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EDITED BY
Anders Hansen,
University of Leicester, United Kingdom

REVIEWED BY
Robin Tschötschel,
University of Hamburg, Germany
Douglas Ashwell,
Massey University Business School, New Zealand

*CORRESPONDENCE
Florian Meier
✉ fmeier@ikp.aau.dk

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Topic modeling three decades of climate change news in Denmark

Florian Meier* and Mikkel Fugl Eskjær

Department of Communication and Psychology, Aalborg University, Copenhagen, Denmark

Climate change is a dynamic and rapidly evolving media agenda. First associated with scientific notions of the greenhouse effect, it was later presented as global warming before reaching the current and broader picture of climate change. Over its development, climate change reporting has touched on a broad range of topics reflecting shifting scientific understandings, political interventions, and public anxieties, all of which condition the public's view and actions on climate change. To better understand which issues the Danish public has been exposed to, this study uses topic modeling to analyse 32 years of climate change communication in Denmark (1990–2021, n = 63,743). It identifies 85 topics grouped into 14 themes dealing with climate change in Danish national media outlets. Topics differ in prevalence and longitudinal stability while reflecting outlet bias in political leaning and communicative modalities. The most pronounced differences in climate change reporting are between public service media and traditional newspapers. This indicates that media users relying mainly on online news from public service providers, without additional access to print media, will receive information on climate change that is more topical and less politicized, more thematic and less structural, more about high-level politics than everyday interventions and more concerned with consequences than solutions.

KEYWORDS

climate change, news media, topic modeling, content analysis, outlet bias

1 Introduction

Over the last decades, climate change (CC) reporting has become a permanent news topic, demanding considerable public attention. It reflects the increasing urgency of the climate crisis (UNFCC, 2023) and the importance of public communication in raising awareness and public support for climate policies (Moser and Dilling, 2011). It has also proven to be one of the most dynamic and rapidly evolving media agendas. First associated with the scientific notion of the greenhouse effect, it was later presented as global warming before reaching the current and broader picture of climate change (Gardiner, 2004). As with most media agendas, climate change reporting has fluctuated since its first appearance (Boykoff et al., 2023). Frequently it has been following the ebb and flow of international climate change events in science (e.g., IPCC reports) and politics (e.g., COP meetings) or driven by natural disasters associated with climate change (e.g., floodings and wildfires). Climate change has defied traditional notions of "attention cycles" (Downs, 1972) and remained a constant fixture on the news agenda for over three decades. The intensity has gone up and down, but the climate agenda has never entered a post-problem stage with only "spasmodic recurrences of interest" (Downs, 1972, p. 40). It reflects the irreversible and increasing urgency of climate change and the progress in scientific understanding of changes to the Earth system caused by global warming.

As a constantly evolving news agenda, climate change reporting reflects changes in the media landscape and technology. Increasingly climate change reporting has become

digitized and digital. It has consequently found new media outlets and distribution platforms. Climate change reporting has sometimes migrated from printed and electronic press to entirely new digital (native) platforms (Painter, 2017). As such, climate change reporting reflects the complex interactions of public, political, editorial, and real-life agendas (Dearing and Rogers, 1996) regarding the accelerating climate crisis (Wonneberger and Vliegenthart, 2021). The digital development also offers new means to study climate change reporting (Schäfer and Hase, 2023). Computational methods have entered the methodological toolbox in the humanities and social sciences, representing a "new chapter" in content analysis that also provides different new approaches to researching environmental communication (Mohr and Bogdanov, 2013).

The present study uses topic modeling, a form of unsupervised machine learning (Blei, 2012; Roberts et al., 2014), to analyse 32 years of Danish climate change communication based on a corpus of articles in seven national dailies since 1990 and all online CC news from two public service corporations since 2006 (n = 63,743). Recent publications have emphasized that studies of public climate change communication in small language regions extend the range of the literature by including findings outside the anglosphere (Chen et al., 2021). Denmark shares several characteristics with other Scandinavian and Northern European countries regarding the media system and political, cultural, and public climate change perceptions. It belongs to a group of so-called small European states (Katzenstein, 1985) that have cultivated a tradition of political consensus on systemic challenges like climate change. Consequently, there is little political disagreement about climate science and the anthropogenic causes of climate change. Public perception of climate change as "the single most serious problem facing the world" is shared with most Nordic and Northern European countries (Eurobarometer, 2022b). Finally, along with the other Nordic countries, Denmark is a quintessential example of the Democratic-Corporatist media system (Hallin and Mancini, 2004), which dominates Northern European media and a handful of post-1989 Eastern European countries (Herrero et al., 2017). Our study aims to uncover how such a comprehensive media agenda develops over time and to detect variations between different news dimensions, media formats, and ideological orientations, which condition public information on climate change. We focus on two aspects: first, as ideological variation is to be expected in the press, and as observed in other countries (Bohr, 2020), we want to know to what degree it influences climate change reporting in terms of topic salience and editorial priorities. Second, as media users migrate online, it is imperative to know whether online news, especially public broadcast corporations (Cushion, 2022), which rank 4th and 5th on the list of most visited websites in Denmark (Similarweb, 2023), present a similar level of climate change reporting as print media.

Our model finds 85 coherent topics ranging from hard news like Economic Growth (#60) to soft news like Literature (#47). Time series analyses show that the climate change agenda has fluctuated over the last three decades and that the media is responding to the urgency of the climate crises. Topics concerning solutions to climate change are increasingly replacing topics relating to causes of and scientific controversies about anthropogenic climate change. Moreover, while partisan bias in newspaper outlets is measurable concerning specific topics, the effect is usually limited. However, our results indicate that media users relying mainly on online news from public service providers, without additional access to other media, will receive information on climate change that is more topical and less politicized, more thematic and less structural (Iyengar, 1996), more about high-level politics than everyday interventions and more concerned with consequences than solutions.

2 Related work: automated content analysis of climate news

Measuring media coverage of climate change has been a stable preoccupation of environmental communication (Schäfer and Schlichting, 2014; Hansen, 2018; Schäfer and Painter, 2021; Guenther et al., 2023). Traditionally, this research field has been dominated by agenda-setting studies (Shanahan, 2017) or framing studies (Schäfer and O'Neill, 2017) mostly in combination with quantitative or qualitative content analysis (Metag, 2016). In the former, manual coding has been the preferred methodological strategy to document media attention and the development of the climate change agenda (Mahl and Guenther, 2023). Early studies frequently revolved around climate science communication, specifically addressing how multifaceted scientific concepts are conveyed to the public. These investigations delved into aspects like framing climate-related risks, depicting scientific uncertainty, and the evolution of climate change from a scientific matter to a societal concern. Later, studies using content analysis turned to text mining strategies to search large databases for keywords, collocations, and co-occurrences in relation to climate change and the environment (Barkemeyer et al., 2018). These studies provide temporal overviews, mainly about the development of a single topic or the distribution of media-specific variables such as news categories, genres, or sources (Holt and Barkemeyer, 2012). More recently, a growing number of studies have turned to automated content analysis, like topic modeling, to investigate climate change communication (Vu et al., 2019; Bohr, 2020; Keller et al., 2020; Hase et al., 2021). This section primarily focuses on contributions to this body of research.

Table 1 compares recent studies of climate science communication and how topics and themes are distributed in relation to sample size and time frames. It is based on a purpose sample to list the most relevant related work and to illustrate variations in research strategies concerning climate change communication (including science communication and micro-blogging). Topic modeling typically identifies a larger number of topics compared to investigations that use manual coding. Some studies find more than 100 topics (Boussalis et al., 2016). Since "topics encapsulate and delineate what might be called the themes of the corpus" (Murakami et al., 2017, p. 254), it is common practice to cluster topics into larger categories, sometimes called overarching categories (Sietsma et al., 2021), meta-topics (Boussalis et al., 2016), or just themes (Keller et al., 2020; Hase et al., 2021). While topic modeling in principle is language agnostic, most studies favor high-resource languages like English. In a Nordic

TABLE 1 Topics, themes, sample size and time frame of selected topic model studies on climate communication.

