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The Impact of the Russian War against Ukraine on the German Hydrogen Discourse

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Abstract: This contribution delves into the transformative effects of the Russian–Ukrainian war on the discourse surrounding German hydrogen. Employing structural topical modeling (STM) on a vast dataset of 2192 newspaper articles spanning from 2019 to 2022, it aims to uncover thematic shifts attributed to the Russian invasion of Ukraine. The onset of the war in February 2022 triggered a significant pivot in the discourse, shifting it from sustainability and climate-change mitigation to the securing of energy supplies through new partnerships, particularly in response to Russia's unreliability. Germany started exploring alternative energy trading partners like Canada and Australia, emphasizing green hydrogen development. The study illustrates how external shocks can expedite the uptake of new technologies. The adoption of the "H2 readiness" concept for LNG terminals contributes to the successful implementation of green hydrogen. In summary, the Russian–Ukrainian war profoundly impacted the German hydrogen discourse, shifting the focus from sustainability to energy supply security, underscoring the interconnectedness of energy security and sustainability in Germany's hydrogen policy.

Keywords: hydrogen; discourse; green energy trade; Germany; Ukraine; STM; structural topic model; text as data; unsupervised machine learning

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1. Introduction

Hydrogen, as an energy carrier, plays a pivotal role in addressing the urgent climate and energy-transition imperatives. This element has garnered increasing attention in the last several years for its potential to decarbonize a wide array of sectors, from transportation to industrial processes. The significance of hydrogen lies in its ability to offer a scalable solution for energy storage, distribution, and utilization. This holds particular relevance for EU Member State countries, such as Germany, which lead the way in advancing and implementing hydrogen technologies. The discourse on hydrogen in Germany has been emerging since 2018, with a peak in 2019/20 around the announcement, within the Federal Climate Protection Act, of the goal of climate neutrality for Germany by 2050, and the formulation of the German National Hydrogen Strategy; both of these events played a vital role in the advocacy for climate-friendly hydrogen technologies, government investment in large-scale hydrogen production, diverse hydrogen applications, technological advancements in hydrogen transportation, and the resulting innovations within these domains, which is reflected in the discourse [1] (p. 8), [2]. The discourse on hydrogen discusses these political developments, as can be observed when sequencing the discourse over time [2].

In 2022, the Russian war against Ukraine impacted profoundly the climate and energy policies in Germany and the European Union [3–5]. Current research literature on the German hydrogen discourse has not yet explored the impact of the start of the war on this discourse. Our research aims to fill this gap and to understand how the Russian war against

Ukraine has affected the German hydrogen discourse. Our research question therefore is the following: how did the Russian war against Ukraine impact the public German hydrogen discourse? It is reasonable to argue that this geopolitical shift has fostered an increased alignment between energy security and climate goals. This alignment is expected to underscore the importance of green hydrogen as a critical storage technology that serves both goals by securing energy supply and meeting climate objectives. This should add a new dimension to the hydrogen debate and draw attention to the question of whether there are sufficient green hydrogen imports to meet the demand.

Against this background we conducted an analysis of the discourse surrounding hydrogen in German-language newspapers, from 2019 to 2022, with a particular focus on examining the impact on the discourse of the start of Russia's war against Ukraine. We employ an innovative natural language processing method, structural topical modeling (STM) [6], to analyze a corpus of 2192 newspaper articles, identify the main themes, and trace any changes originating from the time of the start of the Russian war against Ukraine. Thus, we contribute to the research on how external geopolitical events impact national discourses on energy technologies. We also analyze the effects of the securing of the energy transition, due to these geopolitical shifts, on the hydrogen discourse.

The sections of this article are organized as follows: Section 2 refers to the state of the art with respect to Germany's hydrogen discourse and to the German dependence on Russian fossil fuels, and Section 3 introduces our dataset of media coverage and describes the methods used. In Section 4 we present the main findings, and Section 5 provides a comprehensive discussion and interpretation of the results. Finally, Section 6 delivers the concluding remarks.

2. The German Hydrogen Discourse and the German Dependence on Russian Fossil Fuels

This article delves into the wider body of literature addressing the role of hydrogen in the current energy transition. These studies center on hydrogen's potential for decarbonization, as well as its relevance in diverse economic domains [7–9]. Within the context of the German energy transition, studies underscore the pivotal role of hydrogen in areas where direct electricity usage is deemed too costly, inefficient, or simply impractical [10]. The anticipated low-carbon transformation of key German industries, particularly in chemicals, steel, and transportation, is expected to necessitate substantial quantities of green hydrogen [11] Some researchers, such as Kruse and Wedemeier [12], argue that direct implementation of hydrogen technologies in the German economy is viable, marking the onset of a hydrogen race at both the national and international levels. In the societal context, various studies have scrutinized the public perception and acceptance of hydrogen technologies in Germany, with a primary focus being on its application in transportation [13]. The findings reveal a predominantly positive attitude, with specific attention to the eco-friendly production of hydrogen from renewable sources. Germany demonstrates overall public acceptance and a high awareness of hydrogen technologies [14].

Our analysis ties in with other studies of the German hydrogen market ramp-up discourse. All of these studies concur that, since 2019, there has been a notable rise in media coverage regarding the topic of hydrogen. It becomes evident in the literature that the structure of the discourse has evolved in tandem with and has been in sync with the political agenda-setting during the initial stages of the public debate on hydrogen in Germany [1,2,15]. More recent studies have concentrated on the positioning of stakeholders regarding the hydrogen market ramp-up [1,15,16]. Belova et al. use the Discourse Network Analyzer software to examine how the composition of stakeholders, their positions, and the overall hydrogen discourse structure have developed over time [2]. The question of public perceptions and acceptance of hydrogen technologies in Germany is only addressed by older studies and is not part of the current research [14,17,18]. Overall, the research literature on the economics of technological innovation underscores the strong interconnection

between innovation and economic, political, and socio-cultural factors, all of which find expression in the public media discourse [19].

In the context of the war against Ukraine, energy researchers mainly discussed two issues directly after the full-scale invasion by Russia. First, a number of articles addressed the consequences of the decline or potential end of Russian oil, coal and gas supplies to the EU and its member states [20–22]. Energy has played a pivotal role in the sanctions imposed on Russia since its invasion of Ukraine on 24 February 2022, which has had a significant impact on Germany in particular. In 2022, German imports of oil from Russia decreased from 34 percent of total oil imports to 1 percent, the import of hard coal from Russia was reduced from 55 percent of total hard coal imports to 9 percent, and the import of natural gas was scaled back from 40 percent of total gas imports to 0 percent [23]. The EU prohibited Russian coal imports as of the date when the coal sanctions, agreed upon in the fifth EU sanctions package in April 2022, took effect in August 2022. The ban was extended to crude oil imported after 5 December 2022, and to refined petroleum products imported after 5 February 2023. Approximately 90 percent of Russia's oil imports to the EU fell within the terms of the oil embargo, with the remaining 10 percent subject to limitations until the end of 2023. Notably, there were no sanctions on natural gas, due to its critical importance and limited substitutability. However, Russia significantly curtailed gas exports to EU markets, leading to a substantial slowdown in gas supplies through all pipeline routes from Russia (except the Turk Stream) in 2022. The assault on the Nord Stream I and II gas pipelines in the Baltic Sea on 26 September 2022 further exacerbated the situation, causing a virtual halt of Russian gas supply to Germany. In addition, the approval process for Nord Stream II, which is not yet operational, was indefinitely suspended due to the ongoing war [5]. Secondly, the potential marginalization of energy transformation and climate policy vis-à-vis energy security was discussed. A question has been raised as to whether these developments might actually foster greater alignment between the objectives and tools of energy security and climate-related goals [14,16]. More recent studies present an evaluation of the response of the European Union to the first eighteen months of the war and the war's impact on EU energy policy [3,4]. While short-term reactions prioritized security by reviving coal power and substituting for Russian gas with LNG, resulting in higher global energy prices and climate target risks, the response ultimately encouraged greater alignment between energy security and climate goals. However, research shows that challenges exist in terms of emergency legislation and the EU's limited influence on national energy policies, highlighting the increased need for stronger governance as targets become more ambitious. Regarding climate and energy transformation, all studies advocate for an increased prominence of green hydrogen. In this respect, research showed that the "Energiewende is no longer framed primarily as a domestic climate protection policy, but rather an explicitly geopolitical problem" [24] (p. 1).

