Narratives from Commercial, Business-Focused, Industrial Reports and Articles on Quantum Technology

ABSTRACT

Quantum technology is a rapidly developing field with potential impacts on several industries. While the discourse on the business and commercial aspects of quantum technology can profoundly affect its development, this domain remains insufficiently examined. Our study uses BERTopic, a new topic modeling method based on transformers that captures word relationships and contexts, to extract and analyze topics from a large corpus of industry reports and papers written in English on the business and commercial aspects of quantum technology. We supplement topic modeling with sentiment and emotion analysis also using transformer-based models for greater insights on the discourse. The analysis shows narratives dominated by a sense of urgency and competition, with terms like "quantum advantage" and "quantum supremacy" being frequently used, and a generally neutral or optimistic tone in sentiment and emotion analysis. While we observe a current lack of effective metaphors and critical perspectives on quantum technology, there are some emerging topics, such as "Quantum Ethics" and "Sustainability Climate Change", that reflect the evolution of the discourse. Our work demonstrates the potential of transformer-based models for content analysis and can inform managers and stakeholders of relevant narratives to make informed, responsible decisions about quantum technology.

Keywords:

Quantum Technology; BERTopic; Narratives; Sentiment Analysis; Business Commercial Sector

INTRODUCTION

Quantum technology is an emerging and promising domain that harnesses the principles of quantum mechanics to advance a broad range of revolutionizing systems and applications, including quantum computing, sensors, and cryptography. Quantum computing constitutes a subset of quantum technology, but it has garnered significant attention, attracted substantial investments from diverse public and private entities, and received extensive coverage by industry reports and commercially focused research papers (Grimm, 2021). One reason for this momentum is a change in our perception of subatomic phenomena, which has led to new ways of processing information: Quantum bits, or qubits, enable computations that are virtually impossible using traditional digital bits (Rietsche, Dremel, Bosch, Steinacker, Meckel, & Leimeister, 2022). Prospective benefits of quantum computing include enhancements in safeguarded communications, simulations, and remote detection. Like the dynamics surrounding technologies grouped as Artificial Intelligence (AI), the commercial potential has led to widespread conjectures about its disruptive influence on various industries and our daily lives (Girasa, 2020). As companies are integrating and driving advances in AI with large datasets and concentrated human talent, corporations such as Google, IBM, and Alibaba are investing billions to develop quantum computing and ecosystems for potential industry use cases, too (Elish & Boyd, 2018; Grimm, 2021). Market intermediaries, especially consulting firms, perform certain crucial functions in establishing markets for AI and quantum computing through industry reports (Elish & Boyd, 2018; Hilkamo, Barbe, Granqvist, & Geurts, 2021).

Given the central role of the commercial industry sector, analyzing the rhetoric promoted by these actors around the development of a certain technology fulfills two functions: First, it provides important insights into its potential trajectory. Second, it also helps managers and

decision-makers to evaluate the relevance of the technology for their industry sector and come up with a potential investment strategy for their organization.

While there has been previous work looking at AI discourse, there has been less attention on the discourse concerning quantum technology, especially with a focus on the business and commercial aspects. In one study by Jenkins, Berente, and Angst (2022), the authors describe the quantum business ecosystem and analyze the strategies that firms are following with regards to quantum computing. While their research offers valuable insights into the characterization of the quantum business environment and firms' objectives, it lacks a deep dive into the narratives dominant in this domain. Also, the study's manual review process and simple word frequency counts may have limitations in terms of efficiency and human bias or errors. Another study by Hilkamo et al. (2021) analyzed only the role of management consultants in shaping the emerging market for quantum computing by attending 8 networking events and manually reading 24 consultancy reports. However, their analysis did not include other relevant documents from the business and commercial field. Besides including more consultancy reports, research articles that examine commercial aspects of quantum technology specifically should be added to the pool of analysis because such publications capture information earlier in the cycle of technology development and the topics covered are most often consistent with those covered in industrial white papers (Cozzens et al., 2010; Mazzei & Ramjattan, 2022). More importantly, instead of using the manual methods as Jenkins et al. (2022) and Hilkano et al. (2021) do, employing computational content analysis using topic modeling and sentiment analyses could efficiently uncover latent narratives in documents and reduce human bias or errors.

To address this evident research gap, we used computational methods to explore how the discussion on quantum technology in industry reports on the one hand and research papers

focused on business and commercial aspects on the other hand is presented to the public. In particular, we used BERTopic, an advanced topic modeling technique leveraging bidirectional encoder representations from transformers (BERT), to capture contexts and semantics in text for more comprehensive insights into narratives (Grootendorst, 2022). Then, we evaluated the sentiments and emotions of each topic and their trends over time with pre-trained, open-source transformer-based models from the HuggingFace library. Through this process, we sought to examine quantum technology overall, beyond just quantum computing, and answer the following research questions:

RQ 1: What kinds of phrasings or narratives do these papers use to describe quantum technology?

RQ 2: What emotions & sentiments do these reports evoke concerning quantum technology?

The remainder of this paper is organized as follows. In the next section, we discuss the relevant literature and past work. In the Methods section, we describe the data collection and analysis procedures used. We present our findings in the Results section. Subsequently, the Discussion section provides a detailed analysis of these results, delves into the limitations of our research, and explores potential avenues for future work. Finally, we conclude by discussing the implications of our paper.

RELATED WORKS

Discourse and Narratives

Narratives wield significant communicative prowess due to their potential to influence audiences' attitudes and behaviors and to convey ideas more comprehensibly than traditional scientific discourse (Braddock & Dillard, 2016; Dahlstrom, 2014; Kreuter et al., 2007).

Dahlstrom (2014) underlines that narratives are an especially useful technique to foster engagement with complex scientific topics. He emphasizes their strong potential to communicate topics beyond the human scale, such as microscopic or astronomical phenomena. Grounded cognition theory posits that human understanding is closely tied to routine experiences and interactions with the physical world, hindering our grasp of topics beyond the human scale. This is particularly relevant for quantum technology, as it leverages the unique, perplexing properties of quantum mechanics, which describe the behavior of energy and matter at atomic to subatomic scales. In this case, narratives could help build an understanding of quantum related subjects. Moreover, Grinbaum (2017) concurs on the usefulness of narratives to convey quantum technology, but asserts that the narratives must provoke an aesthetic perception rather than wonder or strangeness in order to promote public trust. Therefore, the details of how narratives are constructed are substantial factors for effectively communicating quantum technology to the public.

Past research has shown that public discourse and specific narratives can affect the implementation of a technology (Gerhards & Schäfer, 2009; Bareis & Katzenbach, 2022). As part of the public discourse on AI, for example, the business and industry communities play a key role but tend to encourage an overhyped rhetoric beyond the technology's capabilities (Elish & Boyd, 2018). In fact, this tendency notably occurred in the 1980s when AI was in an earlier stage of development. Schuchmann (2019) found that the general industry made incredible claims about AI as part of the effort to commercialize the technology during this time. However, when applications of AI could not meet the overstated expectations, a so-called AI winter began: General disappointment set in, research fundings declined, and several AI companies were shut

down (Elish & Boyd, 2018). As this example shows, rhetoric related to business and commercial aspects of a technology can have considerable consequences on its development.

Topic Modeling

Prior works have applied topic modeling to literature on business, marketing, and industry applications of emerging, transformative technologies. For example, Mustak, Salminen, Plé, and Wirtz (2021) used Latent Dirichlet Allocation (LDA) on articles relevant to AI research and applications in marketing. The capabilities of the newer, advanced BERTopic method on research articles and industry reports from consultancy firms were demonstrated by Mazzei and Ramjattan (2022). Their BERTopic analysis identified the most discussed industry 4.0 applications that machine learning can address, and that the identified applications from academic literature closely aligned with the foci of industry experts.

