Exploring the Network and Topic Stability in Climate Change Deniers' Disinformation Network: A Longitudinal Study

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Abstract

This study examines the stability and evolution of network structure and discussion topics among a group of prominent climate change deniers. Focusing on social-mediated information sharing networks, the research addresses two key questions: 1) How stable is the information sharing network among climate change deniers? And 2) do climate change deniers' topic strategies change over time? Using social network analysis, and deep-learning-based natural language models, the study analyzes the stability and structure of climate change deniers' disinformation discourse over a decade. The findings reveal that while the climate change denial network remains stable in terms of size and core group composition, sub-groups continuously emerge and dissolve. Deniers consistently utilized certain topics over the decade. Practical and theoretical implications are also discussed.

Keywords: disinformation networks, climate change denial, network stability, social network analysis, deep learning, natural language processing

1. Introduction

Disinformation networks are a form of coordinated strategic network (IPCC, 2022). Unlike networks formed based on spontaneous relationships, strategic networks are generated to achieve specific goals (Sommerfeldt & Yang, 2017). Some goals are immediate, such as inflating social media metrics to draw public attention to a topic. Other goals are long-term, involving years of coordination and the building and maintenance of stable networks.

Network stability refers to the consistency of both membership and interaction patterns among network members (Oh & Jeon, 2007). Stability is key to achieving long-term goals and for certain members to accrue social influence over time. Additionally, the conceptualization of disinformation networks as strategic networks suggests that the structure of the network is likely to affect the communication strategies generated by such networks. In other words, a stable network is more likely to generate consistent and highly coordinated message strategies that "stay on target" over a long time. Recognizing the importance of stability, this study sets out to understand how stable a disinformation network can be over the course of a decade.

In this study, I apply the concept of network stability to assess whether a persistent network connects climate change deniers. Although years of research have shown that climate change deniers have waged a persistent campaign against climate change science and environmental protection movements and policies (Brulle, 2021; Dunlap & Jacques, 2013; Krange et al., 2019), little has been done to understand their communication strategies on social media. Moreover, in a technological environment that is known for its fast-changing pace, it is unclear if climate change deniers' messages and networks also constantly evolve and change. My focus lies on social-mediated information sharing networks, as platforms like Facebook serve as primary sources of information for a significant portion of the population in many countries (Pew Research, 2021; The Wall Street Journal, 2022). Social media plays a crucial role in the dissemination of disinformation, allowing spreaders of falsehoods to establish powerful networks and expose millions to lies (Yang et al., 2021).

In addition, this study focuses on organizational climate change deniers because previous research suggests that the lion's share of climate change denialism messages is disseminated by a relatively small number of organizations with deep connections to interest groups and oil and gas corporations (Brulle, 2021; Dunlap & Jacques, 2013; Krange et al., 2019). While the number of these organizations may not be large, they exert an outsized impact on public understanding of the climate issue.

The study aims to answer the following key questions: 1) How stable is the information sharing network among climate change deniers? 2) Does the topic strategies of climate change deniers evolve over time?

To address these questions, I draw on recent research on disinformation networks (Giglietto et al., 2020; Keller et al., 2020) as well as social network research on network stability (Friedkin, 1998, 2001; Friedkin et al., 2016; Williams et al., 2021). Furthermore, I incorporate social network analysis to examine network stability (Brewer et al., 2020), and utilize deep-learning-based natural language models (Grootendorst, 2022) to identify disinformation topics. These approaches enable me to examine the evolution

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of network structure and climate change deniers 'disinformation topic strategies over time.

2. Disinformation Networks as Strategic Communication Networks

One common aspect of disinformation campaigns is their strategic nature (Vraga & Bode, 2020). Disinformation campaigns are strategic in the sense that they tend to reflect long-term efforts rather than spontaneous outbursts of information or habitual, mindless sharing behaviors (Marwick & Lewis, 2017). Such campaigns often involve more than one story/post/tweet, and they often pass through synchronized efforts. Some disinformation spreaders take months or even years to fabricate an alternative worldview with twisted, interconnected logics and cultivate networks of supporters who would go on to spontaneously propagate disinformation, form networks around shared beliefs/passions, and even mobilize collective actions, riots, and protests much similar to those of social movements (Krishna, 2017; Rone, 2022; Zhang et al., 2021).