Further, the EU stated nine months after the start of the war that "since existing hydrogen production relies on imported natural gas, Russia's war against Ukraine has put hydrogen, and renewable hydrogen in particular, in an even more prominent place in the EU's accelerated transition to shift away from Russian fossil fuels and diversify its energy supplies" [25]. This is also reflected in newer studies on energy security and green hydrogen [26,27], including analyses focusing on the impacts of the Russian war against Ukraine on German and/or European energy policies [20,28], often focusing on the immediate energy crises in winter 2022/2023 [3,29].

The research literature on the German hydrogen discourse has extensively reviewed its various aspects, like the hydrogen market ramp-up, general developments, conflicts in implementation, and the acceptance of hydrogen in Germany. However, it has not examined the influence of the Russian war against Ukraine on the German hydrogen discourse. Against this background, we will analyze the German hydrogen discourse to understand the impact of this geopolitical event on the German media discourse on hydrogen.

3. Discourse Analysis: Data and Methods

Discourses encompass a body of constantly evolving ideas and concepts that are generated, replicated, and adapted into practices that shape our understanding of reality [26]. The discourse thus has a dual role, in that it both limits and enables social action, depending on the prevailing interpretation of reality at any given moment [27]. Policy formulation hinges on the discourse surrounding an issue, becoming a contest for discursive dominance wherein actors vie for support for their interpretations [2]. The media serve as a proxy for discourse content, collectively acting as an arena for claims-making competition and offering insights into dynamics over time.

External shocks, such as economic crises, geopolitical conflicts, or global health pandemics, have profound impacts on national discourses. These unexpected events can disrupt the status quo and trigger shifts in the discourse. In times of crisis, the focus of public debate may shift towards issues such as economic stability, security, or public health, thereby altering the prevailing narratives and policy agendas. Additionally, external shocks can reveal vulnerabilities in a nation's preparedness and governance, prompting discussions on resilience and the need for reform [19,30].

The media can be collectively viewed as a suitable representation of the contents of discourses [31,32]. They function as a platform where individuals and groups compete for attention by asserting their positions. When these viewpoints resonate with the audience, the points enhance the credibility of the ones making these assertions [33]. Consequently, reputable media outlets offer valuable reflections of claim-making endeavors. Furthermore, when monitoring changes and trends over time, media sources are among the less biased sources for the study of evolving dynamics [2,34,35].

3.1. Discourse Data

In our analysis, we chose renowned and prominent German-language daily newspapers serving as the primary sources of news for national elites, well-informed citizens, and external observers: *Süddeutsche Zeitung* (SZ), *Frankfurter Allgemeine Zeitung* (FAZ), *Die Tageszeitung* (TAZ), *Die Welt*, *Handelsblatt* and *Neue Zürcher Zeitung* (NZZ). This collection of newspapers covers a broad political spectrum from moderately left to moderately right and includes a financial newspaper (*Handelsblatt*) and a conservative Swiss publication that is widely read in Germany (NZZ). Using the query "Wasserstoff* OR wasserstoff*", we retrieved the articles from *Neue Zürcher Zeitung*, *Die Tageszeitung* and *Die Welt* from the academic database *Nexis Uni* and downloaded the articles from *Handelsblatt*, *Frankfurter Allgemeine Zeitung* and *Süddeutsche Zeitung* from the respective newspaper databases.

The time period chosen ranges from 1 January 2019 to 31 December 2022. We begin our analysis by focusing on the announcement of the German National Hydrogen Strategy in October 2019. Prior research has indicated that this was a pivotal moment in the development of the discourse. By concluding our observation period after December 2022, we encompass almost the entire first year of the war in Ukraine, which provides us with a substantial dataset for addressing our research question. Electronic databases storing daily editions of the papers were searched with the keyword W/wasserstoff*. The initial search yielded 7906 articles. To avoid including articles that mentioned hydrogen, but only in passing, we excluded articles with fewer than four keyword mentions. After removing duplicates, this process resulted in a final dataset of 2192 articles. Figure 1 shows the number of articles by year and newspaper.

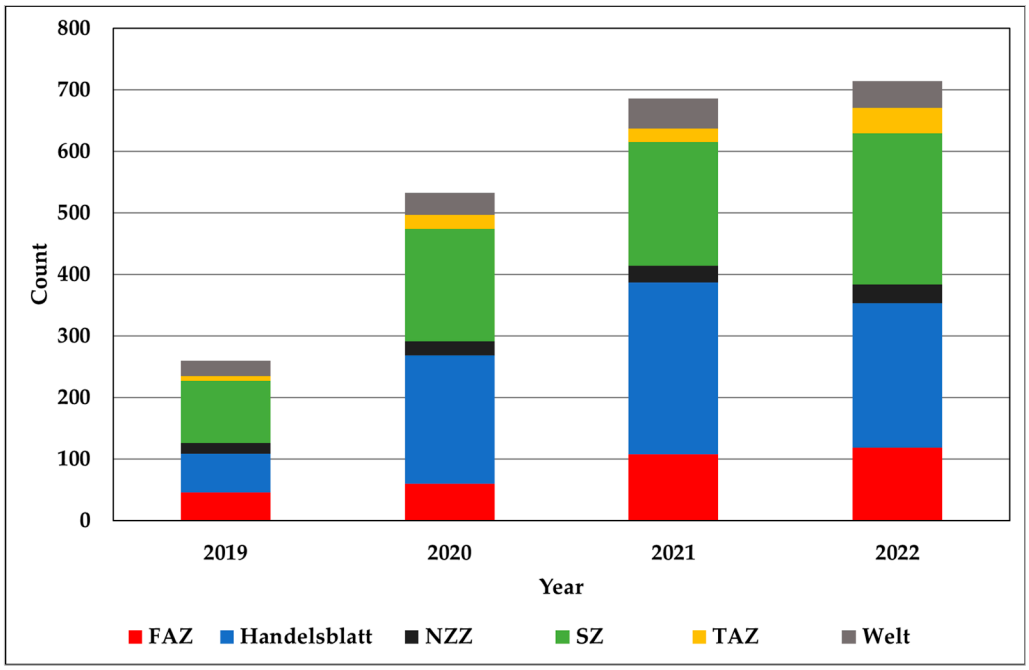

Figure 1. Number of articles on hydrogen, by year and newspaper, 2019–2022.