Topic modeling usage has also expanded into texts related to quantum. For example, Kim and Song (2020) used different topic models on 154 technical articles related to quantum mechanics from phy.org. Their work focuses more on comparing the results of three topic modeling techniques, LDA, Correlated Topic Model (CTM), and Structural Topic Model (STM) on the specific area of quantum mechanics. El Aoun, Li, Khomh, and Openja (2021) used LDA on quantum software engineering related Stack Overflow posts and GitHub posts to uncover the challenges the developer community is facing.

Sentiment Analysis

Sentiment analysis is the process of detecting the attitudes and emotions expressed in natural language text (Zhang & Liu, 2012). Several previous works have used this particular method to investigate narratives in various fields. For example, Macnair and Frank (2018) applied sentiment analysis on prominent Islamic State (IS) media outputs including magazines,

videos, and Twitter posts to discover dominant narratives inherent to online IS media. In addition, LDA topic modeling and sentiment analysis have been combined to study the nature of Twitter discussions on climate change and COVID-19 vaccines (Dahal, Kumar, Li, 2019; Yin, Song, Yang, & Li, 2022). Korneeva, Salge, Teubner, and Antons (2023) used sentiment analysis on indexing terms of articles to deeply examine AI and its legitimacy, which is a crucial form of social evaluation for emerging technologies to gain public acceptance and flourish across new industries. Importantly, past work has shown that legitimacy judgments are created from continuous societal discourse and legitimating framing is commonly correlated with positive sentiments while delegitimating framing is correlated with negative sentiments (Castelló, Etter, & Nielsen, 2015; Etter, Colleoni, Illia, Meggiorin, & D'Eugenio, 2018). Consequently, sentiment analysis is a significant tool to analyze discourse that can uncover the aspect of legitimacy of emerging technologies, such as quantum technology.

At the time of writing, no publications have explored topic modeling, especially with BERTopic, on the narratives and rhetoric in industry reports and research papers focused on the business and commercial aspects of quantum technology. LDA is the commonly preferred method for topic modeling, but the number of topics needs to be known beforehand and the text needs to be preprocessed such as by stemming, lemmatization, and removing stop words and punctuation for optimal results. Even then, LDA is a bag-of-words model, so it struggles at words with multiple meanings because it does not consider the contexts of words. Furthermore, the aforementioned sentiment analysis tools are all lexicon-based. That means they determine the sentiment of a word from pre-built dictionaries, but similarly struggles to consider the context of words. The website of LIWC, the sentiment analysis tool that Korneeva et al. (2023) uses, even

labels itself (along with other sentiment analysis tools that use pre-built dictionaries) as a relatively crude instrument that can make errors on words with multiple meanings.

We have employed BERTopic, a newer topic modeling technique based on transformer embeddings that can capture semantic relationships and context among words without the need to preprocess text. Moreover, we supplemented topic modeling with sentiment and emotion analysis models that leverage RoBERTa (Robustly Optimized BERT Pretraining Approach), which is based on transformers like BERT but is trained on significantly more data, features improved training techniques and hyperparameter optimizations, and performs very well on benchmark tests (Barbieri, Camacho-Collados, Neves, & Espinosa-Anke, 2020; Liu et al., 2019).

METHODOLOGY

Data Sources and Inclusion Criteria

We collected publicly available reports about quantum technology from the websites of the largest 15 consultancy firms by revenue in the world (McCain, 2023). Using the Swisscovery database of the University of St. Gallen, we collected dissertations, published articles, reports, book chapters, and review articles only in English with the search criteria: (*Subject contains "quantum comput*" OR "quantum technolog*" AND Subject contains "business" OR "commercial"*). The search query involves quantum computing because it embodies a particularly notable part of quantum technology. The relevant search timespan is from 1 January 2002 to 31 January 2023 because quantum physicists consider 2002 to be the beginning of the second quantum revolution (Dowling & Milburn, 2003). We skimmed through the keywords, abstracts, and conclusions of each article to determine if they were relevant to our research topic. In the end, we gathered a total of 165 documents.

File Preparations and Cleanup

Each piece of literature collected as a PDF file has different formatting, templates, and additional irrelevant text that can affect content analysis. For instance, some research articles have lengthy acknowledgements or author information listed below the abstract. To remove these parts and focus on the main article for more accurate content analysis, we performed text cleanups by first converting each PDF file into a Word document to remove all headers and footers, acknowledgements, author information, citation notes, glossaries, bibliographies, and appendices in each text document. Lastly, we converted each Word document to a txt file in UTF-8 encoding and used RStudio to perform further text cleaning.

Topic Modeling

To explore hidden topics and narratives in the documents, we applied BERTopic, a topic modeling technique that uses language model embeddings based on transformers, dense clustering algorithms, and class-based Term Frequency- Inverse Document Frequency (c-TF-IDF) scores to generate coherent topics (Grootendorst, 2022). Importantly, the embeddings take into consideration semantic relationships and the contexts of words within a sentence to create higher quality and more interpretable topics. This sets them apart from several previous approaches. However, the pre-trained transformer models that are available for BERTopic are limited in the number of tokens they can process at a time because of runtime and memory resources requirements (Reimers, 2019). Thus, we split each document into individual sentences then passed these sentences into BERTopic. In the end, we obtained a total of 22,005 sentences from the 165 documents.

The first step in the BERTopic algorithm is to select a sentence embedding model. We chose to use the “all-distilroberta-v1” model because of its fast speed, good performance, and maximum sequence length of 512 tokens (Reimers, 2022). This model’s high sequence length

means it is able to successfully embed 512-word pieces in case there are very long sentences in the dataset. Before clustering the topics, we used the Uniform Manifold Approximation and Projection (UMAP) algorithm to reduce the dimensionality of the embeddings because most clustering algorithms perform poorly on high-dimension data. As recommended by Grootendorst (2022b), the creator of BERTopic, we kept the parameters of UMAP at its default values.

Next, we used the Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) algorithm to group similar embeddings without forcing data points into clusters as it takes outliers into consideration. However, depending on its *min_cluster_size* and *min_samples* parameters, HDBSCAN may mistakenly label useful data as outliers leading to either an insufficient number of insightful topics or an excessive number of redundant topics. This issue also arises if the parameters set the algorithm to forcibly minimize outliers and consider potentially irrelevant data in the topic determination process. Under these circumstances, we performed tuning with the *TopicTuner* Python library to find the optimal *min_cluster_size* and *min_samples* parameters from HDBSCAN that obtains a good balance between the number of topics formed and the amount of data discarded. We started with a random search as shown in the top plot in Figure 1 and reviewed the results by manually inspecting each topic and their keywords, as strongly recommended by Grootendorst (2021). We found that a minimum of 70 topics and a maximum of 90 topics was a sensible range for our results; fewer than 70 topics tended to miss interesting topics while greater than 90 topics started to produce redundant ones. After running a refined grid search using this guideline and closely reviewing the results again, we decided to set the parameters *min_cluster_size* to 41 and *min_samples* to 9 for our final result.

Insert Figure 1 about here

The last two components of BERTopic are the c-TF-IDF calculations and the topic representations with *CountVectorizer*. The c-TF-IDF procedure operates on the cluster level to identify the most relevant keywords for each topic based on the keywords' TF-IDF scores. We kept all of the parameters for c-TF-IDF at their defaults, but we customized the topic representations using *CountVectorizer*. First, we set the *ngram_range* parameter to (1,3) so phrases with up to 3 words such as "machine learning" or "quantum artificial intelligence" could display as keywords for a topic. Next, we set the *stop_words* parameter to "English" so that stop words would not appear among the keywords. Lastly, we added a custom function in *CountVectorizer* to exclude the terms "quantum", "quantum computer", "quantum computers", "quantum computing", "quantum technology", and "quantum technologies" from the topic keywords. These terms are all discussed in the texts, so their inclusion does not contribute meaningful insights for topic interpretation.