In the long-term process of spinning alternative worldviews and cultivating fervent followers, disinformation spreaders form collaboration networks, some overtly, whereas others may be behind closed doors. The coordinated or spontaneous co-sharing of disinformation between two or more disinformation spreaders can be viewed as a disinformation network. Disinformation networks are key infrastructures that enable disinformation spreaders' harmful impact.

Recent research has documented the widespread presence of disinformation networks (Krafft & Donovan, 2020). For example, studies have found the presence of disinformation networks in elections in the U.S., UK, South Korea, Italy, and Germany (Giglietto et al., 2020; Keller et al., 2020; Linvill & Warren, 2020). Research shows that networks of groups, pages, and accounts coordinate their sharing of political news and articles within a short window of time to boost the visibility of disinformation (Giglietto et al., 2020), influence media agendas (Krafft & Donovan, 2020), and build social media followings (Zhang et al., 2021).

Scholars have consistently identified coordination as a key factor in identifying disingenuous behaviors (Keller et al., 2020; Linvill & Warren, 2020). For example, Keller et al. (2020) noted that on Twitter, coordination occurs in at least three ways: 1) accounts retweeting each other, 2) multiple accounts co-retweeting the exact same third-party message, and 3) different accounts managed by the same team tweeting the same messages seemingly independently. Linvill and Warren (2020) also found that Twitter accounts with known IRA affiliations coordinated their efforts to build an agenda that sows division among US social media users. Krafft and Donovan (2020) found that far-right groups coordinated their efforts to build evidence collages and push disinformation across platforms.

Highly coordinated actors are capable of generating stable networks and consistent messaging (Quintane et al., 2013). Network stability, in turn, ensure long-term coordination and the accomplishment of large-scale strategic goals such as swaying public opinion on issues like climate change. In the section below, I further delve into these concepts.

3. Network Stability in Coordinated Networks

Network stability "represents regularities in the unfolding of social processes within a certain time frame, rather than a static picture of a set of social relations (Quintane et al., 2013, p. 528). Network stability directly affect the longevity of a coordinated network (Oh & Jeon, 2007; Quintane et al., 2013). For disinformation networks that aim to operate long-term and generate lasting impact on public opinions, enhancing network stability is critical to their operation.

The level of network stability is dependent on the extent to which group members sustain interactions. Network scholars such as Burt (2004) emphasize the idea that sustaining network ties over time require considerable resources such as investment of time and efforts. Therefore, for a network to be stable, it must continuously provide members with benefits to ensure its sustainability. Oh and Jeon (2007) identified two such benefits that could contribute to network stability: 1) the network continues to provide opportunities for affiliation or championship; 2) the network provides opportunities to influence others.

Disrupted network stability therefore could affect the level of benefits received by members and undermine their membership status in such networks. In addition, when a network is unstable, the departure of members may create structural holes that weaken information flow or cooperation (Brewer et al., 2020; Butler, 2001). Research also shows that shifts in

network composition pose constant threat a network's social cohesion and thus its performance.

At the same time, maintaining network stability is no easy task for coalitions in general, and it poses a particular challenge for climate change deniers. As I discuss further below, the cluster of climate change deniers encompasses actors with diverse political, ideological, and economic goals (Brulle, 2021; Dunlap & Jacques, 2013; Krange et al., 2019). In order for the network to sustain itself, it needs to offer substantial benefits to these actors. This can include signaling affiliations with valuable allies and/or providing opportunities to influence peers and the public.

4. Research Questions

Although previous research has documented climate change deniers' tendency to form offline disinformation coalitions (Brulle, 2021; Dunlap & Jacques, 2013; Dunlap & McCright, 2011), little research to date has examined the degree to which they build and sustain coalition networks online. More importantly, little is known about how stable such networks are. As discussed in previous sections, to change the public's hearts and minds on major societal issues such as climate change, these deniers may need to play the "long game" and sustain their network over time. Therefore, the following research question is proposed to explore the stability aspect of the network on social media platforms such as Facebook:

RQ1: How stable is the climate change deniers' network on Facebook?