3.2. Preprocessing Text Data

Raw textual data are routinely preprocessed before being used as inputs in a model. We carried out the following procedure: First, we applied lemmatization. Lemmatization is the process of reducing a word to its canonical form. German is a richly inflected language, and many words have the same canonical form. For example, the lemma (canonical form) of all of the following words is "deutsch": "deutsch", "deutsche", and "deutscher". We performed lemmatization manually. Second, we included a small number of bigrams. The unit of analysis in this study is a single term. However, given the subject matter, including the following selected bigrams proved to generate better results: "Nord Stream", "Europäische Union", "Vereinigte Staaten", "Pariser Abkommen", "grüner Wasserstoff", and "blauer Wasserstoff". We concatenated the two terms to create a single term with camel case. For example, we concatenated the two terms "Nord Stream" in "NordStream". Similarly, the numbers 2020, 2030, 2040, 2045, and 2050 are meaningful for the German hydrogen debate, so we mapped these numbers to their respective German words. Fourth, we removed numbers. However, we wanted to preserve the meaning of the chemical symbols for hydrogen and carbon-dioxide by mapping them to their respective words. Fifth, we removed "stop words". Stop words are words that appear frequently in natural language, but carry little meaning for the purposes of our analysis, such as articles, pronouns, prepositions, and first names. Sixth, we removed short words, those with less than four letters, with the exception of the term "EU", which we mapped to "EuropäischeUnion". Seventh, we dropped terms that appeared less than 25 times in the corpus (collection of articles). The contributions of these words to the topics in the model are negligible; the algorithm becomes faster without loss of statistical information. Note that we decided against transforming all words to lower case, since we wanted to preserve nouns, which, in German, are spelled with capital letters. Words that are capitalized since they appear in the first position of a sentence are mapped to their canonical forms through lemmatization.

After preprocessing, a vocabulary was created containing all terms and their frequencies in the corpus. Each document was represented as a vector of terms and their respective frequencies. The vectors were combined into a matrix, the document-term-matrix. The preprocessing steps facilitate mapping the articles to a mathematical representation, as illustrated in Figure 2.

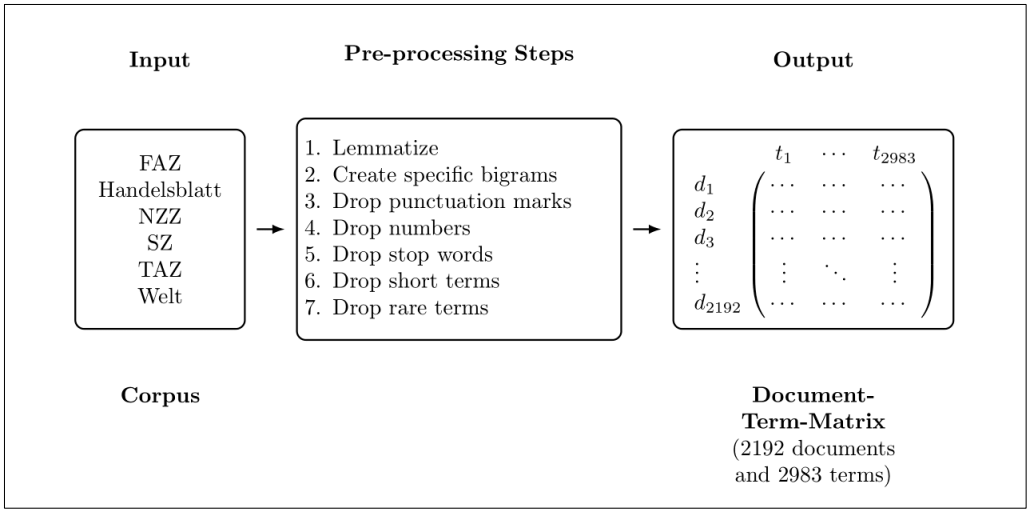

Figure 2. Transforming newspaper articles into a document-term matrix through preprocessing.

3.3. Structural Topic Models (STMs)

We analyzed our dataset using a structural topic model (STM) [6,36,37], a natural language processing method for automated content analysis, in order to evaluate the content of our newspaper article collection and to uncover temporal structures in the content. STMs have been successfully used in several studies, including an analysis of the legitimacy of wind-power technology in Germany [38].

Topic models, in general, uncover latent topics in a corpus (collection of documents) and structural topic models, in particular, facilitate assessing the influences of metadata on the topics. The STM is an extension of the latent Dirichlet allocation (LDA) [39] and the correlated topic model (CTM) [40]. The reason that we selected the STM method was its distinctive feature, the capacity to add covariates, which allows us to incorporate additional document metadata during model estimation. This flexibility sets STM apart from other topic models.

The STM is a probabilistic model based on the bag-of-words approach, in which documents are mapped to a distribution of their words, whereas the syntactical structure and the order of the words are disregarded. The algorithm partitions the distribution of words in the corpus into k topics. Topic models are mixed-membership models: they assume that each document is a combination of several topics with varying proportions. Topic models are unsupervised; given the number of topics k, they create a partition of the distribution of the words in the corpus into k parts based on variational inference, without any prior thematic input of the modeler. This method is particularly suited for exploratory research with limited a priori assumptions.

The model is specified by the number of topics k and the definition of covariates. After evaluating a large number of candidate models, we chose a model with 35 topics, as it performed best in terms of topic quality. Topic quality is a combination of semantic coherence and exclusivity of words to topics [6,41]. Semantic coherence measures the degree to which the content of a topic is meaningful. In a topic with high semantic coherence, the most widely used words frequently occur together. Exclusivity measures the uniqueness of the terms in a topic, as compared to the terms in the other topics. A topic with high exclusivity has many terms that are unique to that topic. To assess the robustness of our findings, we examined two additional models, ones with 26 and 44 topics, respectively. Encouragingly, both models yielded outcomes in line with our primary model. We assigned labels to the topics after evaluating the five most significant articles and their associated word clouds (word clouds of eight important topics are given in Appendix A).

We included two covariates: an indicator variable showing whether the article was published before or after the invasion of Ukraine, and the date of publication. The indicator variable was used to model the prevalence of the topics given the turning point of the

start of the Russian war against Ukraine. The topical prevalence contrast is a measure of the variability of topic coverage, conditional on 24 February 2022, the date of the Russian invasion of Ukraine. Based on the publication date, for each day in the time range, the algorithm estimated the share of every topic using the least-squares method on a polynomial of degree ten. Note that the shares of all topics add up to 1 for each day. Including this covariate facilitated an analysis that traces the change of topic-shares over time. Topic-shares represent the relative importance of the topics at a specific time, since prominent topics have high shares. The fluctuation of topic-shares reveals the topics that shape or dominate the discourse at a particular point in time. Figure 3 illustrates the modeling process. In our data analysis, we estimated the STM model using the R package stm [41].