Study	Topics	Themes	Avg. topics per theme	Sample size	Time frame
Boussalis et al. (2016)	100	23	4.3	11,131	2000–2014
Bohr (2020)	28	0	–	78,599	1997–2017
Keller et al. (2020)	28	4	7.0	18,223	1997–2016
Hase et al. (2021)	46	7	6.6	71,674	2006-2018
Sietsma et al. (2021)	104	16	6.5	62,191	1988–2020
Vu et al. (2019)	45	0	–	37,670	2011–2015
Present study	85	14	7.7	63,743	1990-2021

and Scandinavian context, some longitudinal studies of climate change reporting exist (Lyytimäki and Tapio, 2009; Shehata and Hopmann, 2012), however, none of them focus on Denmark, and the use of computational methods, especially topic modeling, which can help in distant-reading thousands of documents, has been modest (Chen et al., 2021; Vikström et al., 2023). Our first research question addresses this gap in the literature:

RQ1: What are the dominating topics and themes in 30+ years of Danish media coverage of climate change?

The potential for longitudinal research is evident, given the method's ability to handle a large text corpus (see Table 1). The time span of most studies varies between 10 and 20 years (Bohr, 2020; Keller et al., 2020). Apart from documenting similar fluctuations in climate change reporting around the world (Hase et al., 2021), these studies also find media attention driven by trigger events like COP meetings. Longitudinal studies furthermore map topic development. Some studies find that environmental issues have become more prominent, reflecting the increasingly adverse impact of climate change (Keller et al., 2020). The ability to do longitudinal investigations mainly depends on data access and how far data archives go back in time (Boussalis et al., 2016). This study draws on a database that includes almost all Danish news outlets going back to 1990. It consequently offers reliable data for more than three decades. We ask:

RQ2: How have topics and themes developed over time?

So far, topic modeling of climate change reporting has mostly been concerned with identifying frequencies and variations of topics and themes and their temporal development (Rabitz et al., 2021; Song et al., 2022). However, topic modeling also lends itself to more structural dimensions. Structural topic modeling (STM) constructs a model that incorporates document-level information. Such a model can help improve topic estimation by enabling "researchers to encode the ways topic prevalence and content varies across documents based on the document's characteristics, or metadata" (Grimmer et al., 2022, p. 252). This includes variations in the political leaning of different media outlets, but also variations between different media types, for instance between newspapers and online news provided by public service corporations.

Content analyses often use news media's political or ideological orientation as an independent variable or predictor of content variation (Schmid-Petri, 2017). It tends to reveal important differences in media attention and news framing of climate change across the political spectrum (Carvalho and Burgess, 2005; Boykoff and Boykoff, 2007). Ideological orientation of news outlets has been shown to contribute to political polarization and consensus building in relation to climate change (Tschötschel, 2023). Structural topic modeling allows for similar considerations, although few studies have done that (Bohr, 2020). Previous research has shown that ideological orientation influences editorial priorities, resulting in outlet bias across the political spectrum. A topic model of 52 US newspapers by Bohr (2020) finds that liberal papers favor topics on climate impact, whereas conservative papers give outsized attention to climate regulations. It confirms earlier studies showing that US mainstream media are more likely to report climate change as a crisis compared to conservative media outlets (Parks, 2020).

We have sampled all Danish national newspapers currently in print circulation, as well as two public service corporations. Thus, our sample covers ideological diversity as well as different types of media outlets. Nordic media systems are heterogenous in terms of political parallelism (Hallin and Mancini, 2004; Curran et al., 2009). Print media reflect a tradition of external pluralism as newspapers used to be affiliated with political parties. National newspapers are consequently positioned on a classical right-left political scale. Public service media on the other hand are marked by (a legislative guaranteed) internal pluralism and obliged to stay politically neutral. Based on these distinctions, we ask:

RQ3: To what extent are topics and themes reflecting ideological differences in the press?

Topic modeling provides a comprehensive picture of thematic variations in climate change communication. However, most studies typically investigate only single media formats like micro-blogs (Qiao and Williams, 2021; Sanford et al., 2021), web pages (Adam et al., 2020), blogs (Lörcher and Taddicken, 2017; Coan et al., 2021), and print media (Song et al., 2022). Following recent recommendations (Mahl and Guenther, 2023) our study draws on data from several media formats. Our sample consists of climate change reporting in quality news and tabloids (print and online) as well as news from public broadcast corporations (online). It allows us to investigate variations across different media types. Whereas traditional news media produce print news and digitized news for online consumption, public broadcast corporations produce

TABLE 2 Main characteristics of the news outlets in our sample.

News outlet	Type	Political orientation	Article count
Berlingske	Newspaper	center-right	11,732
DR.dk	PBS	Neutral	2,982
Ekstrabladet	Tabloid	center-left	2,752
Information	Newspaper	center-left	7,806
Jyllandsposten	Newspaper	center-right	13,716
Kristeligt Dagblad	Newspaper	center-right	6,016
Politiken	Newspaper	center-left	12,617
TV2.dk	PBS	Neutral	3,820
Weekendavisen	Newspaper	center-right	2,302

online only news. Given that the latter are among the most visited Danish web sites (Similarweb, 2023), ranked respectively fourth (dr.dk) and fifth (tv2.dk), we are interested in exploring whether newspapers differ from online-only news provided by public service corporations when it comes to climate change reporting. Research has shown how public service media have adapted to online platforms (Sehl, 2016) and that public service media report differently on political issues compared to market-driven outlets (Cushion, 2022). To what extent that also applies to climate change news is less researched. We ask:

> *RQ4: How are themes and topics about climate change distributed in national newspapers and public service news?*

3 Materials and methods

To answer our research questions, we have investigated Denmark's most prominent news outlets belonging to the national press. It consists of all printed newspapers currently in circulation (n = 6) as well as online news sites by Denmark's two national Public Service Broadcast (PSB) corporations (n = 2). Data has been collected programmatically by API access to *Infomedia,* one of the largest media archives in Scandinavia. The sample frame included all articles published between 1990 and 2021. We have followed a common practice in previous research (Keller et al., 2020; Hase et al., 2021) by searching for articles containing at least one of three keywords related to climate change, resulting in the following stemmed search query: Greenhouse effect OR Global warming OR Climate change.[1] Our sample contains both print and online articles. News items shorter than 100 words were deemed non-exhaustive and unfit for our purposes and consequently deleted from the final sample. In total, we applied topic modeling to a corpus of 63,743 articles. Table 2 gives an overview over our sample, the name of the news outlet, the type, it's political leaning and the number of articles.

1 The original query in Danish was: klimaforandring OR "global × opvarmning" OR drivhuseffekt.

Figures 1A–D present descriptive statistics of the dataset. Figure 1A shows the number of articles over time and how the climate change agenda has regained momentum in the latter part of the 2010s. To integrate political leaning as a covariate in the model estimation process, we have assigned each newspaper to one of three categories (Figure 1C): center-right (53%), center-left (36%) or public service (11%). Here we follow a traditional right-left political scale used in previous research (Hjarvard and Kristensen, 2014), while also recognizing that news from Public Service Broadcast corporations should be excluded from such a categorization, as these corporations are required to stay politically neutral. This distribution confirms a well-established observation that users of right-wing media, which often cater to more affluent readers, have access to a wider news selection than the less affluent part of the population (Richardson, 2007). Article length ranges from 101 to 13,429 words, with an average of 738.4 words (Figure 1B).