After setting all the parameters, we obtained the topics along with their top 15 most relevant words. Additionally, we edited BERTopic's *_extract_representative_docs* function to retrieve the 15 most representative sentences for each topic. Upon reviewing each topic's keywords and representative sentences, we assigned titles to the topics and used BERTopic's *merge_topics* function to combine similar topics and eliminate irrelevant ones. The remaining topics are diverse, but most of them focus on similar themes. For instance, Shor's algorithm and particle entanglement are two different topics, but they both deal with technical areas. Accordingly, we grouped the remaining topics under five themes: Monetary, Company & Market Development, Rhetoric, Technical, and Applications.

Sentiment and Emotion Analysis

For sentiment and emotion analysis, we used pre-trained, open-source models available on the website HuggingFace. We chose the "twitter-roberta-base-sentiment-latest" model for sentiment analysis and the "roberta-base-go_emotions" for emotion analysis. Importantly, both models are trained on enormous datasets and contain a neutral label to account for the fact that not all sentences necessarily have strong sentiments or emotions.

The "twitter-roberta-base-sentiment-latest" sentiment analysis model returns a polarity score from 0 to 1 for each sentiment: negative, neutral, and positive. These scores collectively add up to 1. We applied the model to the 15 most representative sentences for each topic, then obtained the average sentiment scores across these sentences for each topic. The "roberta-base-go_emotions" emotion analysis model works very similarly to the sentiment analysis model, but it is trained on the GoEmotions dataset so it returns polarity scores for 28 different emotions: admiration, amusement, anger, annoyance, approval, caring, confusion, curiosity, desire, disappointment, disapproval, disgust, embarrassment, excitement, fear, gratitude, grief, joy, love, nervousness, optimism, pride, realization, relief, remorse, sadness, surprise, and neutral (Demszky, Movshovitz-Attias, Ko, Cowen, Nemade, & Ravi, 2020). We also followed the same procedure as in the sentiment analysis to calculate the average emotion scores across the 15 most representative sentences for each topic, but for brevity, we kept only the top five emotions of each topic instead of all 28. Lastly, we determined the sentiment and emotion scores for each theme by averaging the scores of the topics associated with that theme.

RESULTS

Topic Modeling Results

Following the methodology described in the previous section, BERTopic initially extracted 85 topics. Table 1 shows an example output of two identified topics by BERTopic. The

top 15 keywords along with their c-TF-IDF scores are listed in descending order from highest to lowest c-TF-IDF. Three examples of the top 15 representative sentences of each topic are also included. Furthermore, this table illustrates an example of topics that can be merged due to the striking similarities among their respective keywords and representative sentences. By combining other similar topics and removing outlier topics, we ultimately acquired 51 topics.

Insert Table 1 about here

After the merging process, we identified several topics that featured notable expressions and metaphors, as displayed in Figure 2. These topics include the instigation of businesses to prepare early for quantum, the promotion of sustainable applications of quantum against climate change, and prominent terminology such as “quantum revolution”, “quantum advantage”, “quantum supremacy”, “quantum ethics”, and “magic state factories”. In addition, BERTopic detected two topics, namely “Commercialization Challenges” and “Quantum Ethics”, that express a clear skeptical stance on quantum technology. The critical nature of these topics is evident from their keywords and representative sentences as shown in Table 2. In the same table, these two topics altogether consist of 134 sentences across 35 unique documents.

Insert Figure 2 about here

Insert Table 2 about here

We observed that the topics in our results tend to revolve around similar themes but approach them from different aspects. Table 3 provides a breakdown of the number of topics that

fall under each theme. Additionally, to understand the evolution of these topics, we employed dynamic topic modeling, which tracks a subject over time. The changes in the topics-over-time are visualized in Figure 3 and Figure 4, showcasing trends in each theme.

Insert Table 3 about here

Insert Figure 3 about here

Insert Figure 4 about here

Sentiment & Emotion Analysis

The outcome of the sentiment and emotion analysis for each theme is depicted in Figure 5. Overall, the Monetary theme exhibits the highest positive sentiment score, while the Rhetoric theme registers the most negative. However, all themes predominantly display a neutral sentiment and neutral emotion. The second most expressed emotions are positive: “optimism” and “approval” in all the themes, small bits of “desire” in the Monetary theme and “admiration” in the Technical theme. Only the Rhetoric theme shows a tiny trace of negative emotion: “disapproval”. The remaining emotions—“realization” in all the themes, “confusion” in Applications, and “curiosity” in Company/Market Development—are classified as ambiguous in the GoEmotions dataset paper, but it is crucial to point out that in their dataset, ambiguous emotions are associated with positive sentiments and more likely to occur in the context of positive sentiment than negative sentiment (Demszky et al., 2020). As such, the sole definite negative emotion, “disapproval”, comprises a minor portion in only the Rhetoric theme.

Insert Figure 5 about here

Figure 6 presents the sentiment and emotion analyses over time on every sentence in the dataset. The sentiment and emotion trends are remarkably stable, even when examining the years from 2017 to 2023 in detail. In particular, neutral sentiments and emotions consistently hold the majority, followed by positive sentiments and emotions, while negative sentiments and emotions regularly maintain a low presence.

Insert Figure 6 about here

DISCUSSION

RQ 1: Phrasings and Narratives

BERTopic's topic modeling results reveal the narratives and expressions underlying in commercial, business-focused, industrial reports, and articles on quantum technology. One notably omnipresent narrative is the prodding of companies to engage with quantum and to devise strategies in anticipation of a quantum future as evidently exemplified by topic 17 "Businesses Need to Prepare" in Figure 2 and the representative sentences under topic 15 "Future Progress & Opportunities" in Table 4. A prevailing tactic used to persuade companies lies in the extensive number of topics on quantum technology applications as shown in Table 3. These topics delve into tangible use cases and highlight their various potential business benefits including "Drug Discoveries", "Logistics Optimizations", "Cryptography Security", etc. One interesting topic in this theme that stands out for its recent notable surge in relevance and its unique angle is "Sustainability Climate Change". The topics-over-time plot reveals that "Sustainability Climate Change" has quickly climbed from among the least mentioned topics

before 2021 to the second most frequently mentioned topic in 2022 under Applications. As shown in Table 5, sentences like "*Owing to the advancements in quantum hardware and algorithms, quantum computing and quantum artificial intelligence make promising tools to handle renewable and sustainable energy systems even at larger scales,*" discuss quantum technology's role in addressing climate change and supporting sustainability. Taken together, the "Sustainability Climate Change" topic suggests a novel and recently popular angle to trigger companies to engage with quantum by hinting towards environmental, social, and governance (ESG) goals.

In addition to the Application topics, phrases such as "quantum advantage" and "quantum supremacy" stand out as further examples of potent influential rhetoric. Examining the related sentences that contain these phrases under topic 17 and topic 24 in Table 4 shows their attempted persuasiveness towards action. The sentences from those topics portray "quantum advantage" and "quantum supremacy" as a crucial milestone to be achieved by taking immediate steps in a race before others. It establishes a context of competition for companies – and even nation states. Expressions in topic 17 like "*Business leaders in these first-wave sectors need to develop a quantum strategy quickly or they will be left behind by innovative companies such as Barclays, BASF, BMW, Dow, ExxonMobil, and others that already have taken strategic steps into quantum computing*," specifically name early actors to invoke the fear of falling behind the competition in the new quantum area if unprepared companies do not quickly adopt strategies. The pervasive coverage of quantum technology applications coupled with the strategic infusion of some influential phrases urges enterprises to promptly engage and to avoid losing an early advantage in the quantum field.