In addition to networks, it is important to understand if and how climate change deniers' discourse strategies have changed over time. In the digital space, communication occurs within networks. The structural tendency of networks is likely to affect the communication patterns and outcomes. In other words, a stable strategic network is likely to generate stable information strategy that consistently propagate similar worldviews to cultivate long-term commitment from followers. In the current context, it is important to ask if climate change deniers adopt new topics as the reality of climate change becomes direr. Or do they stick with the same strategies over a decade? Therefore, I propose the following research question:

RQ2: How did the discourse of climate change deniers evolve over time on Facebook?

5. Methods

5.1. Sample

In order to construct a sample of prominent climate change deniers, I initially compiled notable deniers previously studied in relevant research (Brulle, 2021; Dunlap & Jacques, 2013; Dunlap & McCright, 2011). These previous studies each identified a list of denier organizations and I compiled a comprehensive, non-redundant list based on previous lists. The initial list has over two hundred organizations. Secondly, I conducted a search on Crowdtangle (https://www.crowdtangle.com), a data archive hosted by a Meta-affiliated organization that contains extensive Facebook historical data. Some of the denial organizations do not have Facebook pages and are therefore removed from the sample. The final sample has 96 organizations. Thirdly, I collected data from the Facebook accounts of these climate change deniers using specific keywords derived from credible sources such as NASA (2022) and the United Nations (2022) to describe climate change. The selected keywords included climate, climate change, greenhouse, greenhouse emission, global warming, sea level rise, global temperature, and arctic ice. The search was conducted in December 2022, encompassing the entire account history (with the earliest account dating back to 2009). Overall, the search collected 10 year worth of data (2013-2022).

5.2. Analytic Procedures

5. 2.1. Network stability.

To assess stability over time, I employed the approach proposed by Brewer et al. (2020) using a multi-measure based coefficient of variation. The coefficient of variation, also known as the relative standard deviation, is a widely used method for measuring stability across time (see Brewer et al. for a review). The analysis involved dividing the network into three time periods: 2013-2016, 2017-2019, and 2018-2022. Each period covers a similar time span, with the first period being relatively longer to account for the lower average number of posts per day during that time.

Next, following Brewer et al.'s framework and choices of measures, I selected a number of network measures (see Table 1) to assess stability across various key aspects. These measures were computed for each actor separately within each time period. For each network measure, I calculated the mean and standard deviation across the time periods. The ratio

of the average standard deviation to the average mean across time provides a measure of stability, referred to as the across-time stability (ATS), for that particular network measure. A lower ratio indicates a more stable measure. I then computed the average ATS across the 6 network measures. Finally, I compared the ATS of each network measure to the overall mean across-time stability. If a measure's ATS was lower than the mean, I considered it to have high stability (HI). Conversely, if a measure's ATS was higher than the mean, I categorized it as having low stability (LO) (for details on rationale, see Brewer et al., 2020). I utilized ORA (http://www.casos.cs.cmu.edu/projects/ora/) for the calculation of network measures and *pandas* in Python for stability calculation.

Network Measures	Definition and Application
Total Degree Centrality	How many neighbors a node has. Central nodes have more connections.
Betweenness Centrality	Measures the frequency with which connections must go through a single actor and identifies those actors likely to be most central and influential.
Eigenvector Centrality	Measures the number of node connections to highly connected people. This node-level metric is averaged to provide a network score. An actor well-connected to other well-connected people can spread information quickly and can be critical if rapid communication is needed.
Clique Counts	Extent to which there are small clusters. A higher clique count supports fast localized information diffusion.
Triad Counts	Another measure for the number of clusters.
Node Count	Total number of nodes in the network. Defines the size of the network.

Table 1. Definitions of the 6 Network Metrics used in this study.

5. 2. 2. Deep-learning-based topic modeling.

To analyze the topics of the messages posted by climate change deniers, this study utilizes the state-of-the-art BERTopic algorithm, which leverages deep learning capabilities in Natural Language Processing (NLP) (Grootendorst, 2022). BERTopic incorporates transformers and a class-based TF-IDF to generate dense clusters, enabling the creation of easily interpretable topics. It supports various modes of topic modeling, including guided, supervised, semi-supervised, manual, long-document, hierarchical, class-based, dynamic, and online topic modeling (Grootendorst, 2022, p. 1). Notably, BERTopic has consistently outperformed traditional NLP models like Latent Dirichlet Allocation (LDA) on short texts, such as social media posts, as demonstrated by previous research (de Groot et al., 2022).