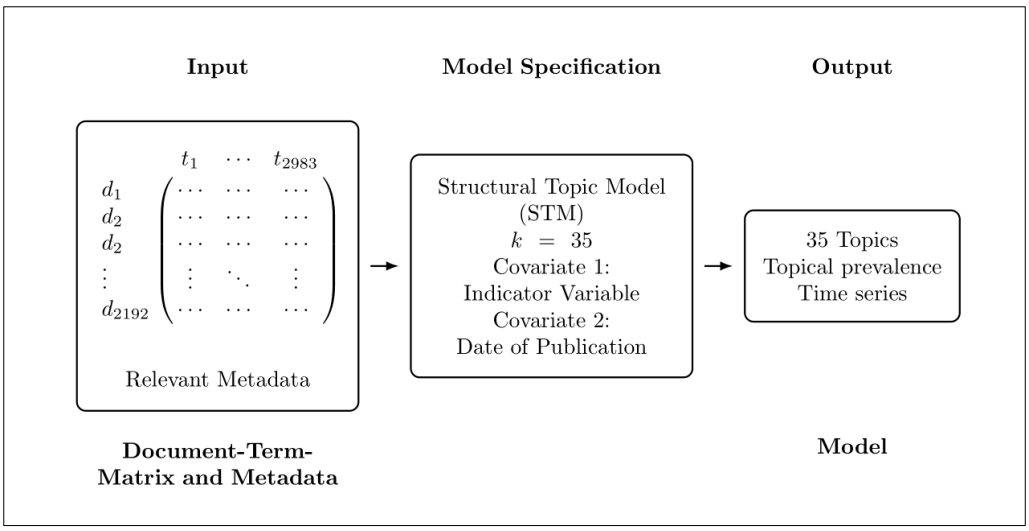

Figure 3. The structural topic modeling process.

4. Results

4.1. Topics of the German Hydrogen Discourse

Table 1 provides an overview of our 35 topics, the six most frequent words per topic, and each topic's proportion, disregarding the timeline. As explained above, each article was mapped to several topics.

Table 1. Topics and Their Proportions, Ordered by Proportion.

Topic Label	#	Top Words	Proportion
Security of Green Hydrogen Supply	11	Wasserstoff, Energie, Deutschland, erneuerbar, Strom, Energieträger	0.0651
Production of Green Hydrogen (Electrolysis)	13	Wasserstoff, Anlage, grünerWasserstoff, Strom, grün, Elektrolyse	0.0531
North German Hydrogen Strategy	27	Wasserstoff, Land, Bund, Energie, grün, Niedersachsen	0.0490
Funding for German Regional Hydrogen Projects	19	Wasserstoff, Projekt, Euro, Unternehmen, Region, Deutschland	0.0488
Hydrogen Trains	20	Wasserstoff, Brennstoffzelle, Tankstelle, Strecke, Batterie, Fahrzeug	0.0456
German National Hydrogen Strategy	32	Bundesregierung, grünerWasserstoff, Wasserstoff, Wasserstoffstrategie, erneuerbar, national	0.0389

Table 1. *Cont.*

Topic Label	#	Top Words	Proportion
Steel Industry (Green Steel)	34	Stahl, Kohlenstoffdioxid, ThyssenKrupp, Stahlindustrie, grün, Wasserstoff	0.0373
Hydrogen in Chemistry	26	Wasserstoff, Wasser, Forscher, chemisch, entstehen, nutzen	0.0357
CO_2 Pricing as Lead-Instrument of Climate Policy	15	Kohlenstoffdioxid, Industrie, Preis, Klimaschutz, Investition, Klimaneutralität	0.0337
Energy Supply During Energy Transition	9	erneuerbar, Energie, Deutschland, zwanzigdreißig, Strom, Ausbau	0.0335
Party Positions on Hydrogen	33	Deutschland, Mensch, Frage, deutsch, Union, Land	0.0320
Asian Hydrogen Car Manufacturers	25	Brennstoffzelle, Wasserstoff, Toyota, Auto, Fahrzeug, Hyundai	0.0304
Local Hydrogen Infrastructure (Bavaria)	10	Landkreis, Wasserstoff, München, Ebersberg, Landshut, Tankstelle	0.0298
Fuel Cells for Trucks	31	Daimler, Brennstoffzelle, Truck, Lastwagen, Wasserstoff, Batterie	0.0296
Hydrogen Policy of the EU and EU Member States	16	EuropäischeUnion, Kommission, Europa, europäisch, Spanien, Frankreich	0.0268
Climate-Friendly Vehicle Drives	23	Auto, Batterie, Elektroauto, Fahrzeug, Verbrennungsmotor, Mobilität	0.0266
EU Definition of Green Hydrogen	14	Kohlenstoffdioxid, Wasserstoff, Erdgas, blauerWasserstoff, herstellen, Emissionen	0.0264
German-Canadian Hydrogen Partnership	30	Habeck, Deutschland, Land, Kanada, deutsch, Scholz	0.0263
German Australian Hydrogen Partnership	1	Wasserstoff, grünerWasserstoff, Deutschland, Unternehmen, deutsch, Australien	0.0245
Heating in Private Households	6	Wärmepumpe, Strom, Gebäude, Haus, heizen, Energie	0.0234
Hydrogen Infrastructure	2	Wasserstoff, Netz, Erdgas, Wasserstoffnetz, Gasnetz, Netzbetreiber	0.0230
LNG Terminals	8	Terminal, Deutschland, Wilhelmshaven, Erdgas, Flüssiggas, Pipeline	0.0218
Aviation	29	Wasserstoff, Airbus, Flugzeug, Luftfahrt, Kerosin, fliegen	0.0216
Nucera (Thyssen-Krupp)	22	Euro, Konzern, Uniper, Unternehmen, ThyssenKrupp, Wasserstoff	0.0211
Nord Stream 2	28	Russland, Ukraine, russisch, Europa, NordStream, Deutschland	0.0210
Stock Market, Shares	17	Bosch, Aktie, Wasserstoff, Unternehmen, Dollar, Euro	0.0209
Hydrogen as Key Technology	35	China, Europa, Unternehmen, Technologie, Welt, Markt	0.0202
E-Fuels	3	Kraftstoff, synthetisch, EFuels, Kohlenstoffdioxid, klimaneutral, Treibstoff	0.0201
Hydrogen Partnerships for Bavaria	5	Bayern, Wasserstoff, Söder, Aiwanger, bayerisch, Energie	0.0191
Global Hydrogen Market Ramp-Up	7	Japan, Land, Wasserstoff, Regierung, Australien, Energie	0.0189

Table 1. *Cont.*

Topic Label	#	Top Words	Proportion
Offshore Wind Power	18	Offshore, Windpark, Projekt, Land, Windrad, Windkraft	0.0186
Hydrogen in Physics	12	Energie, Technologie, Fusion, Element, Neutrino, Wasserstoff	0.0152
Ports	24	Hamburg, Hafen, Bremen, Stadt, Wasserstoff, Standort	0.0150
Siemens Energy	21	Siemens, Energy, Wasserstoff, Konzern, Chef, Görlitz	0.0142
Hydrogen as Growth Potential for German Companies	4	Unternehmen, Start, Linde, Konzern, deutsch, Firma	0.0127

Notably, the topic labelled "Security of Green Hydrogen Supply" (topic 11) emerged as the most prevalent across the corpus, accounting for 6.51% of the corpus, irrespective of the temporal dimension. The topic with the second-largest proportion covered the production of green hydrogen (topic 13; 5.31%). Thus, the two topics with the largest share of the German hydrogen discourse between 2019 and 2022 both relate to the general theme of green hydrogen supply. Other broader themes include governance issues (topics 15, 19, 27, 32, 33, 14, and 16), trade (topics 1, 5, and 30), markets and key players (topics 4, 7, 17, 21, 22, and 35), infrastructure (topics 2, 8, 10, 24, and 28), various hydrogen applications (topics 3, 6, 20, 23, 25, 29, 31, and 34), and basic research (topics 12 and 26). The last two topics mainly appear in articles related to space exploration and planetary systems; they are excluded from our analysis, as they fall outside the scope of the political discourse.

