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The more the merrier? Actors and ideas in the evolution of German hydrogen policy discourse

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ABSTRACT

Hydrogen has set high hopes for decarbonization due to its flexibility and ability to decarbonize sectors of the economy where direct electrification appears unviable. Broad hydrogen policies have therefore started to emerge. Nevertheless, it is still a rather niche technology, not integrated or adopted at scale, and not regulated through particular policy provisions. The involved stakeholders are thus still rushing to set the agenda over the issue. All this plays out publicly and shapes the public discourse. This paper explores how the composition of stakeholders, their positions, and the overall discourse structure have developed and accompanied the political agenda-setting in the early public debate on hydrogen in Germany. We use discourse network analysis of media, where stakeholders' claims-making is documented, and their positions can be tracked over time. The public discourse on hydrogen in Germany shows the expected evolution of statements in connection with the two milestones chosen for the analyses the initiation of the Gas 2030 Dialogue and the publication of the National Hydrogen Strategy. Interestingly, the discourse was comparatively feeble in the immediate aftermath of the respective milestones but intensified in a consolidation phase around half a year later. Sequencing the discourse and contextualizing its content relative to political, societal, and economic conditions in a diachronic way is essential because it helps to avoid misinterpreting the development of stakeholders' standpoints as conflict-driven rather than mere repositioning. Thus, we observed no discourse "polarization" even though potentially polarizing issues were already present in the debate.

1. Introduction

Despite the urgency of climate change, the pace of implementation of low-carbon solutions in the energy sector has not been as fast as in other sectors of the economy (e.g., transport, industry, and buildings). These so-called *hard-to-abate sectors* require more effort to transform them towards sustainability, largely due to the difficulty of their direct electrification [1]. High hopes are therefore placed on hydrogen [2–4], considered a nascent technology [5] and key element of the "future green energy society" [6]. Yet, the technological and market ramp-up of hydrogen is complicated by competition with other low-carbon options, lack of hydrogen technologies and their relatively high developing costs, scarcity of green energy sources, and energy losses within the conversion process [7].

How hydrogen is to be incorporated into the existing energy system

has not yet been determined but has gained importance [8], not least due to the Russian war against Ukraine. However, a possible confrontation among involved stakeholders might still be expected. This article provides an overview of the literature on the relevance of hydrogen in the process of energy transition (Section 2). One of the key arenas where stakeholders both compete and demonstrate their positions is public discourse, which they attempt to shape through constant engagement in public arenas (notably the media space), trying to win broader support and make their respective standpoints visible. We elaborate on the assumptions about the role of media and discourse in policymaking in Section 3.

The goal of the study is to identify and map how the composition of stakeholders, their positions, and the overall discourse structure have developed; how the discourse has shaped the political agenda (agenda setting) in the early stages of hydrogen public debate in Germany; and

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what expectations have been attached to hydrogen as an energy carrier through asserted claims. We see the discourse as a product of actors' claim-making activity and thus approach the goal from the perspective of the discourse structure. Hence, we ask the following research questions: (1) What types of actors participate in the hydrogen debate? (2) What ideas do they subscribe to? (3) What are the discourse structure characteristics? (4) How has the discourse evolved over time?

This article presents data for the evolution of the hydrogen discourse for the case of Germany—a frontrunner in the development and application of hydrogen technologies [9,10]. The time frame, media coverage and selection, and applied methods of content analysis and social network analysis are described in detail in Section 4. In contrast to other analyses, we work with a sequencing method, which has produced innovative results as presented in a descriptive manner in Section 5 and discussed in Section 6.

2. Hydrogen in energy transition – state of the art

This article relates more broadly to the literature on the relevance of hydrogen in the process of energy transition. These studies pay attention to the hydrogen decarbonization potential and the possibility of its application in various economic sectors [2,4,6,7,11–13]. In particular, the prospects of hydrogen use as energy storage are discussed. It is assumed that a wider presence of hydrogen in the energy system may help to solve the problem of intermittent renewables by maintaining balance through converting excess energy into hydrogen and its reverse transformation into energy in the event of a shortage [4,11].