Considering that consultancy reports form a sizable portion of our dataset, the creation of a sense of urgency for firms to engage with quantum technology is comparable and quite consistent with the work done by Hilkamo et al. (2021) on how management consultancies perform temporal work in emerging markets like quantum. In their paper, Hilkamo et al. (2021) also identified two other types of temporal work: bringing the future market category into present existence and constructing ambiguity. Correspondingly, our BERTopic results also allude to these narratives of an imminent quantum future and forming ambiguity. For instance, Table 4 shows the representative sentences in topic 18 that express uncertainty on the specific timeline and development of quantum technology. However, our results also indicate that there is more emphasis on the narrative of bringing the future quantum market category into the present. In fact, most of the results that urge corporate engagement with quantum also support the narrative of an imminent reality of quantum computers, thus implying that these two narratives may be complementary. To illustrate, the representative sentences from topics 15 and 24 in Table 4 demarcate quantum computers and their impact as merely years away while at the same time presenting them as an enticing source of competitive advantage for firms. The many Applications topics in our results can also support this narrative of a definite quantum future because they suggest that timing is already ripe for the discussion of a range of possible use-cases.

Furthermore, the topics-over-time plots may even indicate that this dual narrative is becoming more prevalent through two dominant topics: “Cryptography Security” and “New Tech Skills Business”. Since 2020, both topics have witnessed a notable surge in their representation within our dataset, with "Cryptography Security" now holding the top position, and "New Tech Skills Business" ranking as the second most prominent topic. Based on the details in Table 5, the “Cryptography Security” topic advises companies to prepare now for “post-quantum

cryptography" that can protect their data from future quantum computers and algorithms. In the same table, the "New Tech Skills Business" topic already prompts the need for companies to train and understand required skills in their workforce for the incoming quantum future. Overall, our BERTopic analysis generated results that align with the three specific temporal works identified in Hilkamo's study.

In contrast to enthusiastic narratives on quantum technology, "Commercialization Challenges" and "Quantum Ethics" are two topics that are distinctive for their critical viewpoints. As supported by the example sentences in Table 2, "Commercialization Challenges" details the difficulties with commercializing deep technology such as quantum. The problems include insufficient resources and business skills to market and manage the new technology; additionally, companies may hesitate to invest and implement these novel technologies due to risk of failure or low returns. Moreover, the topic "Quantum Ethics" deliberates on the risks associated with quantum technology, but from a different angle of ethical risks. In aggregate, these two topics are scarcely represented in the dataset as they comprise of merely 134 sentences from 35 documents out of a total of 22,005 sentences from 165 documents. This wide disparity implies that readers of this corpus are rather unlikely to encounter critical perspectives on quantum technology. However, the topics-over-time plot indicates a possibly interesting development. While "Commercialization Challenges" has regularly ranked low in topic representation in the past few years, "Quantum Ethics" is a relatively recent topic that emerged only in 2022.

In parallel to discussions of ethical considerations in the field of AI, this could signal a growing awareness and coverage of ethical considerations. For example, one sentence from "Quantum Ethics" in Table 2, "*To be sure of enabling an ethical future for the quantum*

ecosystem, business and technology leaders need to act now," contains the familiar narrative of prodding companies to embrace quantum technology, but it does so by stressing the need to prevent ethical risks. Some of the cautionary perspectives in "Quantum Ethics" are integrated and adapted into a new approach to create incentives for companies to engage with quantum technology. Although the topics with challenging views on quantum technology currently represent a minority of the dataset, the discourse along with the entire quantum field are both constantly evolving. As such, it is possible that more critical views on quantum will emerge, and that some of these viewpoints might be manipulated to construct narratives in unexpected ways.

As part of the technical theme, we found the peculiar metaphor of the "magic state factory", which describes a technique to create "magic states". These "magic states" are quantum states that enable fault-tolerant quantum computing—a highly challenging task but one that enables complex quantum operations (O'Gorman & Campbell, 2017). While metaphors can greatly affect public perception, this one is unlikely to be helpful in building public trust in quantum. According to the guidelines for effective narratives proposed by Grinbaum (2017), powerful expressions like "Schrödinger's cat" can provide an approximate understanding of what is happening, convey a metaphor about the strangeness of quantum, and most importantly invoke emotional appeal. In contrast, "magic state factory" is missing an explanatory story as it relies too much on invoking wonder with the term "magic". In the original paper where the term "magic state" first appeared, the authors included the word "magic" simply because they were surprised there is a specific quantum state that is fault-tolerant and able to do complex operations (Bravyi & Kitaev, 2005). Above all, "magic state" lacks an aesthetical, emotional appeal for the public. Although "magic state factory" may be an intriguing expression, it is inadequate in promoting public understanding and trust. Our analysis with BERTopic on our dataset did not

reveal further metaphors related to quantum technology. This raises the possibility that industry reports and papers concentrating on the business and commercial aspects of quantum technology might not be well-versed in Grinbaum's proposition of utilizing metaphors to enhance public trust or might not prioritize this aspect.

RQ 2: Sentiment and Emotion Analysis

Sentiment and emotion analysis within the data reveals several interesting patterns. First, it is apparent that most topics and sentences exhibit a neutral sentiment. Emotion analysis corroborates this finding, with the “neutral” emotion holding the largest share across topics and sentences. After neutrality, positive sentiments and emotions emerge as the second most common, while negative sentiments and emotions are the least frequently encountered. It is particularly noteworthy that this specific pattern has remained consistent over the years when examining the sentiment and emotions plots over time. It suggests that industry reports and papers focused on commercial aspects of quantum technology have skewed toward neutral and positive illustrations rather than critical considerations.

Several studies have established a correlation between sentiments and technology legitimacy (Castelló et al., 2015; Etter et al., 2018; Markard, Wirth, & Truffer, 2016). Accordingly, the constant low degree of negative sentiments and emotions indicates that there is little risk of quantum technology becoming delegitimized through these reports. In addition, as mentioned in the previous subsection discussing the first research question, there is a miniscule number of skeptical topics from the dataset, so one is less likely to encounter sentences expressing negative sentiments or emotions on quantum technology in the dataset. Thus, the results from the BERTopic analysis also substantiate the low risk of legitimacy loss for quantum technology.

At first glance, it may seem surprising that several sentences with the top negative sentiment scores are associated with the theme of Applications. However, a closer examination reveals that these sentences primarily emphasize the inadequacies and problems posed by current classical computer technologies rather than newer quantum versions, as evident in the data presented in Table 6. Thus, these critical perspectives are by and large not directed towards quantum applications per se but rather critique the limitations of existing technology. Nevertheless, it is important to acknowledge that there are still some sentences highlighting the negatives of quantum technology, including ethical concerns, commercialization challenges, high implementation costs, and lack of resources. Next, the most neutral sentences mostly pertain to technical aspects, aligning with expectations. Lastly, the most positive sentences convey an unmistakable sense of optimism regarding the "potential" and "promises" of quantum technology. Many optimistic scenarios emphasize the efficiency, cost-effectiveness, and superior performance that quantum may deliver over existing technology.

Even amid a dominant neutral sentiment and emotion, there are certain topics containing expressions like "revolution", "advantage, and "supremacy" associated with quantum and suggesting a positive perspective. As explored in the previous research question, these topics constitute the predominant narrative of urging companies to act and prepare for a quantum future. Although most sentences may be written in a neutral tone, there is an underlying framing that consistently fosters a positive outlook on the transformative potential of quantum technology.

Collectively, these findings suggest an overarching narrative: the discussion of shortcomings of currently dominant technologies and challenges serves as a foundation for the introduction and implementation of quantum technology, showcasing how quantum

advancements can address and overcome these problems and thus, paving the way for an ostensibly better future.

Research Limitations

One of the limitations of this study pertains to our dataset and the accessibility of industry research reports, many of which are not freely available and cost enormous amounts of money. Because of this, our study may not include all the existing data from industry research reports on quantum technology. Moreover, we limited our scope of consultancy reports from only the largest 15 firms by revenue. Although this may exclude perspectives from smaller consultancy firms, Phillips, Lawrence, & Hardy (2004) found that texts produced by organizations that are renowned and well-established are more likely to affect public discourse than texts that are not. Future work could take a different direction to compare and contrast the viewpoints of quantum technology from consultancy firms by size, country, or region. One more possible direction is to include articles in languages other than English and analyze quantum technology topics by country or region.