4.2. Topical Prevalence Contrast

In addition to the topics, the results of the modeling exercise include estimates of the relationships between the topics and the covariates. Covariates can be understood as annotations of the articles' texts; they hold information about the articles which is in addition to that within the articles' texts. The first covariate is an indicator variable showing whether the article was published before or after the invasion of Ukraine. This variable is used to elicit a topical prevalence contrast, a measure of the variability of topic coverage conditional on 24 February 2022, the date of the Russian invasion of Ukraine. The results of our topical prevalence contrast analysis are given in Figure 4.

The majority of the topics displayed an even distribution of articles before and after the invasion, implying that the Russian incursion into Ukraine did not considerably affect the coverage of these topics (Figure 4). However, there were exceptions to this trend. Notably, three topics, namely "Nord Stream 2", "LNG Terminals", and the "German–Canadian Hydrogen Partnership" experienced a substantial surge in coverage after 24 February 2022, suggesting a sudden shift in focus towards these subjects, following the Russian invasion of Ukraine. This shift underscores the clear impact of the invasion on the relative significance and relevance of these topics within the discourse on hydrogen in Germany. Conversely, the topic "German National Hydrogen Strategy" was primarily a subject of discussion and reporting before the invasion, indicating that its peak attention and relevance within Germany's hydrogen discourse occurred prior to the war.

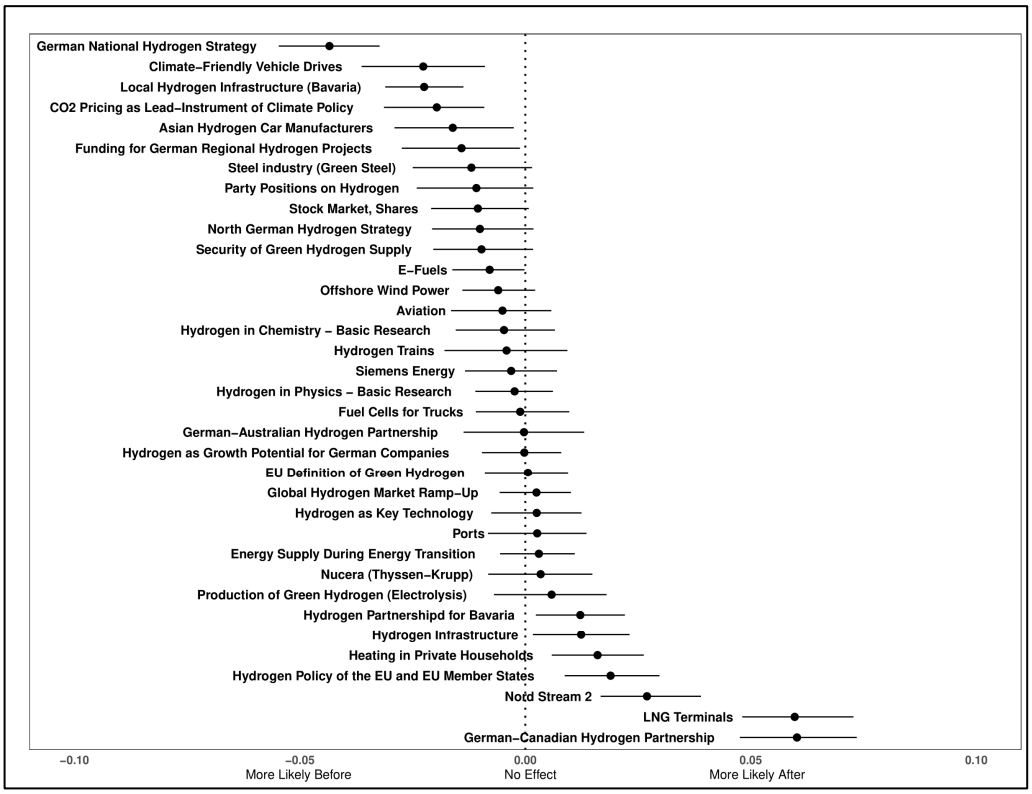

Figure 4. Topical prevalence contrast in the German hydrogen discourse, 2019–2022. Dots denote the means, and lines denote the 95% confidence intervals of the estimates.

4.3. Topic Dynamics

The second covariate in our structural topic model is the publication date of each article. The inclusion of this covariate facilitates an analysis that tracks changes of topic-shares over time. Topic-shares represent the relative importance of the topics at a given point in time. Prominent topics have high shares. The change of topic-shares reveals the topics that shape or dominate the discourse at a particular point in time.

Figure 5 displays the shares of the topics with the highest shares at some point in time during our investigation period (see Appendix A for the word clouds of these topics; the changes of shares over time for all topics are displayed in Appendix B). The topics with the highest shares before the start of the Russian war against Ukraine include "Hydrogen Trains", "German National Hydrogen Strategy", "Funding for German Regional Hydrogen Projects", "CO_2 Pricing as Lead-Instrument of Climate Policy", and "Energy Supply During Energy Transition".

Following the start of the Russian war against Ukraine, three distinct topics gained prominence: "Nord Stream 2", "LNG Terminals", and "German–Canadian Hydrogen Partnership". These are the very topics already identified through our topical prevalence contrast analysis as exhibiting the highest levels of coverage after 24 February 2022. Furthermore, the trajectories of these topics display a noticeable upward trend at the time of the invasion (Figure 5). Remarkably, this upward trajectory began prior to the outbreak of the war, indicating that these topics had already begun attracting attention in the weeks leading up to the war. Both the "LNG Terminals" and "German–Canadian Hydrogen Partnership" topics emphasize the political priorities of the time, which were to ensure a secure energy supply as an alternative to pipeline gas imports from Russia.

The topic "Nord Stream 2" complements the most-discussed topics at the time of the Russian invasion. This topic shows a noticeable shift in content. The articles published before the invasion reported on the dispute over the Nord Stream 2 Baltic Sea pipeline as a means for meeting the energy and resource needs of Germany, an industrial and export

economy, the use of the pipeline for hydrogen, the geopolitical importance of the pipeline given the transit agreements between Ukraine and Russia, and the dependence of Germany on Russian gas. In contrast, articles discussing Nord Stream 2 after the invasion associate the pipeline with the energy dependence of Germany on Russia [42] and the search for alternative energy trade partners in order to become independent of Russia.

