms, variational quantum computing, quantum machine learning, quantum optimization, quantum simulation, error mitigation, error correction, quantum hardware, quantum architecture, quantum compilation and quantum advantage. Subsequently, the research topics were compared in time to identify those with greater growth in the later years of the study period. The study, for this reason, does not apply a formal and strict classification by density of centrality in terms of themes, research hotspots, thematic transitions, thematic diversification, or emerging research frontiers.

RESULTS AND DISCUSSION

This section reports the results of the scientometric analysis of quantum computing research performed in the NISQ period. From the OpenAlex database, 2,524 relevant publications were found in the 2018-2025 time period. After the data was retrieved, cleaned, refined, and checked for relevance, the full data set of 2,524 records were kept for the final analysis. A summary of the dataset and its main bibliometric features are shown in Table 1. This study is intended to analyse the development of research in quantum computing, core research areas, key researchers, citation trends and international cooperation. To give a picture of the structure, development and new trends in NISQ-era quantum-computing research, various bibliometric indicators, network analyses and visualization techniques were applied.

Growth and Development of NISQ Research

The number of publications on quantum computing in the NISQ era (2018-2025) is presented in Figure 3. From the Figure 3, it can be observed that the research output has increased considerably during the study period. There were 142 papers published in 2018. It increased to 180 papers in 2019 and further to 270 papers in

2020. This Figure jumped markedly in 2021 with 380 publications. This steady rise suggests that quantum computing began to attract more research interest in this time. Further, the number of papers published rose to 410 in 2022 and to the highest level of 425 papers in 2023. In 2023 it was nearly 3 times the number of publications that were published in 2018. This clearly shows the growing interest of researchers towards quantum computing and NISQ-related research. Yet it decreased in 2024 as the number of publications dropped down to 327 papers. This may be due to changes in research focus or differences in publication and indexing patterns. Such a decrease in publications, therefore, does not necessarily reflect a decrease in research interest. Research activity continued to recover in 2025 with a further 386 papers published. The Figure shows a significant increase in research on quantum computing, especially since 2020. The number of publications is also growing, indicating that quantum computing related to NISQ is a significant and active field of research.

As seen in Figure 4, there is a noticeable trend towards the more recent NISQ research, as the percentage of publications has risen from 13.7% (2018-2019) to 30.8% (2020-2021) and up to the highest 37.3% (2022-2023). This growth trend indicates that the field of quantum computing with NISQ grew in interest with time, especially during 2022-2023. The percentage, however, dropped to 18.2% in 2024-2025, which could be a result of the recent publication and indexing of the records. The trend is towards a more mature research area and towards an increased research interest in the last few years, with the NISQ research being on the early development stage.

Evolution and Diversification of Research Themes

The NISQ research landscape has been greatly transformed in terms of research themes from 2018 to 2025. The aim of this research is to identify areas of research that are gaining, dropping or remaining stable in terms of research interest over time in the field of NISQ. Unlike a traditional publication growth graph, this analysis offers insights into how the research priorities have evolved during the evolution of quantum computing and which are becoming important research frontiers over the next seven years from 2018 to 2025. Initial research interest in NISQ was fairly high, as was that in variational quantum approaches, which were both efforts to understand and utilize near-term quantum processors. Variational quantum algorithms, in particular, have been gaining in prominence, as indicated by an increasing trend around 2021 in Figure 5, which reflects the rising significance of algorithms suitable for operating on noisy quantum devices. In 2022-2023, there was greater diversity of research interests, with increased activity in variational quantum methods, NISQ, quantum machine learning, quantum hardware, quantum advantage and related algorithmic approaches. The years up to 2023 show a peak in variational quantum research, thus indicating the importance of variational quantum research in the NISQ research landscape. Likewise, the amount of research focus on noisy quantum systems is reflected in the importance

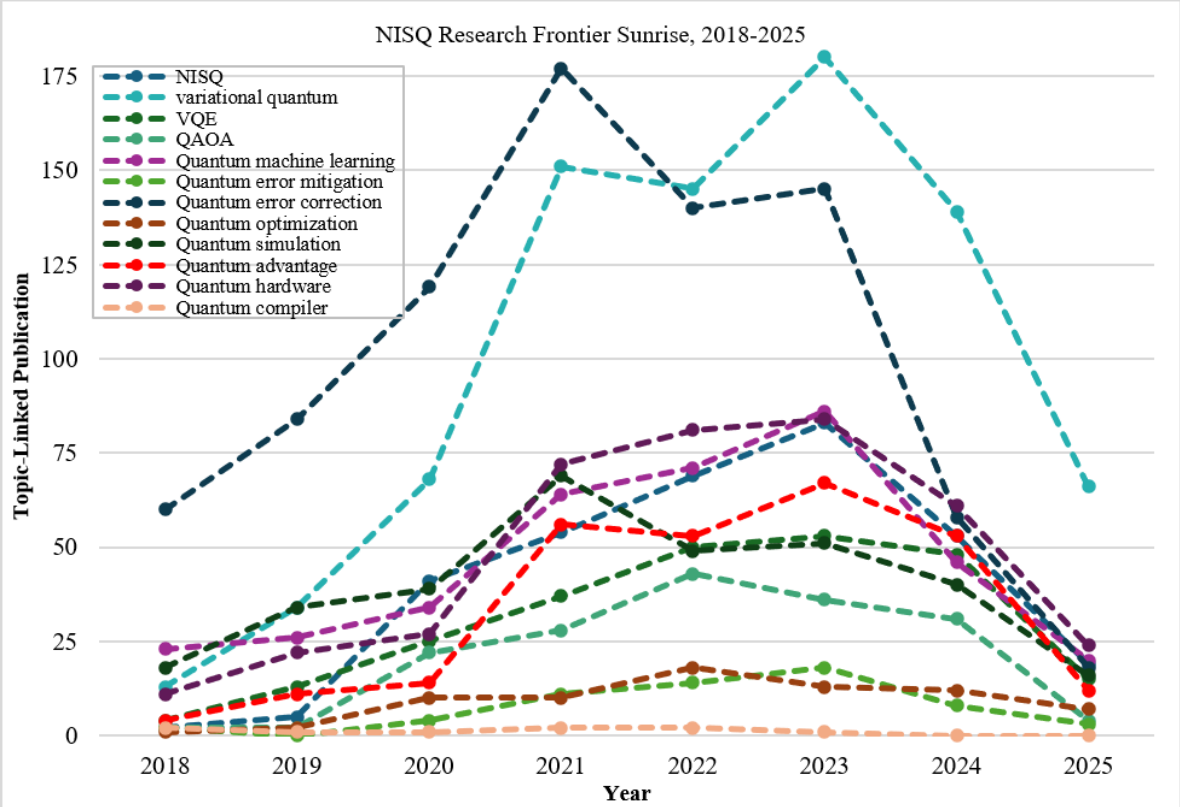


Figure 5: NISQ Research Frontier Sunrise, 2018-2025.