Focusing on the German transition, energy transition studies emphasize the critical importance of hydrogen in areas where direct use of electricity appears too expensive, inefficient, or not possible at all [14–18]. In particular, the low-carbon transformation of the main German industries, especially chemical and steel, together with the transportation sector, will require significant amounts of green hydrogen [19] (produced by electrolysis with electricity exclusively from renewable energy sources and thus CO₂-free; see [20] for more details on hydrogen color classification). Such demand would potentially make hydrogen “one of the pillars of the energy transition” alongside renewables and energy efficiency [14]. Some researchers, such as Kruse & Wedemeier [15], claim that direct implementation of hydrogen technologies into the German economy is possible, and the hydrogen race has already begun at both the national and international levels. However, large-scale hydrogen expansion requires major infrastructure changes. Such changes, in turn, will require a constructive and productive dialogue among authorities, stakeholders, and the public to create transparency, clear sector regulation, and financial confidence for investors.

When it comes to the societal component, several studies have focused on public perception and acceptance of hydrogen technologies in Germany, with a primary focus on its application in transportation [21–24]. A mostly positive attitude has been found, with special attention to the way hydrogen is produced, namely its creation from renewable energy [22]. Overall, public acceptance and a relatively high level of awareness about hydrogen technologies were noted in Germany [25]. Such attitude creates favorable conditions for further communication on the part of decision-makers and stakeholders about the specific structure of the hydrogen economy.

Stakeholders' views on the hydrogen economy development, as well as their positions relative to other stakeholders, have been investigated directly through interviews [26–30] and through analyses of their announcements and publications [31–33]. However, their engagement in public debates as presented in the media and the relational aspect of alignment on ideas has been less explored. Only Ohlendorf et al. [34] have analyzed German media relating to hydrogen, but they cover an earlier time period in a synchronic way, not accounting for discourse development over time. We attempt to fill this gap by mapping the development of the hydrogen discourse over time and thereby

uncovering the (re-)alignment of actors and concepts within that discourse beyond actors' joint initiatives or proclaimed connections.

3. Discourse and policy making

In this section, we first discuss the importance of discourses in policymaking, especially in relation to emerging policies. Second, we elaborate on how and why media allow us to analyze and interpret discourses in a diachronic way. Lastly, we argue that the relational perspective of actors and their concepts is useful in understanding the development of policy discourses.

Discourse is a set of ideas, concepts, and categorizations that are produced, reproduced, and transformed into practices that give meaning to reality [35]. It constrains and, simultaneously, enables social action [36], depending on what interpretation of reality is dominant at the moment. The establishment of any policy is thus contingent on the respective discourse around the issue. Discourses play a crucial role in the policy process [37], and the policy process thus can also be seen as “a struggle for the discursive hegemony in which actors try to secure support for their definitions of reality” [35]. To gain the leading position in a discursive field, actors publicly express their positions or, in other words, make claims in an attempt to make themselves visible and gain or maintain support for their vision of a particular issue. Therefore, claim-making—i.e., publicly stated affiliation towards ideas—is an integral part of the policymaking process [38] and may even be perceived as a form of strategic action [39]. The discursive hegemony of a certain perception of a policy issue is achieved through the process of discourse structuration [36], through which the diverse visions of actors reach a certain coherence. At this point, many trajectories may be taken as actors' positions are formed based on experience from other policy domains (along with other conflicts and cleavages), the input of independent experts, and new emergent interactions [40,41]. The (dis)similarity of positions towards claims may even lead to the emergence of discernible discursive coalitions of actors [35,42]. The ability of any such coalition to dominate the public discourse will influence policy initialization, where articulated concepts come to be acted upon within the policy process [36,43].

Media may be regarded as a reasonable proxy for the discourse content, even though there is no straightforward causal relationship [44,45]. The media act as an arena where actors compete for attention through claims-making. If claims find audiences, these, in turn, legitimize the positions of claims-makers and allow them to further their interests [46]. Thus, quality media provide a useful picture of claims-making activity, albeit not perfectly neutral. Moreover, if observation over time is required, media prove to be among the less biased sources for investigating dynamics [47].