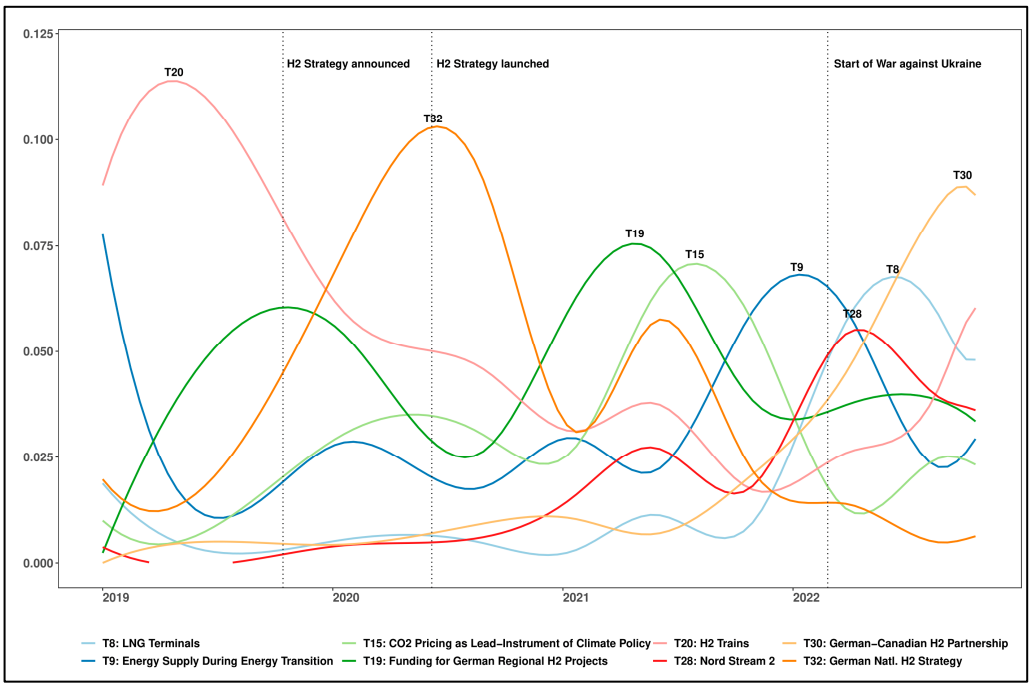

Figure 5. The change of topic proportions over time. This figure shows the shares of the topics with the highest shares at some point in the time frame. The vertical dotted lines denote three pivotal dates: 15 October 2019: the announcement of the German National Hydrogen Strategy; 7 June 2020: the launch of the German National Hydrogen Strategy; and 24 February 2022: the start of the Russian war against Ukraine.

5. Discussion

The evidence of the topical prevalence contrast and topic dynamics of our 35 topics indicate that the discourse on hydrogen has solidly entrenched itself as a fundamental element of Germany's energy strategy. It centered around "green" hydrogen for storing renewable energy as an essential part of Germany's energy transition process (topics 11, 13, 43, and 14). It is evident that some of our topics from the German hydrogen discourse are also discussed in the wider German discourse on energy transition, such as "CO_2 Pricing as Lead Instrument of Climate Policy" (topic 15) and "Energy Supply During Energy Transition" (topic 9). This is in line with the main findings in the literature on energy transformation in Germany [26].

As far as the influence of the Russian war against Ukraine on this discourse is concerned, there is a clear shift in content, marked by the beginning of the war as a critical juncture. Looking at the prevailing topics before and after the onset of the war, we discern three central shifts. (1) The first shift reintroduces the security of supply discourse at the expense of the dominant sustainability discourse. (2) The second shift highlights the external dimension of hydrogen and underlines the crucial role of such imports in the energy transition, with a special focus on energy partnerships. (3) The first two shifts are directly linked to the third one, which redirects the discourse towards the innovation process of hydrogen technologies, with a specific emphasis on infrastructure issues. With a focus on LNG terminals that will be hydrogen-ready in the security shift, the discussion revolved around envisioning hydrogen-readiness, delineating the innovation process, and identifying the necessary infrastructural requirements.

5.1. Shift of Discourse from Sustainability Considerations to Securing Energy Supplies

With respect to discernible shifts brought about by the start of the Russian war against Ukraine in February 2022, our analysis shows that the Russian invasion of Ukraine was a global turning point with implications for German energy policy. In this regard, the findings from our topical prevalence contrast analysis, as depicted in Figure 4, reveal a notable change in the German hydrogen discourse. Prior to 24 February 2022, the discussion predominantly focused on sustainability and climate-change mitigation. However, following the Russian invasion of Ukraine, the discourse shifted to securing energy supplies by obtaining new energy trade partners and introducing a long-neglected form of energy supply, namely, LNG, through its own terminals, terminals which could later be used for hydrogen imports. This is in line with the literature, which identifies a renewed focus on the energy security paradigm after the start of the Russian war against Ukraine [4,5,43].

Before 24 February 2022, the German hydrogen discourse focused heavily on the National Hydrogen Strategy (announced in 2019 and implemented in 2020) and related aspects such as public funding of hydrogen research projects, the contribution of hydrogen to the energy transition, and potential applications of hydrogen technology (Figure 4); these areas had little potential for conflict, as shown by discourse network analyses [2,16]. Before the discussion about the National Hydrogen Strategy, there was a notable absence of discussions specifically discussing (green) hydrogen, despite its high relevance within the context of energy and the energy transition [1] (p. 8). In general, most industry stakeholders supported the use of hydrogen in their respective sectors, with a minority arguing for restricting its use and prioritizing hydrogen for sectors with limited decarbonization alternatives to ensure that it is used where it is needed most [16] (p. 11). Considerations of energy transition, sustainability, and climate-change mitigation led to a strong focus of the discourse being on hydrogen production methods and the choice between using fossil fuels to quickly provide large quantities of hydrogen for a transitional period (blue hydrogen) or focusing exclusively on renewables for hydrogen production from the very beginning of the hydrogen market ramp-up (green hydrogen) [2,16].

With the increasing tension between Russia and Ukraine after late 2021 and the Russian invasion of Ukraine on 24 February 2022, securing energy supplies gained a new urgency and replaced sustainability as the main focus in the German public discussion (Figure 5). As for the timing, the rise of these topics in the German hydrogen discourse started a few weeks prior to 24 February 2022. This underscores the awareness of the Russian preparations for an invasion and the apprehensions regarding its potential consequences for Germany and the European Union. The outbreak of the war exposed the fragility of an economy dependent on a solitary predominant energy trade partner, which in the case of pre-war Germany, was Russia for gas. Indeed, it is the above-mentioned shift within the topic of "Nord Stream 2" which highlights the relevant nuances of the German hydrogen discourse and its embeddedness in the larger German energy discourse. Before the war, there was an ongoing contentious discussion surrounding the potential utilization of Nord Stream 2 for hydrogen transportation from Russia to Germany. In the articles published after the invasion, Nord Stream 2 is discussed with a focus on (green) hydrogen as a replacement for the now-unavailable gas via Nord Stream 2, and the possibility of securing hydrogen access through agreements with new trade partners, including Canada (and nearby North African countries). Even though the war scrambled the natural-gas landscape of Europe as a whole and the European Union developed new policies and sought alternative gas sources in order to reduce Russia's revenues and influence [44], Germany, with its high dependency on Russian natural gas, was especially affected. With Russia no longer an acceptable gas provider, Germany took regulatory action to mitigate the risks associated with a potential gas shortage, while exploring alternative carriers for its gas demand, such as LNG delivered by ship from energy partners to substitute for Russian gas delivered by pipelines like Nord Stream [45]. This highlights the shift towards hydrogen as a key energy carrier for securing Germany's energy supply in response to the geopolitical changes brought about by the

invasion and the shift towards the external dimension of importing (green) hydrogen, in order to realize Germany's energy transition.

This shift has also contributed to the update of the German National Hydrogen Strategy, in which importation now plays a central role. In addition, in 2023 the German government has announced its own hydrogen import strategy.