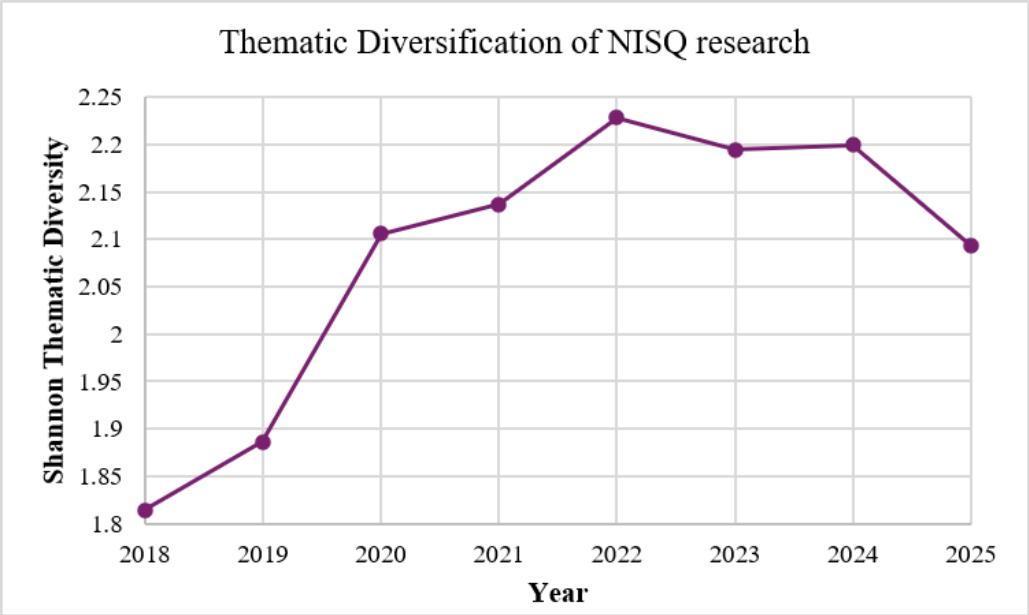


Figure 6: Thematic Diversification of NISQ Research.

Table 1: Summary Metrics of the Quantum Computing Bibliometric Corpus (2018-2025).

Metric	Value
Total Relevant Papers	2,524
Time Span	2018-2025
Articles	2,515 (99.6%)
Reviews	9 (0.4%)
Total Citations	254,627
Average Citations per Document	100.88
Median Citations per Document	43
h-Index (Corpus)	227
Average Co-Authors per Document	5.93
Unique Sources	368
Unique Countries	74

of quantum error correction and error mitigation. Research also saw a boost in quantum optimization, especially the QAOA algorithm. Themes with quantum simulation and quantum compiler research, on the other hand, seem more specific, and are less active than the others. The Figure shows that the number of publications, associated with several topics, has decreased, but the numbers for 2024-2025 should be treated with care since some recently published publications might not yet have full indexing or bibliographic metadata.

The temporal evolution indicates a gradual widening of NISQ studies from basic ideas to techniques designed to gain useful computation from imperfect quantum systems. As variational approaches, optimization, quantum machine learning and hardware focused research become more prominent, the development of algorithms is now being thought of in tandem with the practical challenges of noisy devices, finite number of qubits, and circuit-depth limits. Importantly, these observations are only bibliometric associations and are not indicative of the fact that any one technological milestone led to the observed thematic changes. Instead, the temporal patterns give an idea of the evolution of research focus and research interest in the NISQ literature.

The Figure indicates a shift from the basic NISQ work to the development of the algorithm, variational methods, machine learning, optimization, hardware development, and methods of dealing with quantum noise. This development marks a step towards making the field more focused on solving realistic computational problems and making near-term quantum computing more useful.

Thematic diversity of NISQ research from 2018 to 2025 has been depicted using Shannon thematic diversity index as shown in Figure 6. The aim of this analysis is to explore whether NISQ research has focused on a few broad areas or whether it has spread out over time to other areas of research. The diversity grew from 1.81 in 2018 to 2.11 in 2020, suggesting that the research began to move from the narrow focus on a few topics. The values have been increasing slowly in 2021 (2.14) and then the highest value (2.23) in 2022. This indicates that the NISQ research area became more diversified during this time, with NISQ researchers working on various topics and applications. The value for 2023 was 2.19, and it stayed nearly the same in 2024 (2.20) showing a relatively broad and stable thematic structure. The diversity of 2.09 in 2025 could suggest some focus on key research areas. The recent change needs to be taken with a grain of salt, however, as the current year information may be influenced by the coverage of publications and indexing. In general, the number of papers highlights that the research focus in the NISQ is shifting from

a relatively narrow field to a more diversified research field, especially in the period 2020-2024.

The major challenges associated with NISQ quantum computing based on their publication activity are identified. It helps us to understand which technical issues are receiving greater research attention and where researchers are concentrating their efforts. Figure 7 shows that optimization is the most frequently discussed challenge, with close to 940 publications. This is followed by decoherence, with around 710 publications, showing that maintaining quantum states for useful computation remains an important concern. Limited qubits also receive considerable attention, with around 420 publications, reflecting the hardware limitations of present NISQ devices. Circuit depth has around 230 publications, indicating the importance of designing circuits that can operate within the limitations of noisy hardware. Noise appears in around 150 publications, while barren plateaus and connectivity receive comparatively less attention. Compilation has the lowest publication count among the listed challenges.