Our sample consists of all news stories that contain one of the three keywords. Thus, we have deliberately included news items in which keywords are only mentioned once (Figure 1D). Here, we differ from previous studies that usually consider articles with a single occurrence of keywords as noise (Hase et al., 2021; Mahl et al., 2023). We argue, however, that excluding these articles would not accurately represent the variety of contexts in which climate change is finding their way to the Danish public. In addition, we are interested in topic omissions, i.e., climate change issues that are missing from our model. In this respect, we follow the tradition of classical content analysis (Krippendorff, 2004), which not only documents media content but also points out issues and agendas that are ignored, disregarded, or brushed aside. To do so, we need a complete sample, including more superficial news stories. Such a procedure further exemplifies the notion of human augmentation in automated content analysis (Grimmer et al., 2022), given that only humans can make sense of content-specific gaps and omissions.

With respect to duplicates, we differentiate between exact-duplicates and near-duplicates. We define exact-duplicates as articles containing the exact same content from the same outlet published on the same day. These were removed from the corpus. We deliberately decided not to remove near-duplicates for editorial and methodological reasons. We define near-duplicates as articles that are almost identical but published by different media outlets. A minor share of our corpus consists of such news stories, which are typically produced by news agencies and re-distributed or copyedited by associated newspapers. Picking only one of these articles would not only distort the distribution of certain topics. It would also misrepresent outlet bias, as copy-edited versions are published by outlets of different ideological leaning. Moreover, from a methodological perspective, there is no hard evidence that text duplicates seriously hurt topic model estimation. In a systematic assessment of the effects of text duplication on semantic models, Schofield et al. (2017b, p. 2738) conclude that whereas "a small amount of duplication is tolerable, substantial over-representation of subsets of the text may overwhelm meaningful topical patterns." However, assessing whether this is the case can only be done during a qualitative model validation process. If no indications arise of "repeated texts overwhelming several topics due to low coherence" (Schofield et al., 2017b, p. 2738), de-duplication

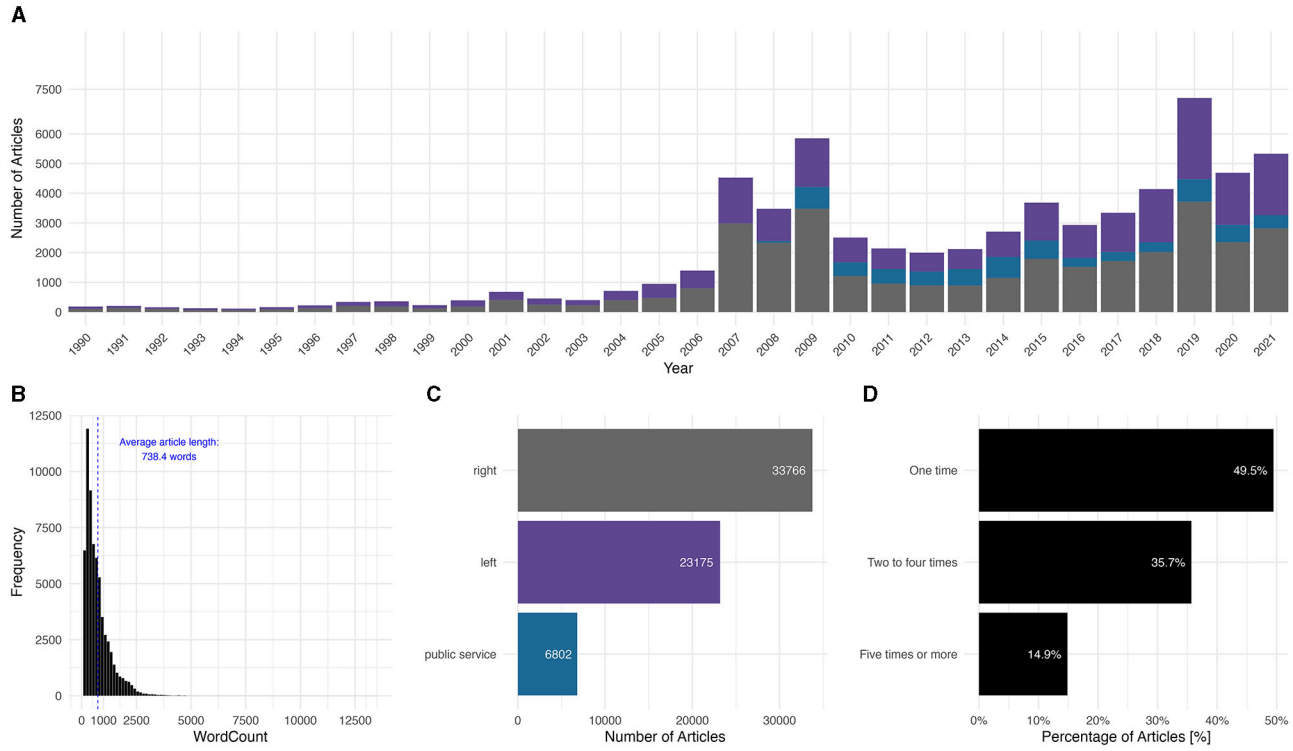

FIGURE 1
(A–D) Timeline, length, outlet distribution, and keyword frequency of our corpus.

and model re-training become unnecessary. As we will show later, topic coherence has been our primary concern in the model validation process.

3.1 Structural topic modeling

In our analyses, we estimate a structural topic model (STM) (Roberts et al., 2014, 2019). Like a standard LDA topic model, STM is a mixed-membership model. However, STM is superior as it allows corpus structure, i.e., document-level information, to influence topic prevalence and content during the model estimation process. When training an STM, researchers need to follow the same recommendations as with any other kind of topic modeling. This includes (1) text pre-processing, (2) model specification, (3) validation and model selection. We primarily follow guidelines by Maier et al. (2018).

3.1.1 Step 1: text pre-processing

We have followed standard procedure for text pre-processing by tokenising text into unigram tokens, lowercasing them and removing all punctuation. Research has shown that stemming, while commonly used in topic modeling, is optional and can even hurt the model quality, so we refrained from applying this process (Schofield and Mimno, 2016). Furthermore, there is experimental evidence that stop-word removal can be done before or after the model estimation process (Schofield et al., 2017a). We decided to remove the most common Danish stopwords beforehand to reduce vocabulary size and estimation time. Finally, to enhance the inference algorithm's performance even further, we followed the recommendation by Maier et al. (2018) by applying pruning (absolute pruning, n <20) to remove rare word occurrences (Denny and Spirling, 2018). The final size of our vocabulary is 61,895 unique words.

3.1.2 Step 2: model specification

During model specification, two choices are essential. First, to decide which covariates to incorporate in the model and second, to choose a value for the number of topics K, which the model is supposed to estimate. In our context, we allow topic prevalence, meaning the proportion of a document focusing on a certain topic, to vary by publication year and political leaning. This methodological choice is motivated by the descriptive analysis (Figures 1A–D), which reveals increasing media attention to climate change during the sample period. We also allow topical content to vary by the newspaper's political leaning. In topic modeling, choosing the number of topics K has for a long time been highly debated. In recent years, especially in the social sciences and the humanities, researchers have concluded that there is no "right" number for K, as the number of topics depends on the nature of the textual material and the analytical goals (Roberts et al., 2014). This also becomes evident from Table 1. This aligns with the recently proposed agnostic and pragmatic approach to text analysis, which emphasizes that no true model exists during exploratory text

analysis, just as there are no true K-values to aim for (Grimmer et al., 2022). Previous studies have relied on approaches originating in computer science when deciding on KK. These methods are typically based on statistical metrics which optimize for K where the model's predictive capabilities are best or where topic coherence is highest (Mimno et al., 2011). However, these operations have been questioned as automated coherence measures do not correlate well with model interpretability (Hoyle et al., 2021). In this study, we refrain from statistical calculations and rely on empirical evidence by performing human validation of our topic model. However, as it would be very time-consuming to manually validate a large number of topic models, researchers can get automated support with picking a reasonable number for K to start with. One approach is to run a k-estimation algorithm (Mimno and Lee, 2014). STM comes with an implementation of an algorithm developed by Mimno and Lee (2014) to find an appropriate number for K. As this is a non-deterministic process, the algorithm should be run multiple times. Following this procedure, we ran the algorithm 100 times ending with an average $K = 91.7$. In general, a higher number of K aligns with our goal of getting a nuanced and holistic picture of the multiple contexts in which climate change is reported. Thus, we settled on training an initial topic model with $K = 90$ before continuing with further manual validation.