We see the claims-making activity as inherently relational. Actors strategically place themselves in positions of alignment or conflict vis-à-vis other actors using certain language patterns. Actors might increase the salience of certain claims by repeating them in the public sphere over and over or set boundaries through disagreement over certain ideas. In addition, some actors subscribe to multiple claims and/or choose conflictual positions, while others do not or cannot. Thus, discursive interactions, as well as emergent discourse structures, can be observed [47] and operationalized as networks of actors and concepts—so-called “discourse networks”. In discourse networks, actors form ties to concepts, and the network is delimited by all actors and the concepts they subscribe to. It is worth noting that most theories related to the political process agree that the primary actors are organizations or institutions; we reflect this and treat individual actors as representatives of the institutions and organizations they are affiliated with [48].

Discourse networks can be investigated systematically. Actors' connections to claims show their relative positioning within the investigated issue, and connections among claims show similarities or differences in actors' positions. Actors and constructs at the center of such a network can be considered the most influential for the policy

process [48,49]. The overall structure of the network reveals specific patterns, such as a tendency towards polarization in clusters or centralization around a certain influential core. Analysis of the discourse network thus does not approach the discourse from the typical content-analytical perspective but from the perspective of actors' discursive micro-actions, which together form a macro-structure—i.e., the discursive landscape over the respective issue. This perspective may then contribute to a better understanding of the discursive layer of policy-making, allowing us to see its content and structural features.

4. Methods

4.1. Time frame

The starting point of the (current) German hydrogen debate is the “Dialogue Process Gas 2030” initiated by the Federal Ministry for Economic Affairs and Energy in December 2018. The dialogue process provided the framework for debate on the future of gas-based energy sources in the energy transition with selected stakeholders and, as an interim result, led to the announcement [50] of a national hydrogen strategy by Economics Minister Peter Altmaier (CDU) in October 2019 (09.10.2019). Thus, the gas dialogue put green gases and hydrogen on the agenda of a broad expert public. One year later, with the publication of the National Hydrogen Strategy in June 2020 (10.06.2020) [51], the topic moved into the focus of the general public for the first time.

The Dialogue Process Gas and the National Hydrogen Strategy are the two main political landmarks of German hydrogen policy. So far, there have been no other key moments in Germany that genuinely relate to the topic of hydrogen, although other events such as the publication of the European Hydrogen Strategy or the German Climate Protection Act have significantly advanced the German hydrogen discourse with hydrogen having now become the main element in the process of the energy transition (as the analysis will show).

The initial phase of the research focused on the requirement of a sufficient number of articles [52] that contain claims (for more details on what constitutes a claim, see Appendix A). This pre-analysis stage required an investigation of media coverage on the issue (number of articles on the topic that delimit the scope of analysis). The results showed quite a low visibility of the issue in the immediate aftermath of both landmarking events (see Table 1) and virtually non-existent coverage before both events, which contradicts the typical assumption of a short media attention span with peak coverage in the aftermath of mediated events [53,54]. Moreover, media studies typically select timeframes after [55–57] or both before and after [58–60] important events but do not additionally segment those periods. Following this observation, we expanded the time frame after both landmarking events to one year. In addition, we broke each of the two periods following the chosen landmarking event into two sub-periods—which we refer to as “phases”—to allow more granular insight. This resulted in four phases of equal length for our analysis: the first six months after each of the two landmarking events (i.e., the *event phase* = E) and the subsequent six months (i.e., the *consolidation phase* = C). The division into two phases of six months each enables us to uncover shifts in actor constellations and

discourse content based on sufficiently comprehensive data. It also allows us to analyze how the discourse has developed in the medium term after each of these two events.

4.2. Data collection – media coverage

For the data collection, *Frankfurter Allgemeine Zeitung* (FAZ) and *Süddeutsche Zeitung* (SZ) were selected. These daily newspapers fulfill the criterion of nationwide quality press and have the highest circulation in this category. Thus, they can be assumed to have a substantial influence on society and decision-makers. In addition, both newspapers cover a large part of the ideological spectrum of German politics. SZ is considered socially liberal, while FAZ has a more conservative profile [61,62].

The text corpus was formed by searching the databases of FAZ (<https://www.faz-biblionet.de>) and SZ (<https://archiv.szarchiv.de>) with the search term “hydrogen”. Only articles dealing with hydrogen in the context of energy were used for the analysis. Articles by news agencies like Reuters or DPA (*Deutsche Presse-Agentur*) were included only once. Letters to the editor and articles on hydrogen as a chemical element (in the context of planets, from a historical perspective, or without a clear assignment of claims to specific actors) were excluded.