Another limitation is the manual process of reading through the keywords, abstract, and conclusion sections to collect the reports and articles. Here, we followed the approach of some previous works. For example, Mustak et al. (2021) "systematically identified keywords" and then carefully examined titles, abstracts, introductions, and conclusions when collecting their dataset for topic modeling of AI in marketing. Guenduez and Mettler (2023) performed a manual search and prescreening of all documents for their STM of government AI policies. Nimbe, Weyori, & Adekoya (2021) conducted a systematic review of quantum computing models and selected their data by skimming through the titles, abstracts, and keywords. Nevertheless, future

work could incorporate a more automated method such as web-scraping or keyword analysis to increase efficiency and reduce human bias.

CONCLUSION

Our approach to use BERTopic for this study offers a novel and effective method for extracting and analyzing topics from large textual datasets. Its ability to discern intricate narratives and sentiments in the discourse on quantum technology underscores its potential as a powerful tool for deep textual analysis in various domains. Our comprehensive analysis provides valuable insights into the prevailing discourse on quantum technology.

We identified that there is a strong emphasis on urging businesses to prepare for the quantum future. This is complemented by the use of influential rhetoric with terms like "quantum advantage" and "quantum supremacy", which are designed to create a sense of urgency and competition among businesses. While the documents employ a generally neutral or optimistic tone about the potential of quantum technology, there are only few critical perspectives, including around the challenges of commercialization and ethical considerations. Based on this analysis, it appears that the industry reports and papers studied here do less to address potential confusion about application possibilities and more to foster competition and engagement with the technology.

As the field matures, the discourse on quantum technology is evolving, with newer topics like "Quantum Ethics" and novel use cases like Climate Change Applications emerging in recent years. It will be crucial for stakeholders to engage in informed discussions, balancing the potential benefits with the associated challenges and ethical considerations.

On a practical level, our results might help managers and decision-makers to become aware of relevant narratives in one major information pool that follow a certain logic of

encouraging industries and organizations to invest in and move forward with quantum technology applications to stay ahead of the curve. They might also raise awareness about relevant ethical and other impact questions of this rather new technology that managers may be well-advised to take into account in the decision-making process to make sure to implement the technology and its applications responsibly.

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FIGURES AND TABLES

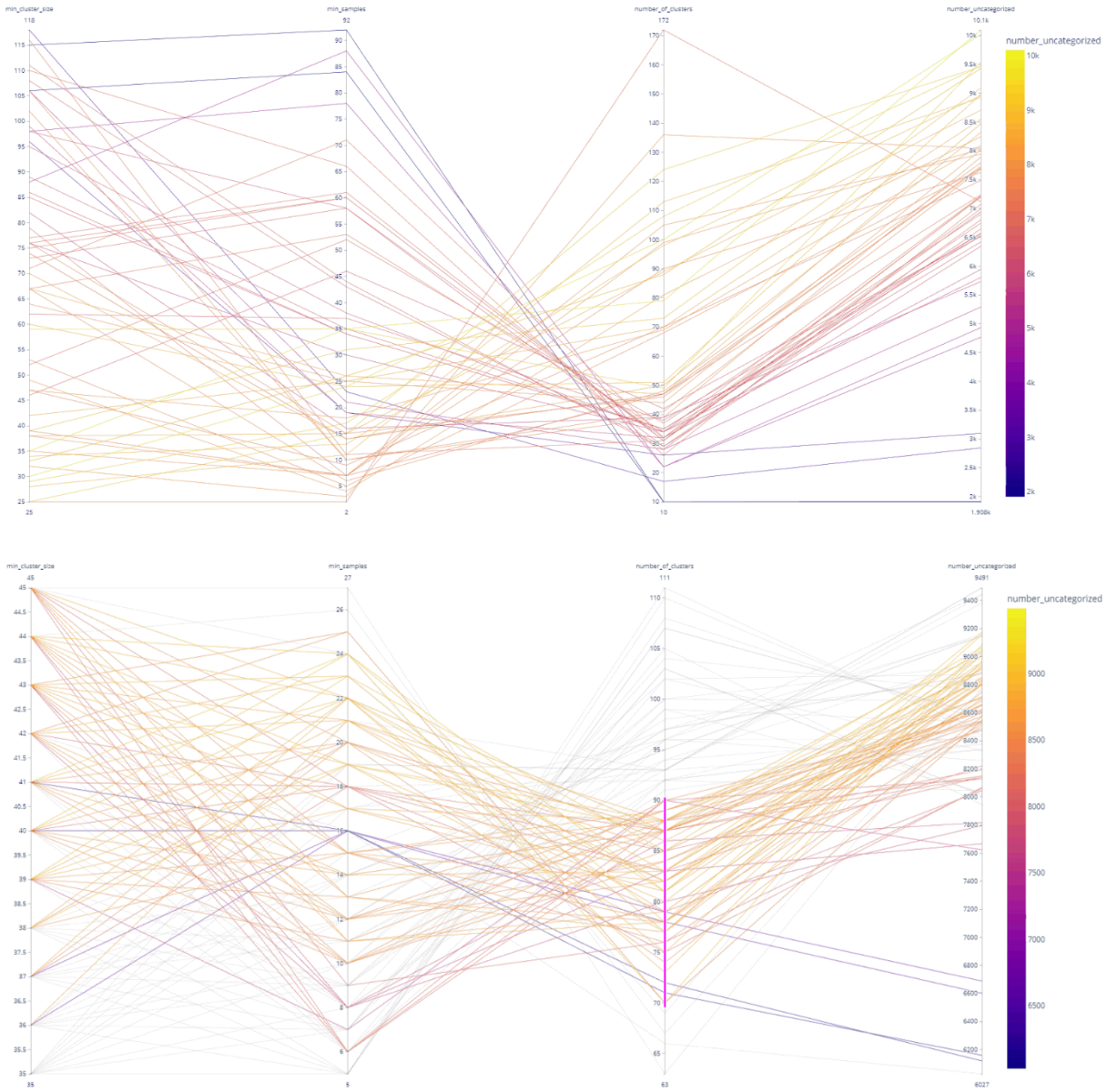


FIGURE 1. **HDBSCAN Parameter Tuning Visualizations from Topic Tuner**. The top graph shows the results of a random search looking through 60 iterations at minimum cluster sizes from 25 to 120 and minimum samples at 10%, 20%, 40%, 60%, 80%, and 100% of the minimum cluster sizes. The bottom graph shows the results of a grid search that is more targeted looking through clusters 35 to 45, samples at 15% to 60% of cluster size. The range from 70 to 90 in the *number_of_clusters* is highlighted because this range tended to produce the most sensible results. *Number_of_clusters* and *number_uncategorized* refer to the number of topics created and the number of sentences treated as outliers, respectively.



FIGURE 2. **Topics with Notable Expressions on Quantum Technology.** The text in bold shows the topic number and manually labeled titles of each topic. The top 15 keywords for each topic are represented as wordclouds with larger text sizes meaning higher c-TF-IDF scores. The topics shown are after the merging process.