TABLE 3 Number of topics and articles per theme.

Theme	Number of topics	Number of articles (n)	Share of articles (%)
Climate politics	10	6,704	12.51%
Climate change impact	10	6,393	10.05%
Foreign affairs	10	4,581	7,21%
Business and Economy	8	5,464	8,56%
Science and Nature	7	4,084	6.41%
Living and lifestyle	7	4,985	7.81%
Arts and culture	6	2,022	3.18%
Climate change skepticism	5	4,536	7.12%
Extreme weather events	4	4,553	7.14%
Energy and transportation	4	4,150	6.50%
Domestic politics	4	2,170	3.41%
Climate change events	4	4,764	7.47%
Climate activism	3	1,349	2.11%
Arctic	3	2,022	3.18%

The number and share of articles is based on the rank-1 metric. The rank-1 metric assigns an article the topic for which it has the highest probability (Maier et al., 2018).

3.1.3 Step 3: model validation and selection

Manual model validation is key to successful topic modeling. Model validation has been a stepwise and collaborative process involving one article author and two collaborators. During this process, we checked for two types of validity; intra-topic semantic validity and inter-topic semantic validity (Quinn et al., 2010; Maier et al., 2018). Intra-topic semantic validity refers to how meaningful and coherent the topics are. Following Mimno et al. (2011), up to 10% of generated topics risk being so-called chimera topics containing non-meaningful or non-coherent combinations of terms. These topics should be discarded. To judge intra-topic validity, three evaluators looked at the ten words with the highest marginal probability and the ten highest marginal FREX words.[2] This process can identify intruder words that interfere with the coherence of topic words (Chang et al., 2009). The validation was furthermore based on close reading of five documents for each topic, randomly selected among documents with the highest proportion of the respective topic. Topics were subsequently labeled and coded as either coherent or non-coherent. The coders reached an average pairwise percentage agreement of 91.11% (Pairwise, Coder 1 and 3: 87.78%, Coder 1 and 2: 92.23%, Coder 2 and 3: 93.33%) We took a conservative approach and only removed topics deemed non-coherent by all three coders. In total, this process resulted in 85 topics. A complete list of all identified topics, including overall topic proportion, a list of 20 keywords, and rank-1 metrics (the number of articles in which this topic is the most dominant), can be found in Supplementary Appendix A. Topics have furthermore been grouped into themes (Table 3 and Supplementary Appendix A) based on inter-topic semantic validity. This process can be done automatically using machine learning to cluster top-n topic words (Maier et al., 2018) or by finding communities in topic-correlation-networks (Lucas et al., 2015). However, we decided to group topics into themes via manual coding as we wanted context-sensitive knowledge of the Danish media landscape to guide the process. These two validation steps showed that the estimated topic model yielded distinct yet adequately coherent and meaningful topics.

3.2 Measuring outlet bias

Bootstrapping has been employed to study the effect of political leaning on expected topic proportion and topic prevalence. We checked whether the 95% confidence interval of the bootstrapped differences in means shows the null effect. For each topic, we compared the expected topic proportions pairwise for center-right, center-left, and public service media based on 1,000 bootstrap re-samples for each combination. This approach not only enables us to investigate significant effects of political leaning but also to quantify the size of the effect. This strategy has been used for both topics (Supplementary Figure S1) and themes.

4 Results

4.1 RQ1: prevalent topics and themes

Among the most prevalent topics, we find Climate Crisis (#38), COP15 (#78), and IPCC Reports (#33). It confirms a well-known pattern in climate change reporting, often driven by international climate change events like international COP meetings or the

2 FREX stands for Frequency and Exclusivity and attempts to find words that are both frequent but also exclusive to the topic at hand.

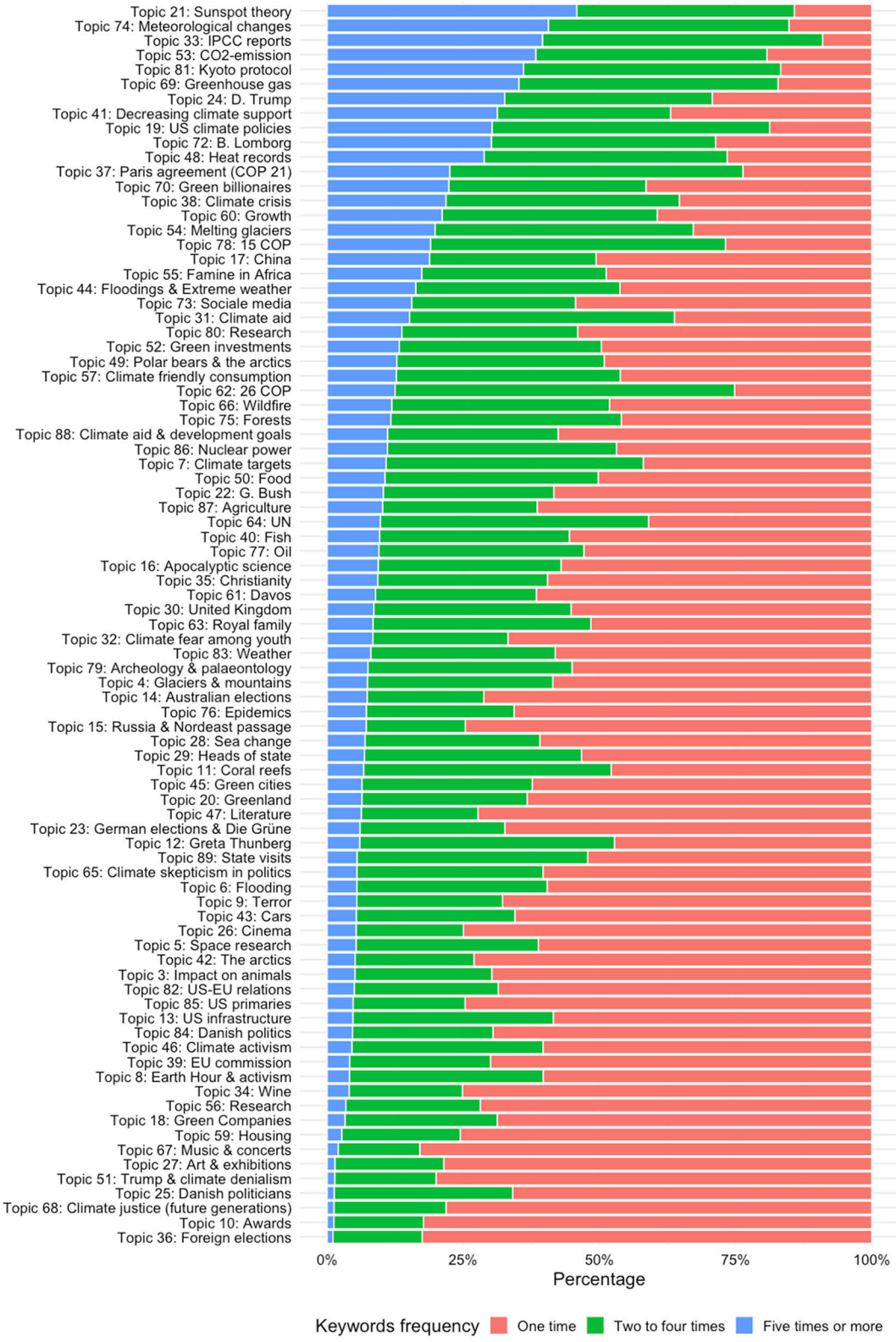

FIGURE 2
Share of keyword frequency in articles per topic (rank-1 metric).

release of major scientific findings like the cycles of Assessment Reports published by IPCC (Eide et al., 2010). However, Climate Concerns Among Youth (#32), Heat Records (#48) and CO_2-Emission (#53) also feature prominently. This diversity reveals that climate change is treated in various contexts and that climate change reporting has many drivers.