The final corpus includes 279 articles (FAZ: 186, SZ: 93). All contain a clear indication of actors who make claims on hydrogen policy in the form of direct or indirect citations. The dataset contains articles published in the selected time frame (see Table 1, also Appendix G).

4.3. Coding

The Discourse Network Analyzer (DNA) software [63] was used for data organization and coding. Coding units—instances of claims-making—were identified, and each coding unit was selected to represent a single coherent idea expressed by a stakeholder (actor). Each coding unit was assigned the following variables: *media source*, *publication date*, *individual*, *actor-type*, *organization*, *concept*, and *agreement*. Media source and publication date (metadata) were assigned to each claim according to the publication date of the article containing the claim.

Individuals, organizations, and organizational (actor) types were coded inductively in two steps. First, in-vivo codes (derived directly from the actual language) were assigned [64]. Second, these codes were reorganized and relabeled in an iterated process over the codebook [52,64]. Two hundred sixty-nine individuals representing 185 organizations were identified (see Appendix B for assignment). We treat organizations as actors/stakeholders. The organizations were classified based on their activities (see Appendices C and D). A distinction is made between four broad groups of actor types: (I) civil society organizations, (II) research institutions (including think tanks), (III) political actors, including government and political parties, and (IV) economic actors. The group of economic actors was further subdivided to better account for prominent types of actors within this broader category. For example, the transportation category represents all actors connected to the transportation sector except for car manufacturers, which are categorized in a separate group. The same applies to actors from the steel and

Table 1
– Overview of the data corpus.

Time span of phase	12/2018–05/2019		06/2019–11/2019		06/2020–11/2020		12/2020–05/2021	
Name of phase used in the text	Gas 2030 E		Gas 2030 C		NHS E		NHS C	
Data source	FAZ	SZ	FAZ	SZ	FAZ	SZ	FAZ	SZ
Number of articles/documents	29	14	60	24	18	21	79	34
Number of DNA claims	68	41	198	72	77	57	324	83
Number of persons	37	22	65	40	26	34	93	39
Number of organizations	30	20	55	35	21	31	78	36
Number of concepts	22	21	41	25	33	27	53	28

Source: Database “DNA Hydrogen Germany 2019–2021”.

chemical industry categories (see Appendix D for a list of all actors and their assignment to higher-order categories).

The content of claims was coded inductively as well through in-vivo coding. The codebook was iteratively improved and reorganized, resulting in the final list of 75 codes (see Appendix A), which fall into seven overarching categories [64]. Each category incorporated a particular stream of discussion on the matter of hydrogen—*Application*: areas of hydrogen use (where and what for), *Leadership*: achievement of leadership in the global hydrogen market, *Opportunities*: potential benefits from hydrogen development, *Organization*: concerns about hydrogen economy organization, *Potential*: German potential for hydrogen development, *Production*: issues related to hydrogen production *Strategic cooperation*: organization of cooperation with external players.

The codebook was established pursuant to Belova [65]. Four coders were involved in the coding process; they independently double-coded a 10 % sample of articles using the initial set of concepts and discussed inconsistencies, resulting in refinements of the codebook. To account for possible inconsistency between coders, inter-coder reliability checks were carried out fortnightly via test coding rounds. The coding of selected articles was compared, coding decisions were discussed, potential ambiguities were resolved, and the codebook was adapted accordingly (for a similar approach, see [34,66]).

4.4. Methods of analysis

Once the coding process was completed, several types of data were exported from the DNA software. Firstly, tabular data for the whole period was extracted. Each row in the table represents a single claim by an actor. For initial exploration, we used approaches of descriptive content analysis, such as concept and actor frequencies, frequencies of (dis)agreement with concepts, and frequency crosstabulation based on various recorded variables (e.g., organization type, concept category, and the like) [52].