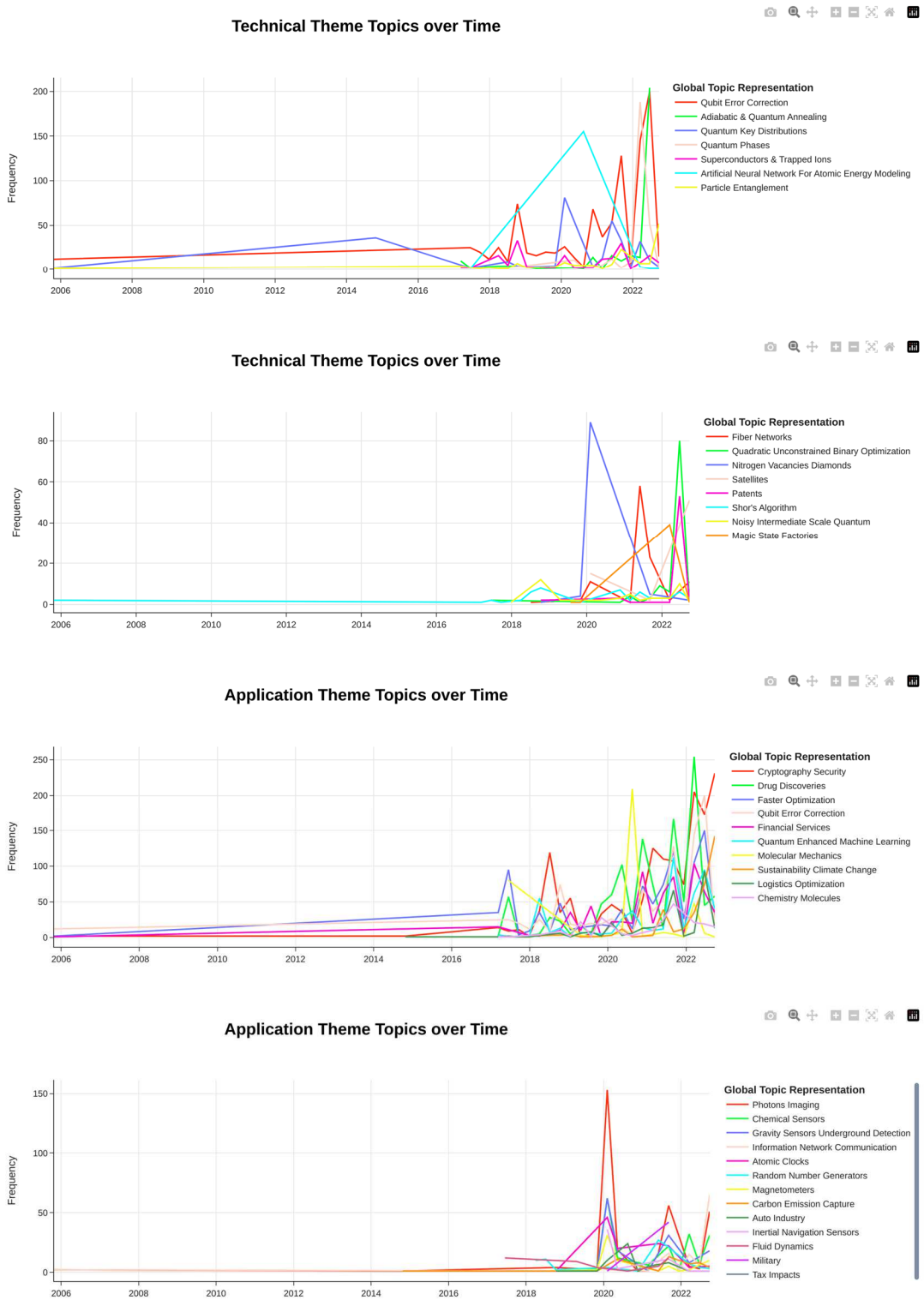


FIGURE 3. **Topics-over-time Plot for Technical and Application Themes.** The frequency of each topic is plotted over the years that span this data corpus. The Application and Technical themes have a large number of topics, so they were both split into two plots to avoid clutter.

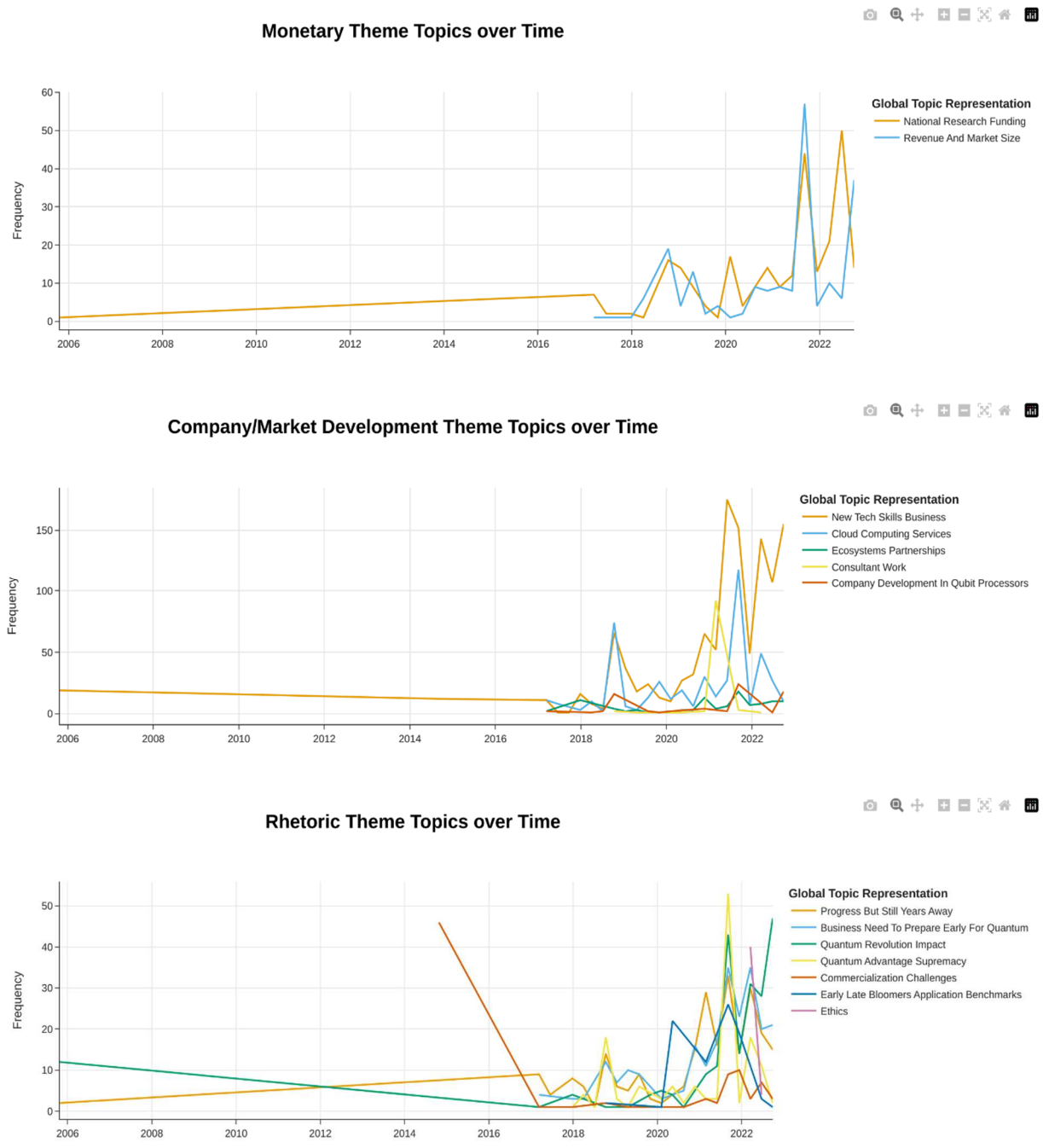


FIGURE 4. **Topics-over-time Plot for Monetary, Company/Market Development, and Rhetoric Themes.** The frequency of each topic is plotted over the years that span this data corpus.