In Table 3 we have clustered topics into themes to better understand the variation and distribution of topics (n = 14). The table shows that the most popular themes concern Climate Politics (12.51%), Climate Change Impacts on nature and ecosystems (10.05%), and Foreign Affairs (7.21%). Given that Foreign Affairs primarily concern politics, it confirms that the press is orientated toward political aspects of climate change. These dominant themes are followed by a group of rather diverse themes, including Business and Economy (8.56%), Science and Nature (6.41%), Living and Lifestyle (7.81%), and Arts and Culture (3.18%). The latter illustrates some of the diversity in the climate change agenda. It shows that media users are offered multiple avenues into understanding and relating to climate change. Topics have been grouped as hard news (89%) or soft news (11%). Most soft news topics belong to the themes of Arts and Culture (six topics) or Living and Lifestyle (seven topics). For instance, Literature (#47) is among the top-10 topics (expected topic proportion = 2.08%), illustrating that soft news can be a non-trivial source of climate change attention.

It is evident that some topics are more focused on climate change than others. To illustrate this pattern, Figure 2 reports how many times keywords (greenhouse effect, global warming, climate change) appear in the articles assigned to a topic. At the top of the figure, we find traditional news topics in climate change reporting like CO_2-emission (#53), IPCC Reports (#33) or Heat Records (#48). In such topics (about the first 10), the share of articles in which the keywords are mentioned five times or more lies around 25% or higher. At the other end of the figure, we find topics dominated by news items, which in most cases refer to the keywords only once. These less focused topics typically include soft news related to Arts and Culture (#10, #27, #67), more narrow climate change topics like Green Companies (#18), or highly complex issues like Climate Justice (#68). There is an important methodological point to be made here. If the corpus only includes news items where keywords are mentioned twice or more, as it is recommended in some studies (Hase et al., 2021), we might lose sight of the diversity of climate change reporting that takes place in the press. Climate change surfaces in all sorts of news stories, from international politics to culture and lifestyle, underlining how climate change has become a universal and ubiquitous media agenda. While some news readers will receive focused news dealing exclusively with climate change, others will mostly read about climate change as embedded in other types of news. Thus, for our purpose it as important to also include articles that feature one of the keywords only once.

4.2 RQ2: temporal development of topics and themes

Our longitudinal data reveals that most topics have remained relatively stable over the 30+ years. However, a handful of topics either fluctuate or have increased/decreased over time. Regarding the former, some topics are rather time-specific or time-sensitive (Figure 3). A good example is the Kyoto Protocol (#81), which was among the more prevalent topics in the 1990s but gradually faded out during the 2000s. In general, topics relating to specific climate change events like COP meetings (#37, #78) or the publications of IPCC assessment reports (#33) are the most time sensitive. However, the most extreme case relates to Greta Thunberg (#12), which emerged in 2018 and peaked in 2019. The prevalence of this topic furthermore follows the same trend as the topic Climate Fear among Youth (#32), suggesting that some topics trigger, or are associated with, the emergence of other topics.

Some topics have almost disappeared over the 30+ year period. The Sunspot Theory (#21), part of a wider Climate Skepticism theme (Figure 4), generated considerable attention in the 1990s but has since failed to produce empirical evidence to remain relevant. Another waning topic is nuclear power (#86), which is somewhat surprising given the international attention it has received as a potential carbon-neutral energy source. Nuclear power, however, was never introduced in Denmark, which instead subsidized an emerging wind power industry. As the price of renewable energy has kept falling, nuclear power never became a viable alternative, generating limited public support.

Topics that have surged in recent years include Climate Crisis (#38) and Climate Targets (#7). Both topics are among top 10 and may reflect editorial recognition of the urgency of climate change. This surge furthermore reflects a pattern, which has also been observed in former studies (Murakami et al., 2017; Sietsma et al., 2021). In early climate change reporting we see a propensity to focus on causes like Greenhouse Gas (#69) and Cars (#43), the latter a recognizable and straightforward token of a contributing factor. In contrast, later news reporting has been more preoccupied with answers and solutions to climate change focusing on topics like Green Investments (#52). Arguably, it illustrates a development from relatively simple to increasingly complex public understandings of climate change.

We can detect similar patterns when looking at the development of themes (Figures 5A–C). A major theme like Climate Change Politics (top of the chart) and a minor theme like Domestic Politics (bottom of the chart) remain relatively stable during the entire period (Figure 5A). Other themes like Foreign Affairs (Figure 5B) fluctuate considerably, reflecting the ebb and flow of international climate change negotiations, peaking around COP15 (2009) and COP21/the Paris agreement (2015). Interestingly, the highs and lows of Foreign Politics move almost invertedly to the Climate Event theme (Figure 5B). It suggests that news reporting on climate change turns to foreign affairs when no major climate summits or scientific publications capture media attention. Viewed together, it underlines the global and political nature of climate change as a news agenda. The tentative development from an early focus on relatively simple causes and effects to more complex climate change issues can also be found in relation to themes. Topics concerning Energy and Transportation (6.5%) and Science and Nature (6.41%) decreased considerably from 1990 to around 2010 (Figure 5C). In the 1990s, scientific disputes over anthropogenic climate change were still permeating the media agenda. As the science settled and climate skepticism proved wrong, the intense concern with climate science waned. So did simple causes and explanations of climate change, like Energy and Transportation. However, the latter is marked

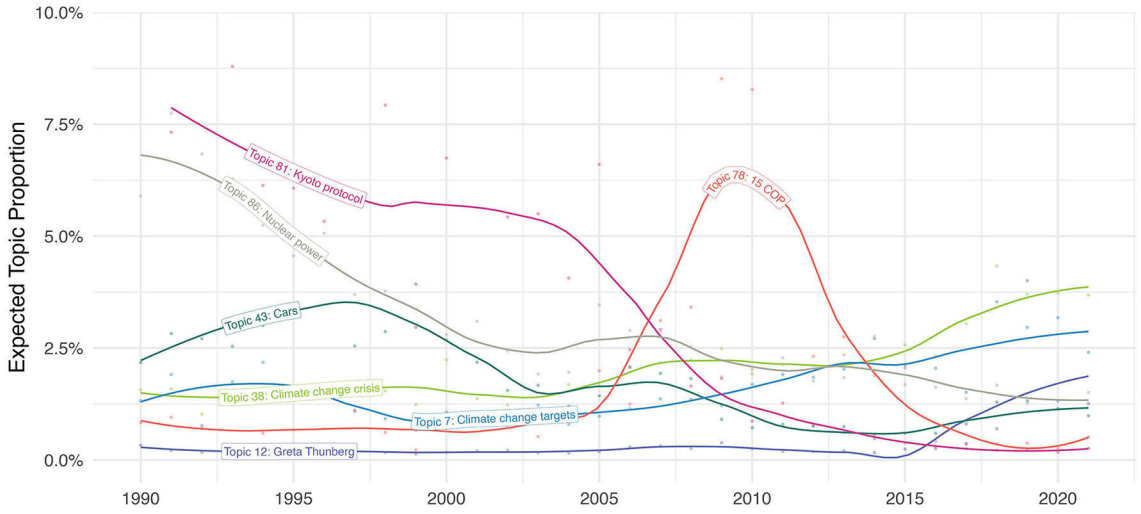

FIGURE 3
Temporal developments (LOESS regression) of selected topics.