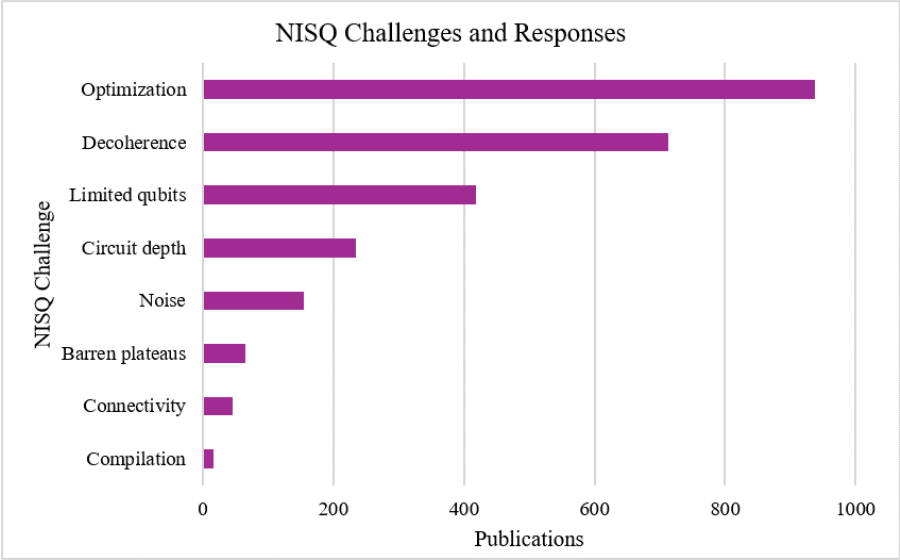


Figure 7: NISQ Challenges and Research Responses.

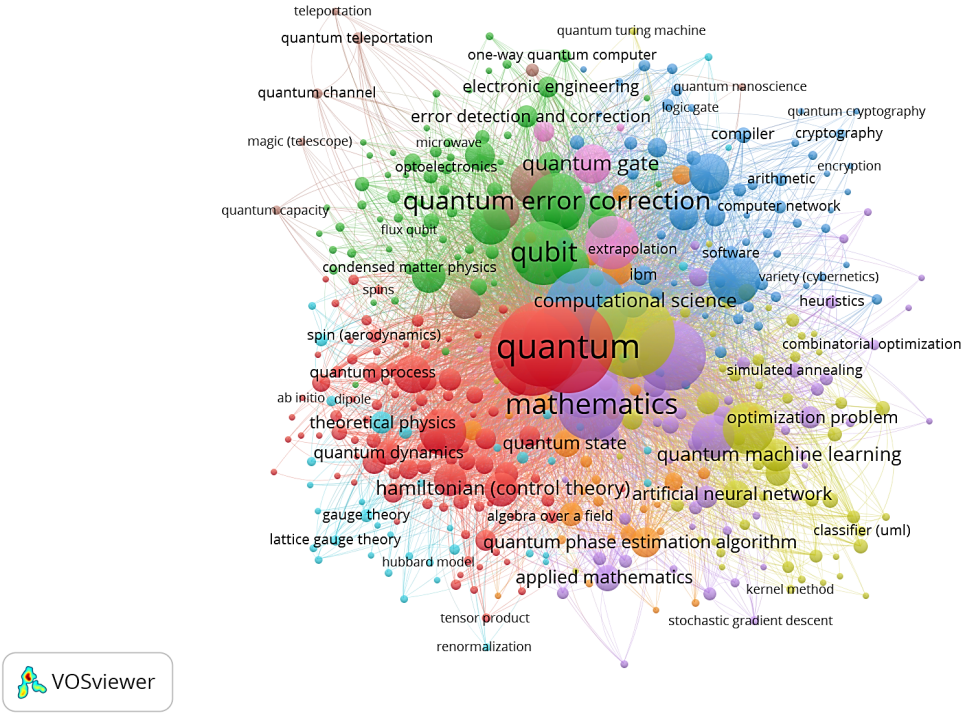


Figure 8: Keyword Co-occurrence Network of NISQ Quantum Computing Research (Source: Vosviewer).

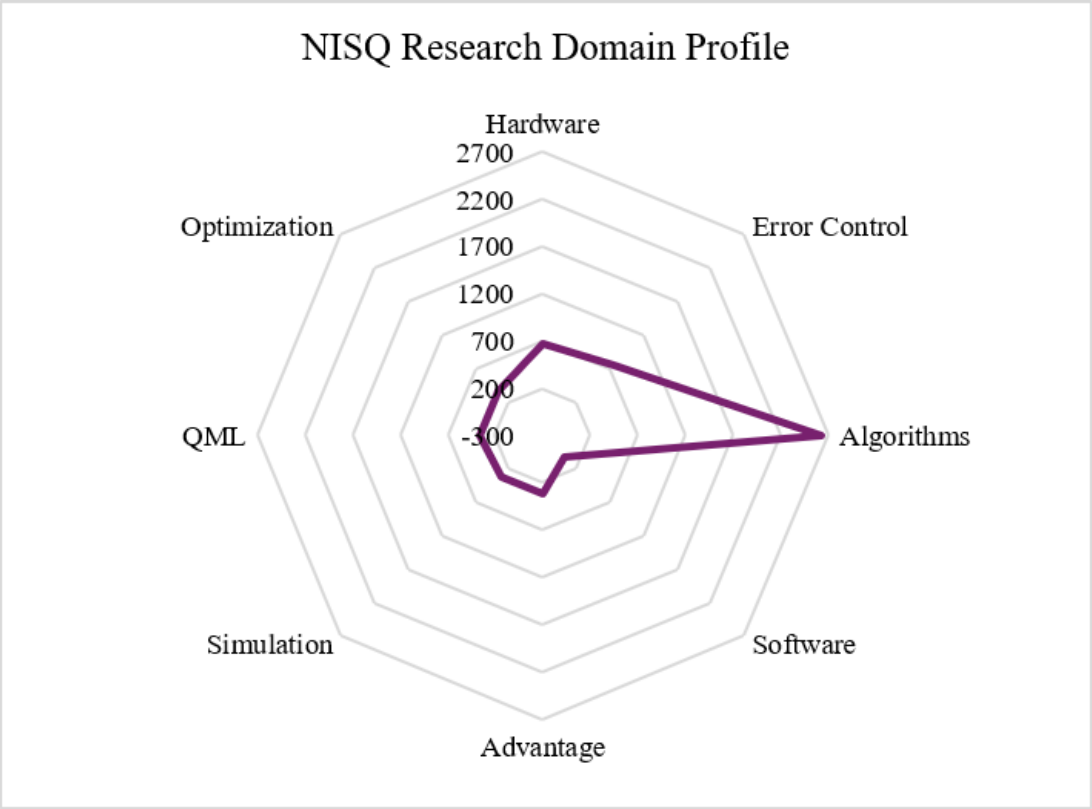


Figure 9: Evolution of Quantum Computing Research Domains.