5.2. External Dimension of Hydrogen Policy—New Energy Trade Partners

Finally, securing energy supplies necessarily required Germany to look for new energy trading partners. Before Russia's invasion of Ukraine, the import of hydrogen, if mentioned at all, was discussed in more theoretical and normative terms. Advocates for hydrogen imports argued that importing hydrogen from countries with better renewable energy conditions could lead to cost savings, and the imports support the development of these regions, while they benefit German technology exports and achieve climate-friendly energy supply. However, critics of hydrogen imports raised concerns about potential import dependencies, environmental and social risks for exporting countries, and the danger of perpetuating exploitation or colonialism [16] (p. 12). While this strand of the discourse did not become obsolete with the events of 24 February 2022, the new discussion about energy imports and the search for energy and hydrogen-partnerships gained prominence. In our STM analysis we identified three topics that relate to emerging energy trade partners (i.e., "German–Canadian Hydrogen Partnership", "German–Australian Hydrogen Partnership", and "Hydrogen Partnerships for Bavaria"). Energy and hydrogen partnerships with politically-less-stable countries such as Morocco or Chile are also mentioned in the media, but they do not form independent topics in the German hydrogen discourse.

The importance of Bavaria in our analysis can be attributed to several factors. The *Süddeutsche Zeitung*, based in Munich, Bavaria, has both a national and a regional readership and, in addition to its national focus, also includes a regional section. More importantly, Bavaria ranks among the wealthiest German states, and its government is committed to expanding Bavaria's technological expertise in the domain of innovative hydrogen technologies, as underlined by the establishment of the "Hydrogen Alliance of Bavaria" in 2019. Bavaria's strategic endeavors further include collaborations with various countries, such as the United Arab Emirates (in February 2022), Scotland (in June 2022), and Austria and Italy (in November 2022).

The German–Australian Hydrogen Partnership originated in June 2021 as an extension of Germany's existing energy collaboration with Australia, which commenced in 2017. The expansion of this partnership to include hydrogen was formalized through a memorandum of understanding on a joint Australian–Germany research partnership signed on 19 November 2020 [46] (p. 14773). Initially, the German–Australian partnership had a mid-term orientation, beginning with applied research projects. These projects included the creation of a German–Australian Hydrogen Innovation and Technology Incubator (HyGATE), the establishment of a German–Australian Hydrogen Hub, and explorations into the possibilities of setting up supply chains for hydrogen and its derivatives, connecting Australia to Germany under the name HySupply [47].

As previously mentioned, it was the emergence of Canada as a new trade partner for hydrogen which gained significant attention following the onset of the Russian invasion of Ukraine. Canada is actively positioning itself as a major player in the global clean-hydrogen market, emphasizing green hydrogen production and leveraging its abundant resources, technological expertise, and proximity to key import markets [48] (p. 7030). The country's ambitious hydrogen strategy, backed by substantial federal investment, aims for it to be a leader in hydrogen exports by 2050, achieving net-zero emissions and fostering its domestic hydrogen sector while addressing the challenge of balancing short-term crisis responses, like LNG supply to Europe, with long-term objectives for renewable energy [49].

Canada and Australia, both highly industrialized Western democracies with strong human rights and environmental standards, are considered normative, correct hydrogen

suppliers for Germany. In the context of Germany's transition to renewable energy sources, these countries offer a reliable source of hydrogen.

Regarding Germany's external hydrogen strategy, experts attest that Germany has assumed a very prominent international leadership role on green hydrogen. Thus, Germany's "H2Global" initiative from late 2022, designed for the international procurement of green hydrogen derivatives in particular, represents an innovative and highly visible effort in this regard [50,51]. Germany's concentration on green hydrogen is also reflected in the national hydrogen discourse, as the two topics with the largest proportions relate to green hydrogen provision covering the security of green hydrogen supply (topic 11) and the production of green hydrogen (topic 13) (see Table 1).

In the years before the war, the EU and Russia had initiated a program of cooperation to develop a hydrogen market. Germany had backed this cooperation on the premise of a shared gas pipeline infrastructure and bilateral industrial cooperation. At the time, the potential of Russia as a hydrogen producer was limited to the production of non-green hydrogen in the short to medium term [52]. The war-related end of Russian gas imports and the dissolution of the energy partnership between Russia and Germany, captured by the topic "Nord Stream 2" in the German hydrogen discourse, is interpreted by observers as an opportunity. The end of gas trade with Russia has led Germany to turn to other energy partners, and the continuing high demand for energy has provided signals and incentives for the development of a hydrogen market at a large scale [53] (p. 9). More than ever before, Germany (not least due to the composition of the government, between Social Democrats (SPD), Liberals (FDP) and the Green Party) is pursuing faster decarbonization and reduced energy vulnerability as key policy goals, similar to the EU [21]. Like the broader energy policy landscape, the German hydrogen policy exhibits a significant interconnection between supply security and sustainability [42]. Likewise, the new energy partnerships are forged in an institutional and political context which is designed to achieve synergies between security of energy supply and sustainability [29] (p. 407). Thus, in Germany, the focus of the development of the hydrogen market is on the promotion of green hydrogen, which is crucial for decarbonization [50]. The partnerships of Germany with Australia and Canada reflect this priority to develop solid, geopolitically risk-free global value chains [53].

5.3. The War as a Driver for the Hydrogen Innovation Process—The Discourse on LNG Terminals and the Focus on Infrastructure

Until 2022, Germany had relied on natural gas transported by pipeline. Thus, it did not have any LNG terminals and was dependent on LNG imports via neighboring countries, such as Belgium or the Netherlands. Yet, only three days after the Russian invasion of Ukraine, Chancellor Olaf Scholz announced at a special session of the German Bundestag that two LNG terminals were to be built in Germany in Brunsbüttel and Wilhelmshaven, at short notice [34]. In addition, a rapidly formulated "LNG Acceleration Act" came into force on 1 June 2022.

With regard to the hydrogen discourse, the focus was on LNG as a "bridge fuel" to be used until renewable (green) hydrogen would be accessible in sufficient quantities, as well as on the "H2 readiness" of the new LNG terminals to be constructed. Indeed, "H2 readiness" of the LNG terminals was also incorporated in the German LNG Acceleration Act, which stipulated that land-based LNG terminals and their peripherals, such as associated gas pipelines, be suitable for future use with hydrogen, aligning with the climate protection goals outlined in the Federal Climate Change Act.

Thus, Russia's invasion of Ukraine has not only triggered a fundamental shift in Germany's approach to LNG and the construction of an LNG import infrastructure, but the argument of "H2 readiness" for LNG terminals in Germany is also an indicator of the growing integration of green hydrogen as a technology and energy carrier into the energy system. The adoption and integration of hydrogen into practical applications, various industries, and infrastructure, like LNG terminals, are essential steps in establishing

hydrogen as a viable energy solution. This integration is crucial for the transition of hydrogen from a research environment to a technology that has a substantial impact on the country's energy landscape. As previous research has shown, technology adoption is often a bottleneck in the innovation process [19]. External shocks, like, in the present case, the start of the Russian war against Ukraine, can accelerate the discussion and adoption of new technologies [30], here, green hydrogen as a (clean) energy source. This external event acts as a driver for the innovation process, facilitating the diffusion of hydrogen technology in Germany. The principle of "H2 readiness" for LNG terminals is not merely a symbolic gesture, but represents a practical step in the larger process of technology adoption, ultimately contributing to the successful deployment of green hydrogen in the German energy landscape. However, it is important to note that the concept of adoption does not rule out the possibility of "H2 readiness" becoming technically unfeasible or economically unviable in the future [54].

The Russian war of aggression against Ukraine has substantially increased the expenses related to natural gas, and, consequently, it has impacted the costs associated with blue hydrogen produced from natural gas using the carbon capture and storage (CCS) technique to separate and store CO_2. The construction of LNG terminals and their associated infrastructure in Germany, as a direct reaction to the war, was designed to cater to immediate and direct natural gas requirements, with hydrogen production not being their primary objective. Rather, the post-invasion discourse surrounding hydrogen is concentrated on "H2-readiness" of LNG terminals and the development of energy partnerships for hydrogen, both of which, in 2022, were medium-term endeavors.