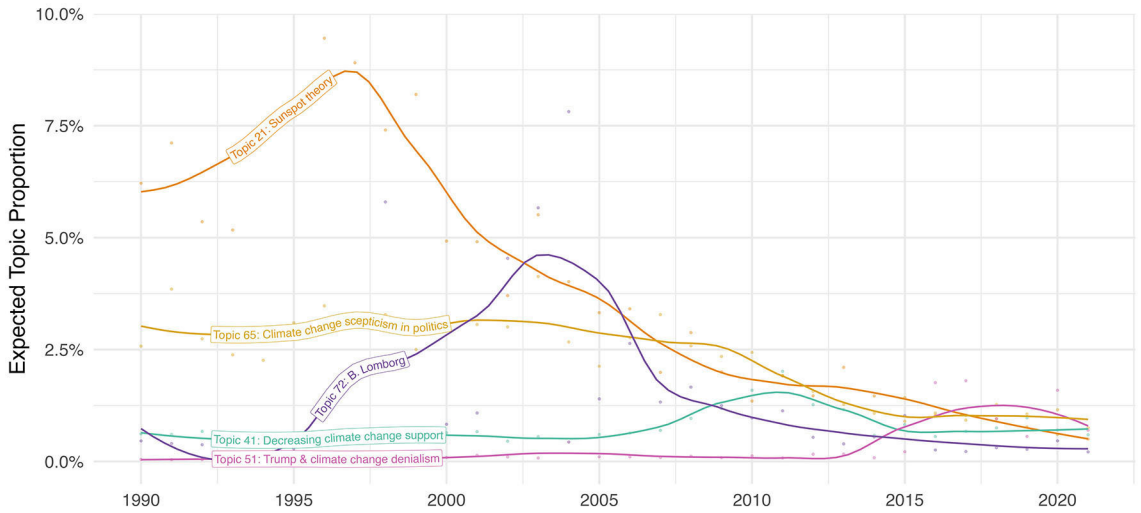

FIGURE 4
Temporal development of topics grouped into the climate skepticism theme (LOESS regression).

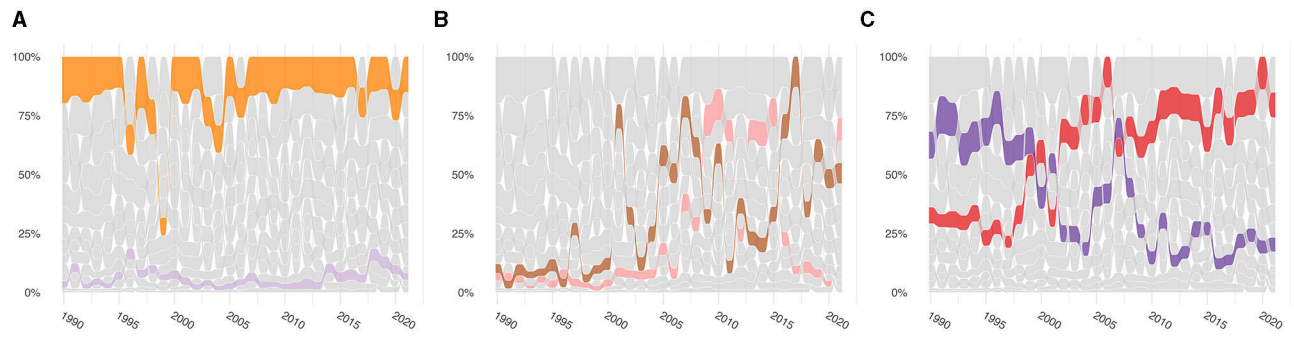

FIGURE 5
Temporal development of selected themes. **(A)** Climate vs. domestic politics. **(B)** Climate change events vs. foreign affairs. **(C)** Climate change impact vs. energy and transportation.

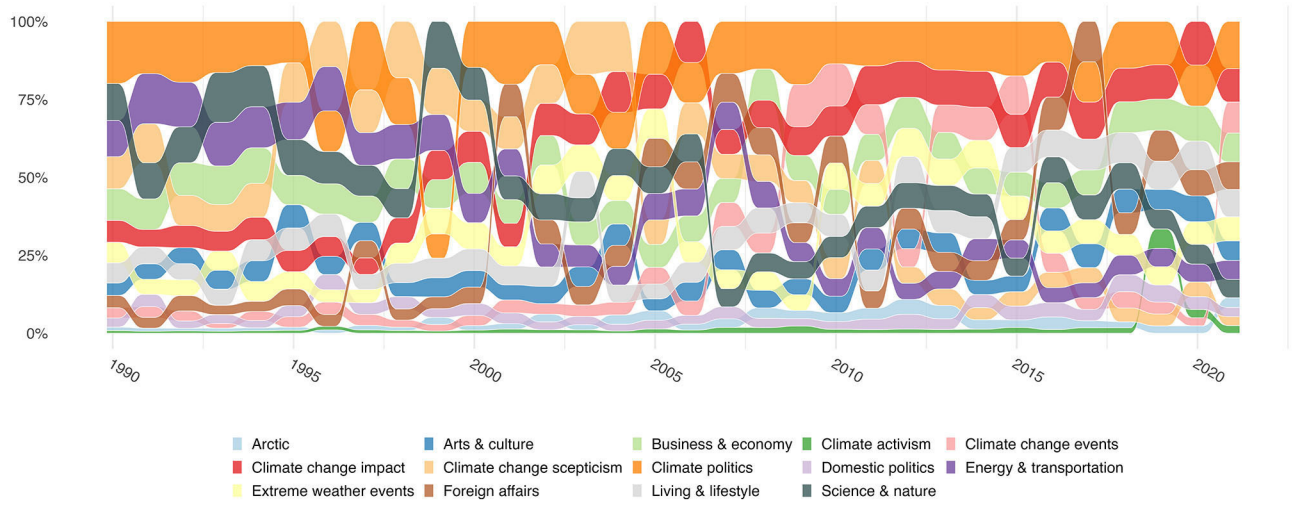

FIGURE 6
Temporal development of themes (1990–2021). The themes are ranked top to bottom from most to least dominant.

by periodically upticks in years of important climate change negotiations (e.g., Paris Agreement 2015, EUs green deal in 2019), which suggests that Energy and Transportation may surge again when concrete solutions to outfacing greenhouse gases is on the political agenda. In contrast, topics relating to themes of Climate Change Impact (Figure 5C) and Foreign Affairs (Figure 5B) have increased, indicating that media concerns have moved from if climate change is real to how climate change is affecting the world and what to do on the international stage to mitigate and adapt to climate change.

Apart from these early and recent variations, most themes stay relatively stable over time, absorbing oscillations of individual topics (see Figure 6). A significant exception to this general picture is Climate Skepticism (7.12%), consisting of five topics (Supplementary Appendix A). Not only have these topics fluctuated considerably over the years, but they have also mostly died out within the last 10–15 years.

Denmark represents a curious case when it comes to climate change skepticism. It generally follows a pattern in Northern Europe and Scandinavia in which climate skepticism has been much less pronounced in media discourses than in North America (Adam et al., 2020). Yet Denmark has produced two major international climate skepticism phenomena. The first is the so-called solar wind theory, propagated by the Danish scientist Henrik Svensmark (#21). It argues that variations in solar wind, or cosmic rays, offer a better explanation for climate change than manmade CO_2. Another well-known topic relates to the Danish climate contrarian Bjørn Lomborg (#72). The publications of the Danish version (1999) of Lomborg's The skeptical Environmentalist (2001) and, to some extent, the publication of Cool it (2007), a follow-up to the first study, generated significant media coverage at home and abroad (Lomborg, 2001, 2007). However, domestic media attention peaked in 2003 and 2004 when Lomborg was formally charged with scientific dishonesty. Although Lomborg received considerable political (and financial) support from the then-right-wing government, public support for Lomborg always remained limited. Even at the top of Lomborg's media fame, he was perceived as a divisive and controversial figure that galvanized public acceptance of anthropogenic climate change as much as it mobilized climate deniers.