Structure and Transition of NISQ Research Domains

The most central and highly connected term in the NISQ research is "quantum" with strong relationships to the terms "qubit", "quantum error correction", "quantum gates", "mathematics", "computational science", "optimization", and "quantum machine learning" (shown in the keyword co-occurrence network, Figure 8). These keywords are highlighted and linked together to show the main thematic areas of the field and the significant conceptual overlap between them. There are several distinct, but closely related clusters: quantum hardware and error correction; quantum algorithms and optimization; quantum machine learning; quantum software and cryptography; and fundamental physics. This close relationship between qubits, quantum hardware, and error correction highlights the on-going problem of ensuring the reliability of computation in noisy quantum systems. The links between quantum machine learning, optimization, artificial neural networks and mathematical methods indicate growing integration of quantum computing and data-driven computational techniques. Further evidence of the ongoing impact of fundamental physics on NISQ research comes from the inclusion of physics-related terms such as quantum dynamics, spin, Hamiltonian, gauge theory and quantum state. In summary, the network suggests that NISQ research is not centered around specific technical challenges, but rather that hardware constraints, error control, algorithm design, optimization, machine learning, software, and theoretical research are interdependent and represent a research ecosystem. The tight connections between these themes indicate that from a scientific point of view, the development of NISQ computation with useful applications requires to take into account at the same time the limitations of the hardware, its error resilience, its algorithmic efficiency and its computational goals. Hence, the co-occurrence structure represents a research field that is becoming more and more characterized by the integration of different domains, and not by the development of each technological component independently.

The distribution of research activity across major domains of NISQ-era quantum computing is shown in Figure 9.

The profile highlights the highest research activity in the field of algorithms, clearly dominating the profile, which shows that algorithm development has been the main focus of NISQ research. The next is hardware, which is continuing to evolve and be improved in order to build quantum processors. Because of the noise and reliability constraints in current quantum systems, Error Control is given a considerable amount of attention, as well. Moderate interest levels are experienced by software, optimization, and Quantum Machine Learning (QML), which are all technologies that are developing ways to utilize quantum computing for real-world computational challenges. The profile shows simulation and quantum advantage are relatively smaller, indicating that these are more niche areas in the existing research landscape. Overall, the Figure shows that quantum algorithms and hardware are the primary drivers of NISQ research, with

error control, software, optimization, and QML emerging as secondary research areas. This distribution demonstrates that in the present research, the emphasis is on the practical capability of near-term quantum systems, but not just on the theory.

The Thematic Transitions is employed to monitor the changes in the major research topics of NISQ quantum computing in the period 2018-2025. This is useful for determining what topics were discussed more during certain time periods, and where the focus is changing over the years. Figure 10 reveals that the research focus was rather narrow in 2018-2020, with NISQ, quantum error correction, VQE, quantum simulation and quantum machine learning being given some attention. Research activity grew for many topics during 2021-2023. During this period, there is strong activity in variational quantum research and quantum error correction. The visibility also increased of NISQ, quantum hardware, quantum machine learning and quantum simulation. This indicates that the research field started to branch out in multiple directions. The activity of most topics has decreased for 2024-2025 compared to the previous period, with variational quantum research, NISQ, and quantum machine learning remaining prominent. Reducing quantum errors is one of the key challenges in near-term quantum systems, which is why the high activity in quantum error correction in the years 2021-2023 is significant. Likewise, the significant number of variational quantum methods demonstrates the role of these techniques in dealing with today's noisy quantum devices. Overall, this Figure suggests a gradual shift of NISQ research from simple NISQ concepts and error-related problems to algorithms, hardware, machine learning, optimization and practical applications.

Global and Institutional Research Structure

This analysis provides information on the key authors, countries and institutions that have contributed to NISQ research. It is useful to have background information on the focus of research and on the leading researchers and organisations in the field. As can be seen from the Table 2, the author with the largest number of publications is Ivano Tavernelli with 43 publications, followed by Patrick J. Coles and Ryan Babbush who have each published 41. Others who are active include Jarrod R. McClean (34), Hartmut Neven (29), and Keisuke Fujii (28). Researchers of quantum

Table 2: Leading Authors, Countries and Institutions in NISQ research.

Leading Authors in NISQ Research		Leading Countries		Leading Institutions	
Author	**Publications**	**Country**	**Publications**	**Institution**	**Publications**
Ivano Tavernelli	43	US	1043	California Institute of Technology	87
Patrick J. Coles	41	CN	395	IBM Research - Zurich	82
Ryan Babbush	41	GB	336	University of Maryland, College Park	77
Jarrod R. McClean	34	DE	297	Google (United States)	76
Hartmut Neven	29	CA	196	University of Oxford	76
Keisuke Fujii	28	JP	194	Massachusetts Institute of Technology	71
M. Cerezo	26	CH	173	Tsinghua University	71
Xiao Yuan	25	ES	135	Los Alamos National Laboratory	69
Åukasz Cincio	25	IT	130	University of California, Berkeley	68
Kosuke Mitarai	24	NL	115	University of Science and Technology of China	65
Sergio Boixo	24	FR	101	Lawrence Berkeley National Laboratory	64
Panagiotis Kl. Barkoutsos	24	AU	91	ETH Zurich	62
Simon C. Benjamin	22	AT	78	Harvard University	57
Craig Gidney	21	SG	71	Centre National de la Recherche Scientifique	57
Stefan Woerner	21	IN	63	University of Waterloo	55
Nicholas C. Rubin	20	KR	44	University of Chicago	52
Ying Li	20	RU	39	IBM (United States)	51
Wibe A. de Jong	20	PL	35	University College London	49
Suguru Endo	19	DK	31	Delft University of Technology	49
Nathan Wiebe	19	SE	22	National University of Singapore	48
Yuya O. Nakagawa	19	AE	22	University of Toronto	48
Sabre Kais	19	FI	20	UniversitÃ¤t Innsbruck	48