In this study, the "*bertopic*" package in Python was employed to analyze how topics evolve over time. After the initial model predictions, I manually reviewed and corrected some potentially questionable topic classifications. These manual corrections were incorporated into the final models to ensure reliable results. Overall, the analysis adopt a semi-supervised approach towards topic classification.

6. Results

RQ1 explores the stability of the climate change deniers' network. To assess network stability, I calculated key measures for the deniers' network at three different time periods. The first network consisted of 75 actors (density = 0.045), the second had 79 actors (density = 0.039), and the third had 73 actors (density = 0.035). None of these networks had isolates, and there were 69 actors that appeared in all three networks. Table 2 presents the stability measures. Stability is a multidimensional concept in network analysis (Brewer et al., 2020). In this study, I assess stability both in terms of prominent actors and small groups. Among these measures, total degree centrality, eigenvector centrality, and betweenness centrality indicate how network ties are concentrated around highly connected elites. Both total degree centrality and eigenvector centrality demonstrated significant stability. However, betweenness centrality, which examines the frequency with which ties must pass through a single actor, was found to be unstable. A closer examination of the trends revealed a decline in betweenness centrality over time.

Network Measures	Time 1		Time 2		Time3		ATS	ATS Stable
	Mean	SD	Mean	SD	Mean	SD		
Total Degree Centrality	.032	.030	.027	.025	.022	.025	.987	High Stability
Eigenvector Centrality	.035	.070	.022	.054	.014	.054	2.507	High Stability
Betweenness Centrality	.009	.019	.004	.010	.001	.010	2.785	Low Stability
Clique Counts	.400	1.039	.265	.728	.205	.728	2.867	Low Stability
Triad Counts	.800	2.404	.949	2.985	.205	2.984	4.286	Low Stability
Node Count	75	-	79	-	73	-	-	-

Table 2. The disinformation sharing network metrics, mean, standard deviation, and results of across time stability (ATS) calculations.

Both triad counts and clique counts indicate the number of small groups within the network. Previous studies (Brewer et al., 2020; Effken et al., 2013) have suggested that a high number of small groups in a network can lead to fragmentation and reduced interactions across the whole network. The analysis

showed low stability for these measures, indicating that the small groups within the climate change deniers' network fluctuate over time.

In summary, the analysis reveals that the climate change denier network exhibits high stability in terms of its core leaders. The overall size of the network also remains relatively stable over time. However, dynamics at the sub-group level within the network fluctuate, suggesting the formation and dissolution of different clusters within the larger network.

RQ2 explores how the discourse of climate change deniers evolves over time. The Bertopic model initially identified 128 topics based on pre-trained embeddings. After manual correction, the model reduced the predictions to 41 topics.

Furthermore, a dynamic topic analysis revealed that among the most prominent topics, while some topics exhibited fluctuations in message frequency, certain topics persisted consistently throughout the sampled years. For instance, topics such as the harmful impact of environmental policies and treaties (topic 0), the economic cost of renewable energies (topic 1), and the smearing of political oppositions (topic 2) were frequently discussed over the decade. In terms of audience engagement, the analysis indicated that the top 10 topics and topic 21 (Kathleen Hartnett White) consistently received exceptional engagement outcomes, suggesting their enduring popularity among followers of these disinformation accounts (see Figure 1). Additionally, to comprehend the major dimensions of these topics, I conducted multi-dimensional scaling analysis based on the cosine distance of each topic. Figure 2 illustrates these major topics.