6. Conclusions

In conclusion, our central aim in this study was to analyze the impact of the Russian–Ukrainian war on the discourse on hydrogen in the German media. To achieve this objective, we employed an innovative natural language processing method known as structural topical modeling (STM). This approach was applied to a substantial dataset comprising 2192 newspaper articles spanning the years 2019 to 2022. Through the application of STM, our intention was to uncover the prevailing thematic elements within this discourse and discern significant shifts that could be attributed to the Russian invasion of Ukraine.

The comprehensive examination of topical prevalence contrast and topic dynamics across our 35 topics offers crucial insights into the discourse surrounding hydrogen in Germany. Looking at the impact of Russia's war against Ukraine on this discourse, there is a discernible shift in content which marks a critical juncture with the start of the war. Examining the prevailing topics before and after the war's onset reveals three key shifts.

First, Russia's war against Ukraine intensified the debate on securing energy supplies, replacing sustainability as the main focus in the German public discourse. Prior to this point, discussions primarily revolved around the National Hydrogen Strategy, hydrogen research projects, and applications, with little attention to (green) hydrogen despite its relevance to the energy transition. The war revealed the vulnerability of an economy heavily dependent on Russian gas, and Germany began to explore alternative energy carriers such as LNG. Consequently, the discourse shifted towards hydrogen as a key energy carrier to secure Germany's energy supply, influencing the update of the German National Hydrogen Strategy and the announcement by the Federal Government of a hydrogen import strategy for 2023.

Secondly, the external dimension of hydrogen is highlighted, emphasizing the pivotal role of imports in the energy transition, particularly through energy partnerships, as evident in topics such as the "German–Canadian Hydrogen Partnership" and the "German–Australian Hydrogen Partnership." These partnerships exemplify Germany's commitment to developing stable and geopolitically secure global value chains in the hydrogen market. Germany's external hydrogen strategy, in particular the "H2Global" initiative, has further underlined its leading role in promoting green hydrogen on the international stage.

Thirdly, the war redirects the discourse towards the innovation processes of hydrogen technologies, with a particular emphasis on infrastructure issues. With a notable focus on LNG terminals preparing for hydrogen integration during the security shift, the discourse includes discussions on envisioning H2-readiness, outlining the innovation process, and identifying essential infrastructural requirements.

All in all, these three shifts clearly illustrate the influence of the Russian war against Ukraine on the hydrogen discourse, redirecting the conversation from internal to external dimensions of the German hydrogen policy, including technology and infrastructure issues.

From a methodological perspective, our contribution shows that analyzing German texts with structural topic modeling (STM) remains a challenging endeavor. Standard stop-word lists proved insufficient for this task and supplementing them with custom stop word lists can introduce inherent biases. Furthermore, the selection of the optimal number of topics, denoted as "*k*" in the model, relies on expert judgment. In our study, we employed semantic coherence and exclusivity measures to determine this value and checked for robustness of our choice. However, it is important to note that different modelers may opt for alternative measures, potentially leading to different "*k*". In addition, it is worth highlighting that the labeling of our topics is based on our interpretation of the content. Although the partitioning of the corpus into 35 topics is performed by an algorithm based on statistics, an evaluation of the results by experts is essential. This clearly shows that, especially in times of increasingly frequent use of large language models (LLM), in-depth knowledge of the context in which the algorithms are used is becoming ever more important.

Regarding the structural topic modeling (STM) method for automated content analysis, which relies on a probabilistic model that maps documents to word distributions, it provides a valuable means to uncover latent topics and hidden structures within a collection of documents. However, it does not readily reveal stakeholder positions [55] or conflicts among stakeholders [2,16], as can be achieved through other discourse analysis tools.

The next logical step involves a compelling endeavor to establish connections between the topics and their evolution before and after the start of the Russian war against Ukraine, together with stakeholder perspectives. These connections would aim to discern the roles of policy entrepreneurs and the existence of conflicting positions within the discourse.

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Appendix A

Word Clouds of the Topics in Figure 5.

Figure A1. Word cloud topic 8—"LNG Terminals".

Figure A2. Word cloud topic 9—"Energy Supply During Energy Transition".

Figure A3. Word cloud topic 15—"CO_2 Pricing as Lead Instrument of Climate Policy".

Figure A4. Word cloud topic 19—"Funding for German Regional Hydrogen Projects".

Figure A5. Word cloud topic 20—"Hydrogen Trains".

Figure A6. Word cloud topic 28—"Nord Stream 2".

Figure A7. Word cloud topic 30—"German–Canadian Hydrogen Partnership".

Figure A8. Word cloud topic 32—"German National Hydrogen Strategy".

Appendix B

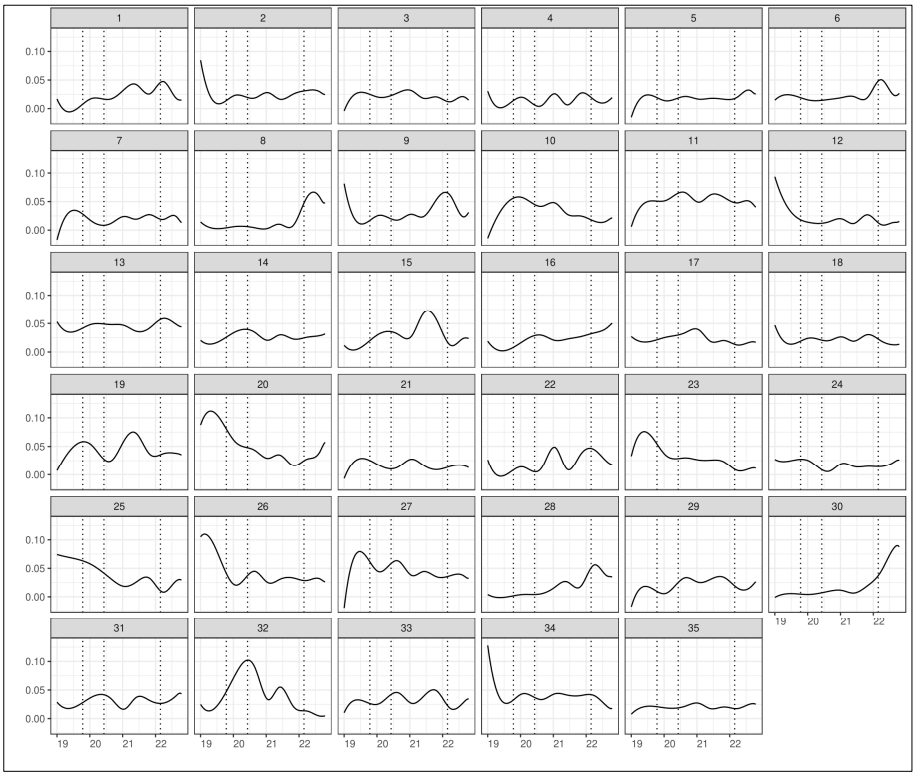

Figure A9. Topic proportion change over time—all topics. The vertical dotted lines denote three pivotal dates: 15 October 2019: the announcement of the German National Hydrogen Strategy; 7 June 2020: the launch of the German National Hydrogen Strategy; and 24 February 2022: the start of the Russian war against Ukraine.

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