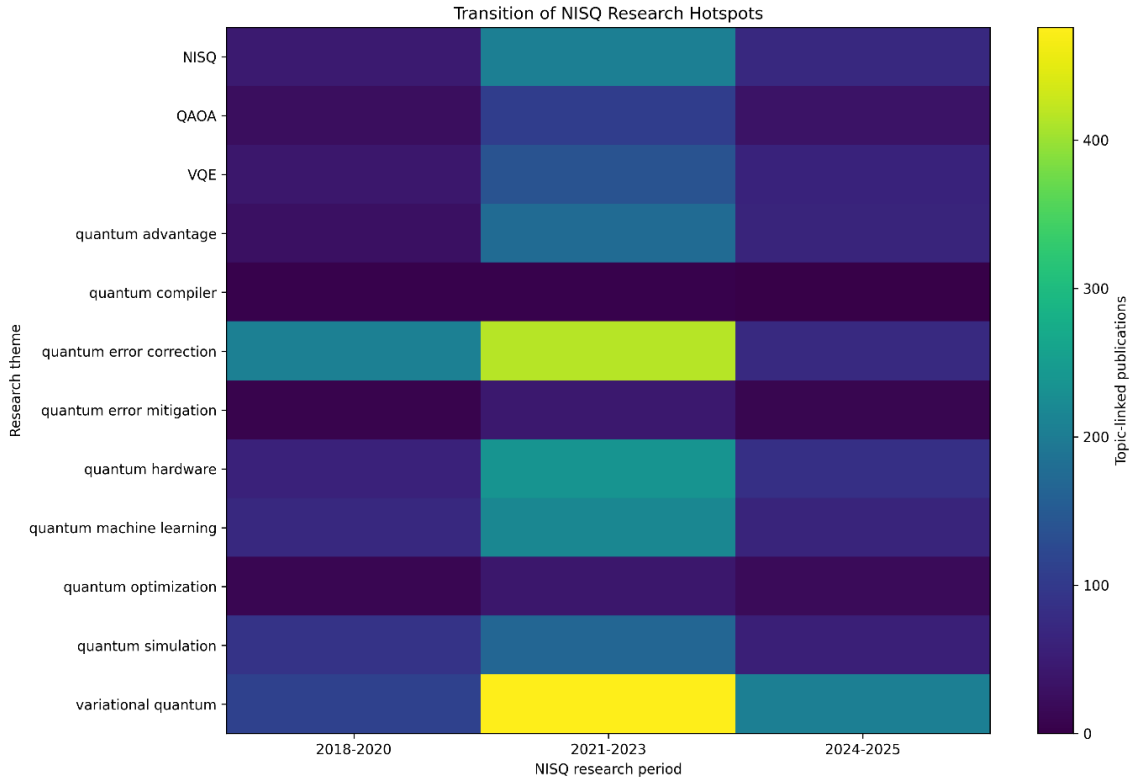


Figure 10: Quantum Technology Research Hotspot Transition.

algorithms, quantum hardware, and related technologies for NISQ (Noisy Interacting Superconducting Quantum) circuits show the diversity of the field. The country analysis shows that the United States is by far the front runner with 1,043 publications, followed by China (395) and the United Kingdom (336). The research activity is also very high in Germany, Canada, Japan, Switzerland, Spain, Italy and the Netherlands. The significant representation of the United States suggests that it plays a leading role in conducting NISQ research, whereas the involvement of multiple European and Asian countries demonstrates a geographical diversity in research. Institutions, California Institute of Technology publishes the most (87), followed by IBM Research - Zurich (82) and the University of Maryland, College Park (77). University of Oxford has 76 publications and Google (United States) has 76 publications. Other top schools include MIT, Tsinghua University, Los Alamos National Laboratory, and the University of California, Berkeley. Generally, the results indicate that there is a cluster of highly active researchers and institutions conducting NISQ research, with the USA as the main research centre and significant involvement from China and European countries.

The country-domain analysis gives an overview of the distribution of research activity across eight major domains of quantum computing: Algorithms, Quantum Machine Learning (QML), Error Control, Optimization, Simulation, Hardware, Advantage, and Software. Figure 11 shows the heatmap which gives a comparative perspective of the top countries research priorities.

The United States (US) is clearly the leader in nearly every research area. It shows a high level of research activity in Algorithms (766 papers), Error Control (287) and Hardware (270). This means there is a wide range of research on computation and hardware needs of quantum computing. There is also a significant amount of activity in the US for Advantage (143), Optimization (126), QML (108), and Simulation (161). China (CN) is the second leading country in general research activity with the most dominant domain being Algorithms (334). It also has significant entries in Error Control (129) and Hardware (77), with QML and Advantage coming in next. Also relatively active are the United Kingdom (GB) and Germany (DE), especially in Algorithms, Error Control and Hardware.

The other countries, such as Canada (CA), Japan (JP), Switzerland (CH), Spain (ES), Italy (IT), the Netherlands (NL), France (FR), and Australia (AU), have relatively small research volumes and are active in a number of areas. The gaps in the field of Algorithms and Error Control are significant in Japan, and in the field of Hardware, the activity shown is relatively high, compared with the overall research volume. There is also comparatively high activity in Error Control in the Netherlands. Algorithms is the most prevalent research field across countries, with a strong focus on this field. The next two areas of research focus are Error Control and Hardware. On the other hand, Software has few representations in all countries with only a few papers recorded. Likewise, QML, Optimization, Simulation and Advantage are emerging research topics but are less prominent.

Citation Impact and Research Influence

The impact of NISQ research has grown over the course of the study. It is used here to compare the growth in the number of NISQ publications to the average citations per paper of the same NISQ publications between 2018 and 2025. It helps to comprehend the publication growth and citation maturity of research. The publications have consistently increased from 2018 to 2023, with the highest number in 2023 (Figure 12). On the other hand, the older works had the highest number of citations per paper and this number visibly decreased with the year of publication. This is a normal phenomenon as papers published in the earlier years have been longer to have citations and the newer papers have been published with a shorter time to gain visibility. One interesting fact is that growth in publications was highest in the 2021-2023 timeframe, and the citation maturity had already begun to decline in that same time period. Recent research does not necessarily have less impact, but it demonstrates that impact of citation grows over time. The significant drop of publications and citations per publication in 2025 should be viewed with caution, as the records are only a few years old and have not yet been long enough to accumulate citations. The overall Figure reflects the fast growth in the number of publications in NISQ research and the development of impact of the more recent research in terms of number of citations.