4.3 RQ3: ideological variations and outlet bias

Climate change skepticism has been highly politicized, particularly in the anglosphere (Oreskes and Conway, 2010). It is often a predictor of ideological leaning in climate change perceptions and in editorial priorities (Leiserowitz et al., 2013). That is also the case in Denmark, although the picture is less clear-cut. In the next two sections, we turn to questions of outlet bias.

The influence of political leaning on news reporting can be studied on the level of both topics and themes. Figure 7 presents the effect of outlet bias on the distribution of themes. Bias is measured pairwise among three political categories (center-right, center-left, and public service media). A significant effect is present if the 95% confidence interval of the differences in bootstrapped means does not cross the dashed line at zero. The green dots show the prevalence of themes according to a right-left distinction. The dot on the right side of the dashed line indicates a higher topic proportion in right-leaning papers (and vice versa if it is on the left side). The same logic applies to the relations between public service and left-leaning newspapers. If the red dot is on the left side, it shows a higher topic proportion in left-leaning newspapers compared to public service media. Thus, the Climate Skepticism theme is more likely to appear in right-leaning papers than left-leaning papers (green dot) or public service outlets (blue dot).

More interestingly, Business and Economy is slightly less prevalent in right-leaning than left-leaning papers. This is

surprising because right-leaning papers often serve the business community and favor market-based solutions to climate change. We do not have any simple explanation for this finding, which calls for further investigations. However, we suspect that left-leaning papers may be more concerned with stakeholders that cause climate change, such as oil companies. Thus, if we look at individual topics like CO_2 emission (#53) or green investments (#52), they are more prominent in left-leaning papers (Supplementary Figure S1), indicating that center-left papers pay greater editorial attention to investment in the green transition. There are also themes where outlet bias is almost non-existent, such as Climate Politics and Domestic Politics, where variations are tiny, and the dots almost overlap. Thus, while we detect clear evidence of ideological bias on the theme level, the effect is only marginal (around max 1%, see *X*-axis Figure 7). However, if we look at individual topics, there is clear evidence of ideological bias with high effect. Figure 8 shows topics where political leaning has the most significant influence on topic proportion. For example, Flooding (#6) is more dominant in public service media (∼3%) than in other media outlets. It is a rapidly evolving, episodic and non-political topic well suited for online news updates. It further underlines how topics relating to Extreme Weather Events (Figure 7) are overrepresented in public service media.

The ideological dimension of climate skepticism is evident via the Sunspot Theory (#21). This topic has close to a 2% higher likelihood of being reported in right-leaning papers. On the other hand, news on the Climate Change Crisis (#38) is more prominent in left-leaning papers, indicating a preoccupation with the urgency of the climate crisis. It also suggests a willingness to engage in more structural and abstract news on climate change compared to episodic topics associated with climate impact.

4.4 RQ4: the influence of media modalities

The most apparent evidence emerging from Figures 7, 8 is that outlet bias is less pronounced in relation to a right-left distinction, while it is public service media that differ. Thus, the prevalence of themes in both right- and left-leaning papers is closer to their overall share of news stories than in public service media. It indicates that editorial priorities in right and left-leaning newsrooms adhere to similar news values across ideological divides. Although ideological variations occasionally manifest themselves in editorials and op-eds, internal pluralism has become the editorial norm in general news reporting, including climate change news. It further reflects a high degree of journalistic professionalism in the Danish (democratic-corporatist) media system (Hallin and Mancini, 2004).

There are two main reasons why public service media differ from newspapers. First, public service media are required to stay politically neutral. Arguably, that results in an editorial preference for episodic news like Floodings (#6) or even the Royal Family (#63) and a tendency to avoid highly politized and controversial topics, such as climate skepticism. It also reflects how public service media publish only by-lined or copy-edited articles. There are no op-eds or letters-to-the-editor, which are dominated by opinionated and conflictual perspectives on climate change. Some variations in the distribution of themes and topics in relation to public service media can be explained by the fact that online news only took off in the mid-2000s, halfway into our sampling period. An early topic like the Kyoto-protocol (#81) is much less prevalent in public service media compared to newspapers. However, even when controlling for that, there are marked differences between print media and online news. It suggests that topic distribution is contingent not only on ideological leaning but also on variation in media types. Future research should pay more interest to these differences when designing topic modeling of climate change coverage.

5 Discussion and conclusion

Research questions one and two explored the distribution and temporal development of topics and themes. In this study, we trained a structural topic model on a corpus of around 63,000 articles from Denmark's nine largest media outlets. We decided on an inclusive corpus strategy by selecting all articles in which climate change keywords were used once or more frequently. By doing so we aimed at gaining a holistic picture of the different contexts in which the Danish public encounters climate change and how the press contributes to communicate climate change. While previous research usually considers articles with single occurrences of search words as "noise," our findings suggest that what counts as noise cannot be uniquely defined and should be re-negotiated from case to case. In contrast to studies with a tight text corpus, our approach to text sampling reveals how climate change can be found in a wide variety of topics, including slightly surprising topics like Wine (#34) or Christianity (#35), but also in relation to other soft news like Cinema (#26) and Literature (#47), which provides different conversations about climate change. This shows how climate change is widely discussed and driven by many topics. Far from being restricted to a few specialized media agendas, climate change surfaces in an extensive range of topics, including hard news, soft news, cultural news, economic news, and lifestyle matters (Doyle, 2011). It indicates that no matter how the public receives (national) news, they will almost unavoidably be exposed to climate change reporting.

To contextualize our findings even further, Table 4 compares the present investigation with single-nation studies from three other regions (Russia, India, US) by listing the most prominent themes or topics (Boussalis et al., 2019; Bohr, 2020; Keller et al., 2020). The latter illustrates some of the methodological variations within this field, which complicate the direct comparison between different topic models. Whereas Keller et al. (2020) only identify four themes, Bohr (2020) doesn't operate with themes at all. The comparison shows that Climate Change Politics, including International Agreements (Bohr, 2020), rank high in most countries. It reflects the global nature of climate change and its association with high-level politics, compared with other environmental discourses (Dryzek, 2005). Except for the US, we can also see a focus on Climate Change Impacts. The increasing evidence of the latter also seems to explain why climate change denialism is a spent force in Denmark and most other countries, although it still weighs heavily on US climate change reporting. Links between climate change and Business and Economy are prominent in Denmark and Russia suggesting regional differences