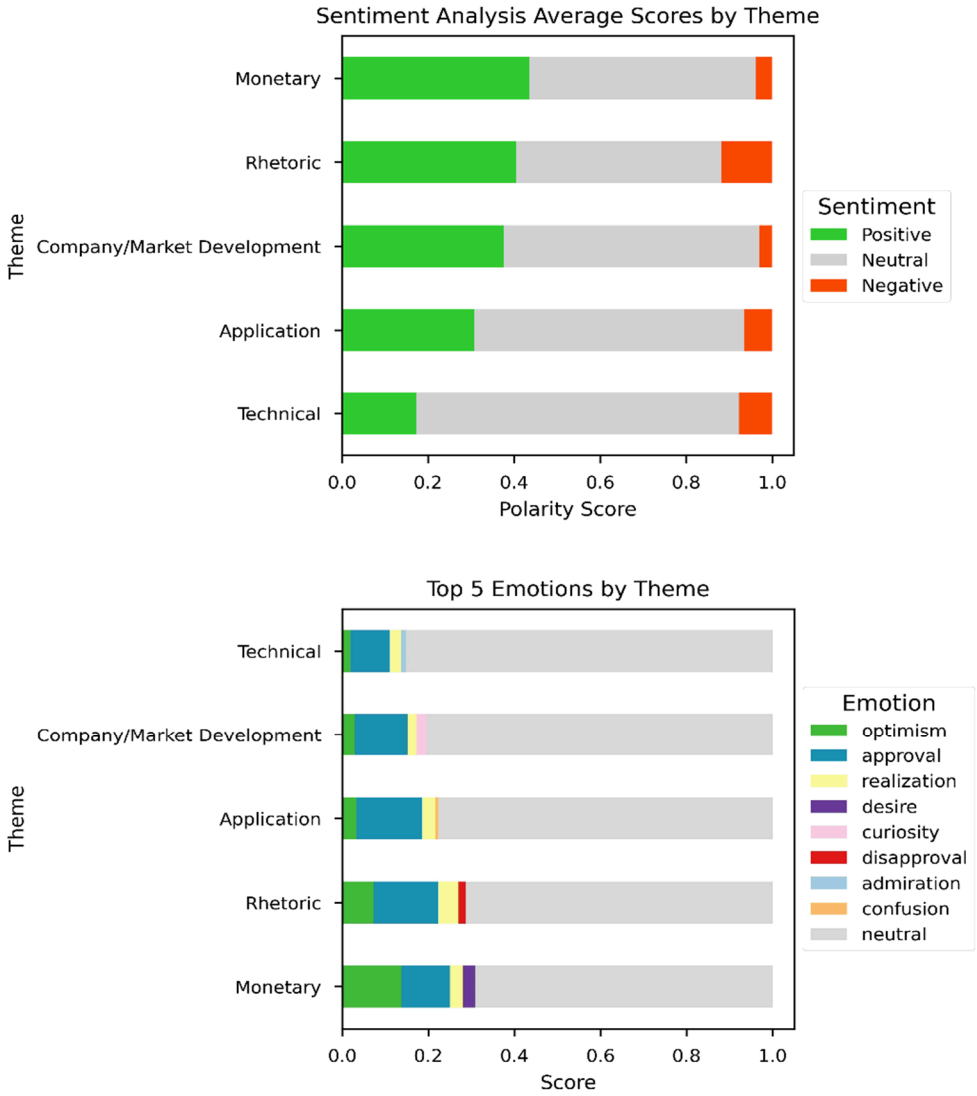


FIGURE 5. **Sentiment and Emotion Scores for each Theme.** The top plot shows the sentiment scores for each theme. The bottom plot shows the top 5 emotions present by score in each theme.

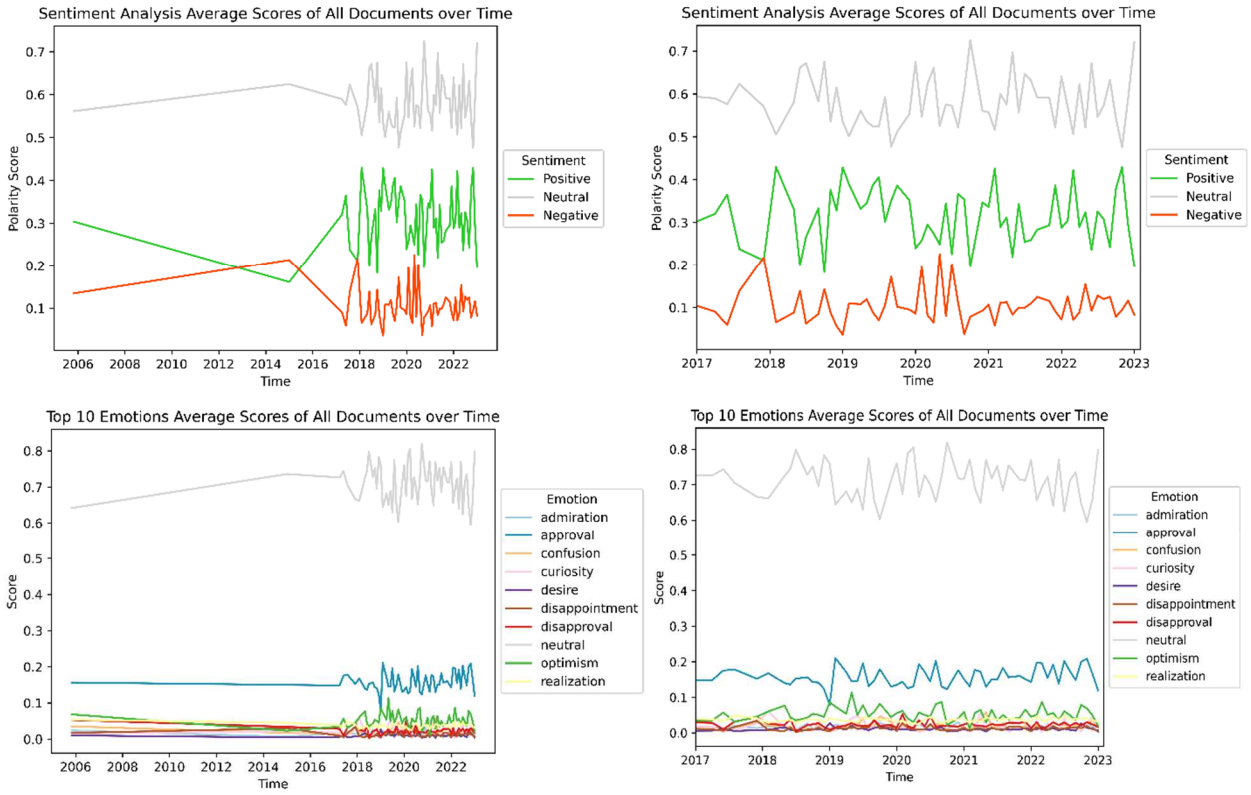


FIGURE 6. **Sentiment and Emotion Scores for all Sentences.** The top plots show the sentiment scores of every sentence in the dataset. The bottom plots show the top 10 emotions scores of every sentence in the dataset. The plots on the right side are zoomed in to the years 2017 to 2023 in order to visualize recent trends more clearly.

9 **FINANCE**	12 **FINANCIAL SERVICES**
Top 15 Keywords	
('financial', 0.0287)	('financial', 0.0284)
('risk', 0.0213)	('risk', 0.0224)
('portfolio', 0.0193)	('portfolio', 0.0195)
('credit', 0.0148)	('trading', 0.0147)
('customer', 0.0134)	('financial services', 0.0135)
('derivatives', 0.0129)	('finance', 0.0134)
('pricing', 0.0100)	('pricing', 0.0125)
('financial institutions', 0.0099)	('services', 0.0112)
('banks', 0.0099)	('optimization', 0.0111)
('institutions', 0.0099)	('portfolio optimization', 0.0102)
('financial services', 0.0097)	('financial industry', 0.0092)
('services', 0.0096)	('management', 0.0081)
('scoring', 0.0093)	('use', 0.0078)

('price', 0.0091)	('industry', 0.0072)
('assets', 0.0086)	('portfolios', 0.0070)
Examples of Representative Sentences	
We explore potential use cases in each of these categories, providing examples that apply to three main industries in financial services: banking, financial markets, and insurance.	Alongside, many leading financial services firms are exploring quantum solutions in the areas of customer need prediction, trading optimization, financial risk management, and quantum safe encryptions.
Today, Monte Carlo simulations— the preferred technique to analyze the impact of risk and uncertainty in financial models— are limited by the scaling of the estimation error.	Quantum computing's specific use cases for banking and financial markets can be classified into three main categories: targeting and prediction, risk profiling, and portfolio optimization.
In this complicated trading landscape, investment managers struggle to incorporate real-life constraints, such as market volatility and customer life-event changes, into portfolio optimization.	First quantum applications for the financial industry involving optimization, simulation, and machine learning problems have already been proposed and applied to use cases such as portfolio management, risk management, and pricing derivatives.