It is seen that the major focus areas of NISQ research are quantum algorithms, variational methods, quantum machine learning, hardware development, and error control as seen in the top 20 papers in Table 3. Preskill's contributions to NISQ computing have had the highest citation impact, demonstrating the fundamental concept and problems of NISQ systems. A recent series of other highly cited quantum supremacy, variational algorithms and quantum-enhanced machine learning papers suggest that there is significant interest in identifying practical applications for near-term quantum devices. Other significant drawbacks like noise, barren plateaus, too few qubits and hardware constraints are also mentioned in the papers. In general, the research direction has shifted from showing the capabilities of NISQ devices to designing efficient algorithms and methods that can help to provide useful computation in the presence of hardware and noise constraints.

Emerging Research Frontiers

The new research frontier in Figure 13 indicates the topics that are being studied more recently. The fastest growth is in quantum error mitigation, which is nearly 383% higher. This could be due to the fact that current NISQ devices are noisy, and full error correction is still challenging to implement, and large number of high-quality qubits is required. Quantum advantage has also seen a significant improvement, around 355%, perhaps due to the increasing focus in the field on proving useful tasks that quantum computers can outperform classical computers. Variational quantum methods have grown by approximately 235% - largely because they are applicable to today's NISQ devices and involve the use of quantum circuits in conjunction with classical optimization.

Then, NISQ research is increasing by approximately 223%, and quantum hardware (182%), VQE (176%), QAOA (173%)

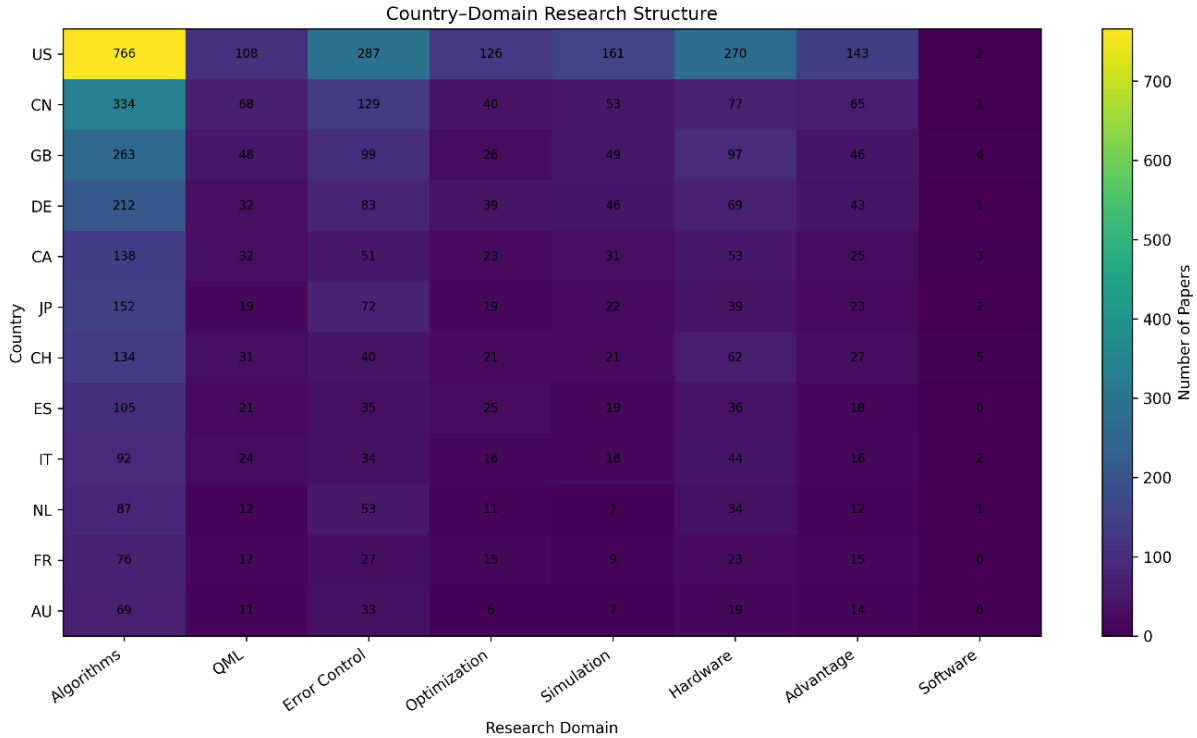


Figure 11: Country Domain Research Structure.

Table 3: Most Cited Papers.

Sl. No.	Authors	Article Title	Citations	Total Link Strength
1.	John Preskill (2018)	Quantum Computing in the NISQ era and beyond	8,514	184
2.	Arute *et al.* (2019)	Quantum supremacy using a programmable superconducting processor	7,116	172
3.	Arrasmith *et al.* (2021)	Variational quantum algorithms	3,141	156
4.	Dunsworth *et al.* (2019)	Quantum supremacy using a programmable superconducting processor	2,645	149
5.	Kandala *et al.* (2019)	Supervised learning with quantum-enhanced feature spaces	2,480	143
6.	McClean *et al.* (2018)	Barren plateaus in quantum neural network training landscapes	2,229	137
7.	Yan *et al.* (2019)	A quantum engineer's guide to superconducting qubits	1,945	132
8.	Schuld and Killoran (2019)	Quantum Machine Learning in Feature Hilbert Spaces	1,747	128
9.	Anand *et al.* (2022)	Noisy intermediate-scale quantum algorithms	1,722	124
10.	Fujii *et al.* (2018)	Quantum circuit learning	1,646	119
11.	Cong *et al.* (2019)	Quantum convolutional neural networks	1,472	116
12.	Aspuru-Guzik *et al.* (2019)	Quantum Chemistry in the Age of Quantum Computing	1,460	112
13.	Braumüller *et al.* (2019)	Superconducting Qubits: Current State of Play	1,449	108
14.	Neven *et al.* (2018)	Characterizing quantum supremacy in near-term devices	1,180	103
15.	Zhang *et al.* (2021)	Strong Quantum Computational Advantage Using a Superconducting Quantum Processor	1,130	98
16.	Gogolin *et al.* (2019)	Evaluating analytic gradients on quantum hardware	1,093	94
17.	Lloyd *et al.* (2019)	Parameterized quantum circuits as machine learning models	1,087	91
18.	Dunsworth *et al.* (2023)	Suppressing quantum errors by scaling a surface code logical qubit	1,084	88
19.	Sone *et al.* (2021)	Cost function dependent barren plateaus in shallow parametrized quantum circuits	1,084	85
20.	Barnes *et al.* (2019)	An adaptive variational algorithm for exact molecular simulations on a quantum computer	1,067	82