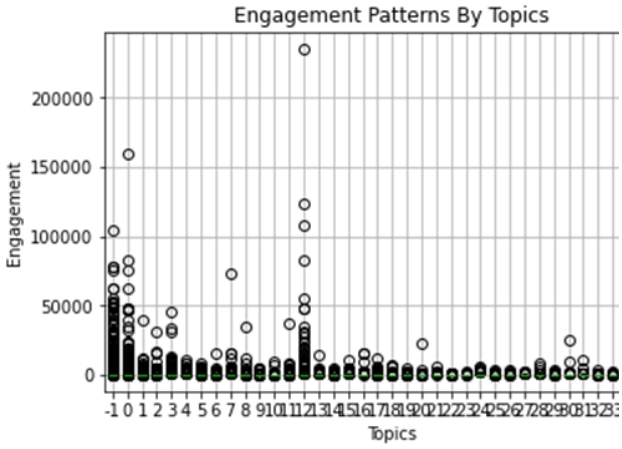
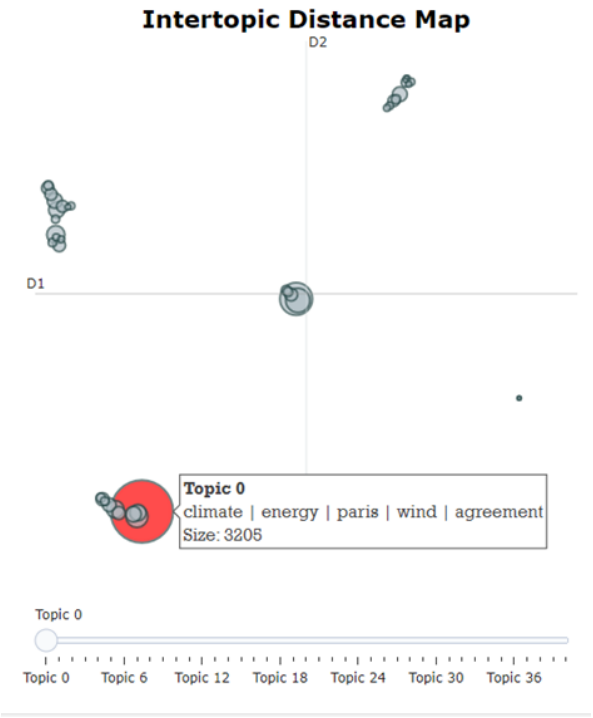


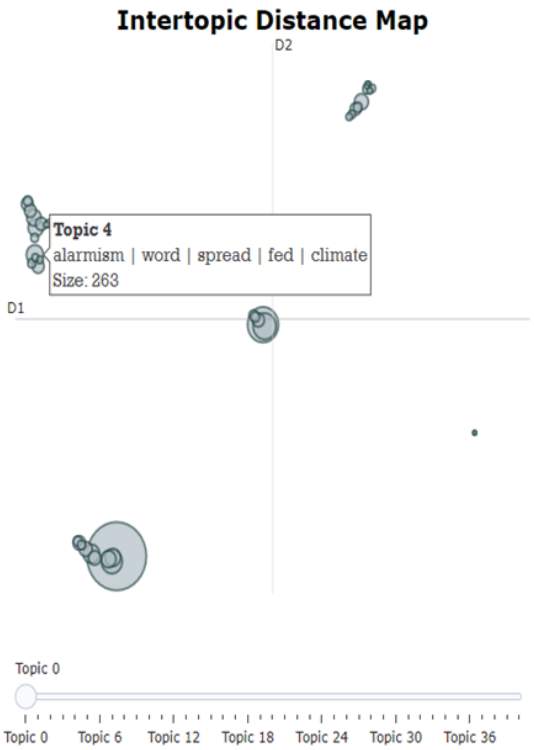
Figure 1. Engagement patterns over time per topic.

Dimension 1



Dimension 2

Dimension 3



Dimension 4

Figure 2. Inter-topic distance and representative topics from each cluster.

Overall, the analysis revealed that the most prominent topics in climate change deniers' posts remain consistent over a decade, and these topics consistently achieve exceptional engagement outcomes compared to other topics. The analysis identified four dimensions of topics (see Figure 6): social and economic harm of environmental policies, attacks on (political or religious) oppositions, questioning of climate change science, and national and economic values of traditional energy sources.