TABLE 1. **An Example of Two Similar Topics that can be Merged.** The numbers on the top row indicate the topic number and the text in uppercase bold are topic titles we labeled after reading through the keywords and representative sentences. The top 15 keywords for each topic are displayed along with their own c-TF-IDF scores, which measures how important a keyword is to the topic. Three examples of the top 15 representative sentences of each topic are shown at the bottom.

Topics	Keywords	Example Sentences	Total Sentences	Unique Documents
Topic 35 Commercialization Challenges	'commercialization', 'market', 'technology', 'lack', 'high technology'	"…the resource challenges of the commercialization process are an inability to acquire and assign resources, inadequate managerial and business skills, and insufficient funds to market the new product."	90	29
		"There is a fear, not unfounded, that companies that make significant investments now carry		

		the risk of backing what turns out to be the wrong technologies…"		
Topic 47 Quantum Ethics	'ethical', 'ethics', 'quantum ethics', 'risks', 'ethical risks'	"In the absence of quantum ethics, quantum-enabled artificial intelligence stands to accelerate ongoing digital ethics pitfalls…."	44	6
		"To be sure of enabling an ethical future for the quantum ecosystem, business and technology leaders need to act now."		

TABLE 2. **Two Topics that Express Critical Viewpoints on Quantum Technology.** The top 5 keywords are listed according to the top 5 c-TF-IDF scores, which are not shown for brevity purposes. The example representative sentences have also been shortened for conciseness.

Themes	Number of Topics
Applications	22
Technical	15
Rhetoric	7
Company & Market Development	5
Monetary	2

TABLE 3. **The Number of Topics Grouped by Theme.**

Topic 15 Future Progress & Opportunities	Topic 17 Businesses Need to Prepare	Topic 18 Quantum Tech Impact Potential	Topic 24 Quantum Advantage Supremacy
As hardware, software, and algorithmic advancements in quantum computing coalesce… new opportunities for advantage will emerge across industries.	Business leaders… need to develop a quantum strategy quickly or they will be left behind by innovative companies such as Barclays, BASF, BMW, Dow, ExxonMobil, and others that already	It is therefore very tempting to just look at the complete range of things we do today with conventional information technology, and to try and do these things better with	While it may sound like a sci-fi dream, experts believe that for a limited number of computing problems, quantum supremacy will be a reality in a matter of years.

	have taken strategic steps into quantum computing.	quantum information technology.	
While broad commercial applications may remain several years away, quantum computing is expected to produce breakthrough products and services that will likely solve very specific business problems within three to five years.	… and subsequently measure Quantum Advantage as your organization moves from early adoption to mainstream quantum computing.	Although the technology is nascent, its impact could be transformative; many key quantum technologies are still in their infancy.	Quantum Supremacy, or Quantum Advantage, will be the next significant milestone that many industry players are hoping to achieve first.
The Quantum Decade will be driven by mounting pressure to solve the biggest business and societal computational problems…	The case is clear, organizations looking to build a first mover advantage and lead the field in years to come should invest in building quantum capabilities today.	The practicality and cost-effectiveness of quantum technologies will determine whether particular quantum technologies are manufactured and deployed.	While attaining Quantum Advantage can take some time, it can still trigger exponential achievements in usage and learning that can benefit your business—and industry—now.
… quantum computing is a perfect candidate for a timeline-accelerating discovery that could come at any point.	Organizations that enhance their classical computing capabilities and aggressively explore the potential for industry transformation will be best positioned to seize Quantum Advantage.	If quantum technology is not yet mature enough for deployment, then are quantum-inspired solutions really a form of quantum technology, or just advanced algorithms?	Quantum supremacy as a concept indicates that a quantum computing based device can provide a solution that no classical computer (even a present-day supercomputer) can feasibly solve… thus affecting every business domain.

TABLE 4. **Representative Sentences from Four Interesting Topics in the Rhetoric Theme.** Some sentences were shortened for conciseness.

Security Cryptography	New Tech Skills Business	Sustainability
"Quantum communications also includes post-quantum	"… quantum computing requires both, highly	"Owing to the advancements in quantum hardware and

cryptography, the development of classical algorithms which can secure our data from future quantum algorithms."	specialized and interdisciplinary skills that bridge different research fields, including engineering, industrialization, and business."	algorithms, quantum computing and quantum artificial intelligence make promising tools to handle renewable and sustainable energy systems even at larger scales."
"... it is critical for businesses to prepare for post-quantum cryptography today that is resistant to attacks by both classical and quantum computers."	"... stakeholders need to know from data-driven measures which, and to what extent, quantum skills, in contrast to more traditional skills, are actually needed…"	"… hold the potential to address climate change as the rapid evolution of quantum computing technologies presents exciting opportunities in renewable and sustainable energy."
"While post-quantum cryptography standards are still being finalized, businesses and other organizations can start preparing today."	"Even a small team of up to three experts may be enough to help an organization explore possible use cases and screen potential strategic investments in quantum computing."	"By considering sustainability at the point of design, businesses have an opportunity to enable a quantum ecosystem that supports our planet, instead of working against it."
"… financial institutions will need to shift their data-security strategies... to drastically reduce the likelihood that it will be broken by a quantum computer"	"... technology adoption in an organization not only requires commitment from the top but also requires relevant technology skills to deliver on a roadmap…."	"We believe that one of the solutions is quantum technology, which offers a range of levers to help societies act on sustainability."

TABLE 5. **Representative Sentences from Recently Trending Topics.** Some sentences were shortened for conciseness.

Negative	Neutral	Positive
Faster Optimization "Optimization problems are notoriously difficult for classical computers…".	Satellites "Provincial company C was the Provincial Power Dispatching Control Center (PPDCC) point and it was the dispatching automation substation."	Future Progress & Opportunities "… quantum computing is a perfect candidate for a timeline-accelerating discovery that could come at any point."
Fluid Dynamics "…simulations are currently hindered by the inability of classical computers to model	Satellites "The RTU (original production system) sends the remote signal	Superconductors & Trapped Ions "Currently two technologies show great promise: superconducting qubits and trapped ions."

fluid behavior on large surfaces…"	and telemetry information…"	
Logistics Optimization "…last mile delivery has only gotten trickier amidst current disruption."	Magnetometers "Magnetometers are frequently used in geophysical surveys to detect changes in the Earth's magnetic field…"	Drug Discoveries "… quantum computing has the potential to significantly improve the pharmaceutical industry's drug discovery process and improve patient outcomes."
Quantum Ethics "In the Global Risks Report 2021, the World Economic Forum identifies the possible adverse outcomes of quantum computing…"	Information Network Communication "This section addresses general considerations on the organization of a Quantum Information Network…"	Financial Services "The most promising use cases for quantum computing are in portfolio and risk management."
Commercialization Challenges "… challenges, including a lack of available or adequate business infrastructure, low market potential, and insufficient business partners."	Atomic Clocks "Initial applications for quantum clocks will include space satellites used for research and commercial use."	Company Development in Qubit Processors "GlobalData is taking a positive stance on Intel's announcement of significant yield and uniformity improvements to their silicon spin qubit devices…"

TABLE 6**. Top 5 Sentences with Highest Negative, Neutral, and Positive Sentiment Scores.** The underlined text is the topic that these sentences come from. Sentences are listed from highest to lowest scores for each corresponding sentiment column. Some sentences are shortened for conciseness.