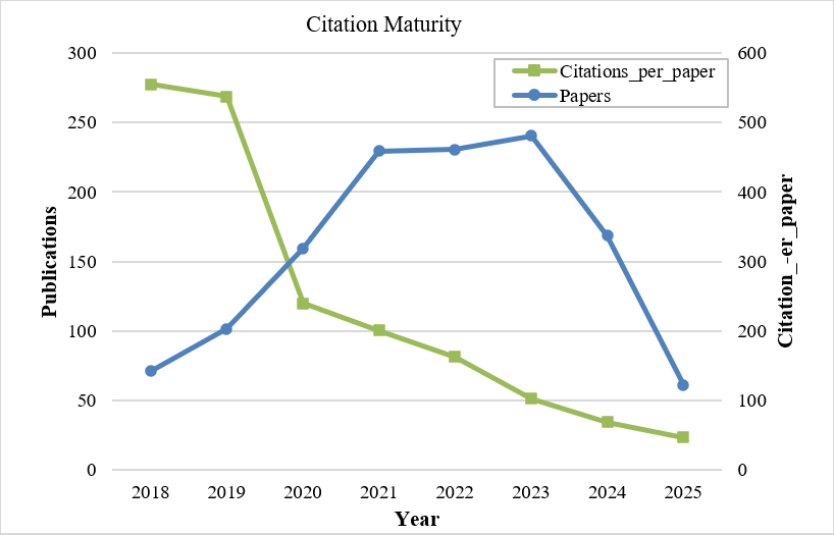


Figure 12: NISQ Research with Citation Maturity.

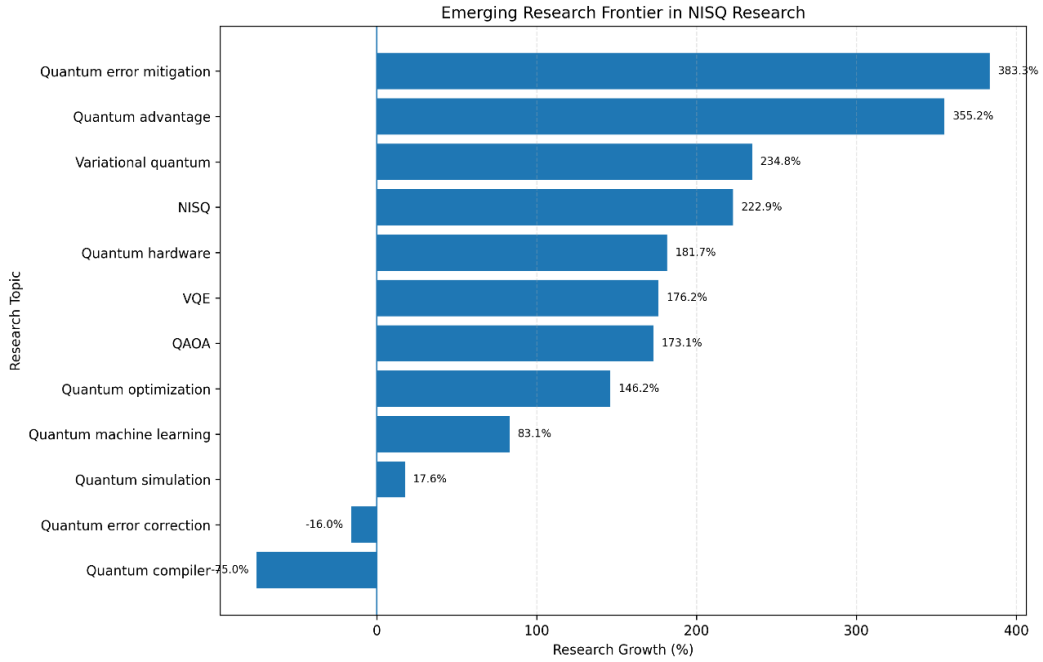


Figure 13: Emerging Research Frontiers.

and quantum optimization (146%) have also seen significant growth. These areas are attracting interest because researchers are searching for practical applications that can be implemented with the hardware that is available today and is limited and noisy.

Quantum machine learning has grown by about 83%, reflecting growing interest in applying quantum computing to data analysis and machine learning problems. Quantum simulation shows a smaller growth of about 18%, suggesting that it is a more established research area. In contrast, quantum error correction shows a decline of about 16%, which may indicate a shift in recent research from developing full fault-tolerant correction methods toward more practical error mitigation techniques that can be applied to existing NISQ hardware. Quantum compiler research shows a large decline in this dataset, although this may also be influenced by the small number of papers and the choice of keywords. Overall, the results suggest that the research frontier is moving toward practical quantum advantage, error mitigation, variational algorithms, optimization, and hardware development, with greater focus on extracting useful results from today's imperfect quantum computers.

The recent snapshot of the major research areas appearing in NISQ-related publications during 2025 is shown in Figure 14.

It is useful to have an idea of the area of research currently being undertaken and the subjects that are being covered in the most recent section of the study period. The graph reveals that the keyword with the highest frequency in the 2025 publications is quantum, followed by computer science and physics. This suggests that there is ongoing strong interaction between NISQ research and computing and physical sciences. There is also significant presence of quantum mechanics and quantum computer, pointing to the ongoing research and interest in fundamental aspects and quantum computing systems. The word algorithm, quantum algorithm, and quantum circuit are all evidence that algorithmic and circuit-level research continue to be important aspects of the field. The term "artificial intelligence" also made the list of frequently used terms, reflecting the increasing linkage between quantum computing and AI-related research. The various other terms like mathematical optimization, computational science, qubit and statistical physics illustrate that NISQ research is bringing in several supporting areas. Overall, the snapshot indicates that research on NISQ is currently multidisciplinary, with Quantum Computing being the subject of study in computing, physics, mathematics, algorithms, optimization and AI.