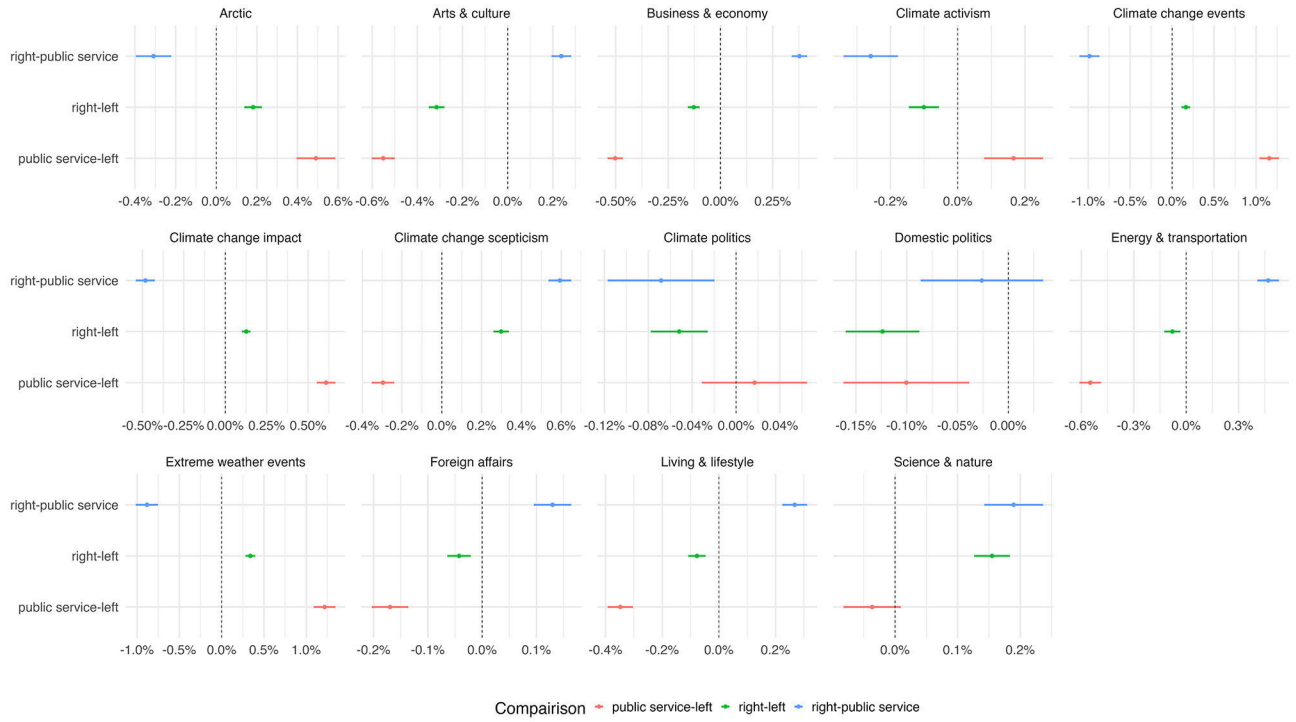

FIGURE 7
Outlet bias in relation to themes (organized pairwise). The bars indicate the 95% confidence interval.

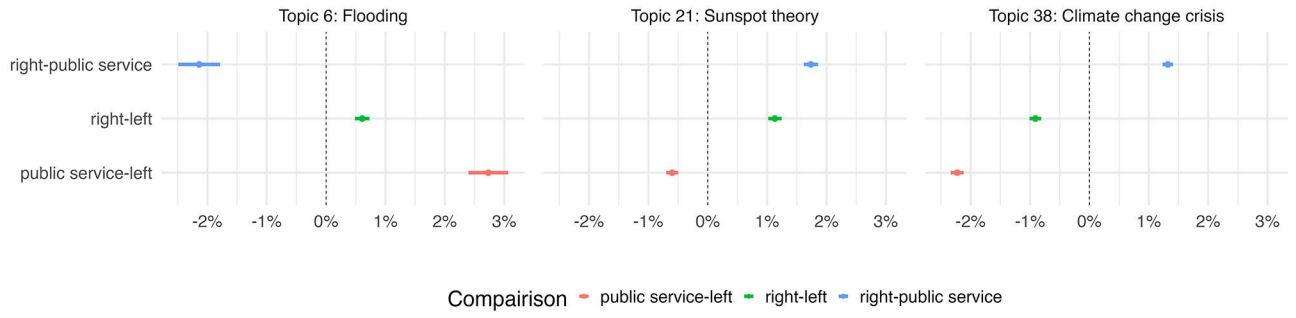

FIGURE 8
Outlet bias in three selected topics with the highest effect (left to right) for public service, right-leaning and left-leaning media (organized pairwise). The bars indicate the 95% confidence interval.

TABLE 4 **Comparison of the most prominent themes/topics of four topic models from four different countries.**

Study Country	Boussalis et al. (2016) Russia	Keller et al. (2020) India	Bohr (2020) United States	Present study Denmark
1	Society and culture	Climate change and society	International agreements	Climate politics
2	Climate impacts	Climate politics	Emission and pollution	Climate impact
3	Climate science	Climate impacts	Climate change denial	Business and economy
4	Economy and business	Climate science	Letters to the editor	Living and lifestyle
5	Disasters/extr. weather		Enviro protection agency	Climate change events

in the presentation of climate change in areas beyond science and politics.

Another clear finding is the increasing sense of urgency. Topics relating to climate change consequences, risks, or reactions have surged or remained stable in the last decade. However, more recent topics relating to the climate crisis have yet to be detected by our topic model. We are surprised not to find topics on health or health-related issues, which have been reported in other studies (Weathers and Kendall, 2016). From an audience perspective this is also surprising as we know that 84% of the Danish population believe that tackling climate change can help improve health and wellbeing (Eurobarometer, 2022a). Thus, the wellbeing of humans and nature has become a significant concern as the ecological crisis has accelerated. The main reason why it has yet to crystallize into a separate topic could be that health issues are embedded in themes on extreme weather and climate change impact. News on Heat Waves (#48) and Floodings (#6) sometimes revolve around health hazards and vulnerable segments of the population.

Other notable absences are topics about climate change justice, loss and damage, and climate change adaptation, which is prominent in other parts of the world (Das, 2020). Again, these questions are typically raised as secondary topics concerning Climate change aid (#31), Development goals (#88), the UN (#64), and the Kyoto protocol (#81). However, what theories on news selection call resonance and limited cultural proximity (Harcup and O'Neill, 2017) probably also explain why these issues do not constitute individual topics. It leaves an impression of climate change reporting in Denmark being heavily dominated by perspectives pertaining to the Global North.

Research question three and four have looked at different types of outlet bias. While the possibility of documenting bias is key in traditional content analysis (Krippendorff, 2004), questions of ideological impact on topic prevalence have, with a few exceptions (Boussalis et al., 2019; Bohr, 2020), been absent in most topic models of climate change reporting. Our study shows that political leaning is an essential variable in topic distribution, just as variation in communicative modalities contributes to overall outlet bias. At the same time, our study points to the likely influence of national media systems as a homogenizing factor in topic variations. Although we can trace ideological differences concerning specific topics and themes, e.g., Climate Change Skepticism being most prominent in right-leaning outlets, ideological orientations tend to have a limited impact on our findings. This aligns with findings by Bohr (2020) on US print media, which points to limited partisan bias in most topics, with Climate Change Denial as the main exception, and predominantly reported by conservative news outlets. However, ideological differences can be challenging to detect on a mostly agenda-setting level, as editorial and journalistic norms can mask political nuances. A more granular analysis is required to capture subtle ideological variations regarding source selection, framing, and visualization of climate change. Such additions can be informed by traditional and computer assisted framing analysis (Shehata and Hopmann, 2012; Stecula and Merkley, 2019).

Interestingly, the most pronounced differences in climate change reporting are between public service media and traditional newspapers. These differences also reflect different communicative modalities. National public service media provide broadcast news (television, radio) and online news. This study only includes the latter. Unlike hourly news bulletins on radio and television, which are limited to a handful of news stories, there are no such restrictions when publishing online news. In addition, online news excels in news updates and breaking news. The distribution of themes in public service media seems to be a product of mixed editorial priorities. It hints at political constraints, the tendency to shy away from overtly controversial topics, and more technical considerations by adjusting news topics to the modalities and frequencies of individual media technologies. The implications of such differences call for more detailed studies. Still, it indicates that media users relying mainly on online news from public service providers, without additional access to print media, will receive information on climate change that is more topical and less politicized, more thematic and less structural, more about high-level politics than everyday interventions and more concerned with consequences than solutions.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions. The original articles are under copyright by Infomedia and cannot be shared with the public. Requests to access these datasets should be directed at: fmeier@ikp.aau.dk.

Author contributions

FM: Writing – original draft, Writing – review & editing. ME: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2023.1322498/full#supplementary-material

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