7. Discussion

7.1. Theoretical and practical implications

When we look at the history of climate change deniers, in 1973, when Joseph Coors funded the conservative think tank Heritage Foundation, he was looking for weapons to win the "war of ideas" against progressive thoughts and movements (Dunlap & Jacques, 2013). Half a century later, the study shows that a disinformation network in which Coors' foundation participates is likely to be a powerful weapon to politicize the issue of climate change, muddy the waters of public understanding of science, and may have contributed to the delay of policies and collective actions aimed at addressing climate change (IPCC, 2022).

The disinformation network is highly stable and resilient. Its core group of leaders has consistently been present over the decade. Meanwhile, the dynamics at the sub-group level are much more volatile, suggesting a lack of persistent existence for small clusters. Taken together, these stability measures reveal a highly centralized and coordinated network, where elites hold a highly central and visible position, while small clusters do not last long enough to undermine cross-network interactions and coordination.

This highly stable network structure and the lack of diverting sub-groups likely contribute to consistency in terms of deniers' topic strategies. The analysis shown that, over the decade, climate change deniers may discuss a wide range of topics, but the most frequently discussed ones remained highly stable and consistent. Furthermore, these highly stable topics were exceptionally engaging, outperforming most other topics in generating public engagement. The consistent choice of highly engaging topics over such a long period of time is unlikely to happen by chance but rather reflects deliberate choices of topics and strategic coordination

to ensure the consistent deployment of messaging strategies in communication campaigns.

As noted by previous scholars (Oh & Jeon, 2007; Quintane et al., 2013), for a network to stay stable over time, it needs to provide substantial benefits to its members. Consistency in messaging is likely one such benefit that ensures stability among disinformation spreaders. Future studies should examine if such patterns exist in other disinformation campaigns, and interventions could target messaging consistencies as a way to disrupt disinformation networks.

Another important contribution of this study is its emphasis on long-term dynamics in disinformation networks. A longitudinal perspective is critical for understanding the impact of disinformation. This is because, unlike misinformation that comes and goes without a clear strategy and purpose (Marwick & Lewis, 2017), the highly stable and persistent disinformation shared by networks of disinformation spreaders may have a unique and lasting impact. To assess such lasting impact and understand how disinformation spreaders achieve their long-term goals, it is necessary to study how their networks and communication strategies evolve over time. Future studies may also explore how repeated exposure to such disinformation over time affects audiences' perceptions of scientific facts or political realities. The long-term impact may be essential in terms of forming twisted worldviews and creating extremist communities.

The study also underscores the importance of the network approach in disinformation research. The analysis echoes previous research on disinformation networks and demonstrates that coordination is pervasive within these networks (Giglietto et al., 2020; Keller et al., 2020). Additionally, this study extends previous studies that focused on a single time period and shows that not only do disinformation spreaders coordinate, but their coordination networks are highly stable and organized, resembling those of organized crime clusters.

7. 2. Limitations and future research

This study has limitations that could be further strengthened through future research. For instance, in terms of communication strategies, the study primarily concentrates on topic stability as an indicator. While this approach effectively utilizes topic modeling, it does not provide a more detailed understanding of communication strategies at the whole-text level. Future studies could incorporate deep learning techniques to identify additional textual features. Moreover, researchers may consider employing a mixed-method approach, combining rhetorical studies with computational methods to explore more nuanced insights.

Secondly, the study primarily focuses on climate change deniers as a group responsible for spreading disinformation. It remains unclear whether the findings revealed in the current study can be generalized to other contexts, such as political disinformation. Therefore, future studies should also examine other types of disinformation networks and investigate the stability of such networks in a broader context.

Finally, the study focuses on networks among climate change deniers and therefore does not explore if climate change deniers also connect with other conspiracy theorists such as Flat Earthers or anti-vaxxers. Future studies may map the connections among disinformation spreaders to understand the ecology of disinformation and how conspiracy theories may relate to one another.

8. Conclusion

The study sets out to explore the dynamics of network stability within a group of climate change deniers. The analysis revealed a strikingly stable disinformation-sharing network that existed among a group of prominent climate change deniers and persisted over a decade. This disinformation network also retained highly consistent topic strategies. These findings highlight the importance of viewing and understanding disinformation networks as long-term oriented, strategic networks. In addition, efforts to understand their operation and potential impact should also adopt a longitudinal approach and carefully consider the cumulative effects.

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