LIMITATIONS

There are some limitations of this study. Firstly, the analysis is conducted from publications that have been found in OpenAlex and hence, papers that are not indexed properly in the database might not be included. Second, the study spans only the timeframe 2018-2025, which means that the more recent the study is, the less likely it is to have a full citation. However, it is important to note that the slight drop in citations for 2024 and 2025 might be interpreted with caution as these papers have less time to be cited. Thirdly, the search and relevance filtering might not include all of the publications about NISQ quantum computing, particularly papers that discuss NISQ concepts but do not contain the chosen search terms. Fourth, keyword and thematic analysis rely on the metadata provided in the database and the terminology of each research theme can vary, which can influence the categorisation of research themes. Finally, the bibliometric indicators (citation

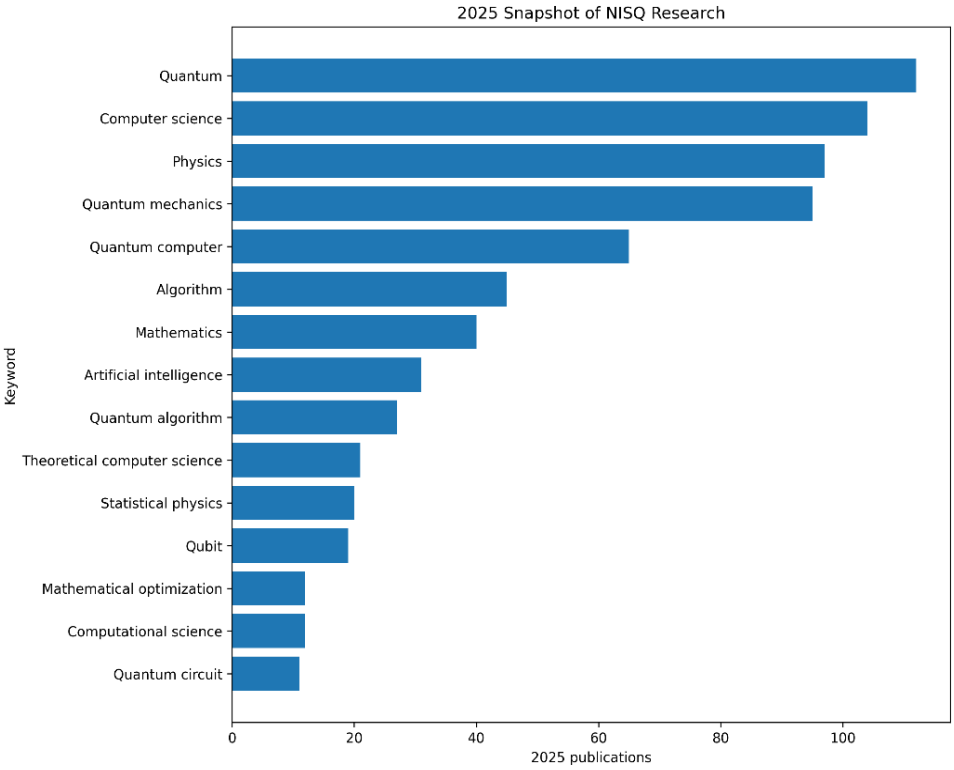


Figure 14: Research Snapshot 2025.

count, publication numbers) reflect mostly research activity and influence rather than individual studies' technical quality or practical contribution. The analysis is useful for providing a broad general sense of the evolution of the field and shifting research areas of NISQ quantum computing, given these limitations.

FUTURE RESEARCH DIRECTIONS

Error mitigation, scalable algorithms, quantum machine learning, benchmarking, hardware-algorithm co-design and practical applications can be considered as areas of NISQ research that can receive more attention in the future. While these are still significant issues, such as noise/decoupling and reducing the number of qubits and circuit depth, it is important to improve the reliability of current quantum systems. However, QML is also anticipated to be an active field, with further effort needed with actual quantum devices, with more data sets and fair comparisons with classical approaches. Common benchmarks enable researchers to compare results across platforms in a common way. Furthermore, additional research can be done on quantum software, testing, compilation and verification as quantum systems grow larger. The application-based research in optimization, chemistry, materials, healthcare, finance and energy can further illustrate where NISQ systems can be helpful. These areas can assist in moving NISQ research out of the realm of possibility to the realm of usefulness and problem solutions.

CONCLUSION

This study presents the growth of NISQ quantum computing research from 2018 to 2025 based on 2,524 publications. The number of publications rose significantly during this time, especially after 2020 with the greatest number of publications in 2022-2023. The research areas of NISQ include quantum algorithms, variational quantum methods, quantum machine learning, optimization, quantum hardware, simulation, software, error control, etc. Over time the research themes have also gotten more varied, reflecting that researchers are tackling research problems related to near-term quantum computing. The variational quantum research, quantum error correction, quantum machine learning, quantum simulation, QAOA, and quantum hardware were all hot topics, evidenced by the hotspot analysis. The analysis of NISQ challenges reveals some of the main problems mentioned in the publications are optimization, decoherence, limited number of qubits, circuit depth and noise. This indicates that research isn't just about new algorithms, but also about the constraints of the existing quantum computers. The United States has the highest number of publications, followed by China, the United Kingdom, Germany, Canada, and Japan. Older publications have been cited more, and recent publications are still gaining in citations as they have a shorter publication lifespan. In the research snapshot 2025, quantum computing is closely related to computer science, physics, quantum mechanics, algorithms, optimization, and artificial intelligence. NISQ quantum computing has thus evolved into a more broadly based

field of study, with algorithm design, hardware, error control, optimization, and machine learning. Meanwhile, other challenges such as noise, decoherence, few qubits and circuit size remain significant issues. Future research has the potential to focus on developing algorithms and circuits with fewer errors, using fewer qubits, developing better hardware and software, and making more practical use of near-term quantum computers.

ABBREVIATIONS

NISQ: Noisy Intermediate-Scale Quantum; **VQAs:** Variational Quantum Algorithms; **QAOA:** Quantum Approximate Optimization Algorithm; **VQE:** Variational Quantum Eigensolver; **QML:** Quantum Machine Learning; **AI:** Artificial Intelligence; **RQ:** Research Question; **DOI:** Digital Object Identifier; **IBM:** International Business Machines; **EPJ:** European Physical Journal; **US:** United States; **CN:** China; **GB:** United Kingdom; **DE:** Germany; **CA:** Canada; **JP:** Japan; **CH:** Switzerland; **ES:** Spain; **IT:** Italy; **NL:** Netherlands; **FR:** France; **AU:** Australia; **AT:** Austria; **SG:** Singapore; **IN:** India; **KR:** South Korea; **RU:** Russia; **PL:** Poland; **DK:** Denmark; **AE:** United Arab Emirates; **FI:** Finland; **USA:** United States of America; **MIT:** Massachusetts Institute of Technology; **ETH:** Swiss Federal Institute of Technology.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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