As discourse networks are a subset of social network analysis (SNA), we also employed exploratory SNA tools. For each phase, we generated two types of weighted networks—two-mode networks and their one-mode projections of actor relationships. Two-mode networks are networks where ties link actors to concepts with no direct ties between any two actors or between any two concepts. Ties might have different weights depending on the frequency with which an actor uses a given concept [49]. One-mode networks are derived from two-mode networks. In these projections, ties between any two actors are established through concepts shared by the given actor pair or, conversely, ties between any two concepts are established through a shared actor uttering these two concepts. The weights of ties in one-mode projections represent actors' cumulative similarity in their use of concepts or concepts' similarity with respect to uttering actors [67]. Both types of networks were stored in matrix format [68,69]. Furthermore, we distinguished between agreement and disagreement with a concept in each tie in two-mode networks. In one-mode projections, we subtracted the number of disagreement ties from the number of the agreement ties to form so-called “subtract” networks [70]. These indicate the overall similarity of actors' positions on the discussed issue. Furthermore, we created derived networks of ties between organization types, where all actors of the same type are aggregated into a single category node. This allows us to account for the cumulative importance of the given types of actors in discourse networks.

We also used node-level and network-level measures from the SNA toolkit [71]. For example, we calculated degree centralities for networks of organizations at the node level. To reveal the overall structure of the discursive interaction, we used network-level measures such as degree distributions, degree centralization [69,72], and the so-called Louvain clustering algorithm [73], which finds clusters via modularity optimization. The algorithm spots the clusters where nodes within the group have more dense connections compared to those outside it. First, small

communities are spotted by optimizing modularity locally on all nodes, and then each identified community is grouped into one node, after which the first step is repeated. We also extracted the maximum modularity score, which measures the overall fragmentation of the network based on the obtained clustering. We omitted isolates in the presentation of the results, as there were very few and their appearance seemed inconsequential (e.g., a single actor making a single claim in a single article).

5. Results

5.1. Overall discourse characteristics

The opening part of the *Results* section provides an overview of discourse activity, i.e., claims as they appear. The two chosen periods are characterized by an increase in the number of hydrogen-related claims (Fig. 1). The Dialogue Process Gas 2030 brought the topic of hydrogen onto the general political agenda in Germany, but hydrogen apparently received little media attention in the first few months (event phase = Gas 2030 E). Over time, especially with the expected interim report of the Dialogue Process Gas 2030, hydrogen became more and more present in the public discourse. The publication of the interim report in October 2019 was accompanied by the announcement of the drafting of a national hydrogen strategy, and the consolidation phase is characterized by the renewal and intensification of the hydrogen discussion.

The second period shows a pattern of activity similar to the Gas 2030 phases, but with much larger inflation of the discussion from February 2021 to May 2021. We see contextual information as a useful supplement to these observations. The content of the National Hydrogen Strategy is formulated in a way that allows for multiple pathways of hydrogen development and thus opens up much leeway for the development of the hydrogen economy. In addition, considerable financial resources have been made available. Thus, the first phase after the NHS publication (NHS E) can be regarded primarily as an orientation phase for industry, research actors, and the public related to the drafting process of the strategy. Despite the cross-sectoral nature of hydrogen development, the Federal Ministry for Economic Affairs very much dominated the development of the strategy, with other involved ministries remaining merely information receivers. Also, finalization of the strategy took place under significant time pressure in the mode of negative coordination. Thus, although the strategy release was expected by the stakeholders, its ultimate substance only surfaced after its publication [74]. Here, too, the public discourse on hydrogen only increased in the consolidation phase (NHS C). The media coverage picked up on the launch of the many hydrogen projects by business enterprises and research institutions, which form the basis for a positive and encouraging tone of public discourse. In the NHS C phase, hydrogen increasingly became the focus of public discourse as an essential element of a climate policy aiming at climate neutrality: *Without a hydrogen economy, Europe will not become climate-neutral* (Volkmar Denner, Bosch) [75]. It is worth mentioning that the German Climate Protection Act (*Bundes-Klimaschutzgesetz* – KSG) was subjected to scrutiny during this phase. In March 2021, the Federal Constitutional Court partially upheld a constitutional complaint against the KSG, which led to an amendment of the Act in August 2021.

5.2. Actors in the public discourse

An essential step in the analysis of discourse networks is an exploration of actors present in the discourse. Since its very beginning, the discourse has been essentially shaped by economic actors, who dominate with a share generally around 60 % (Fig. 2; see also Appendices C and D). Political (19–28 %) and research (9–26 %) actors are the next most prominent. By comparison, civil society organizations (CSO) are hardly involved in the hydrogen discourse, accounting for only 3–9 % of

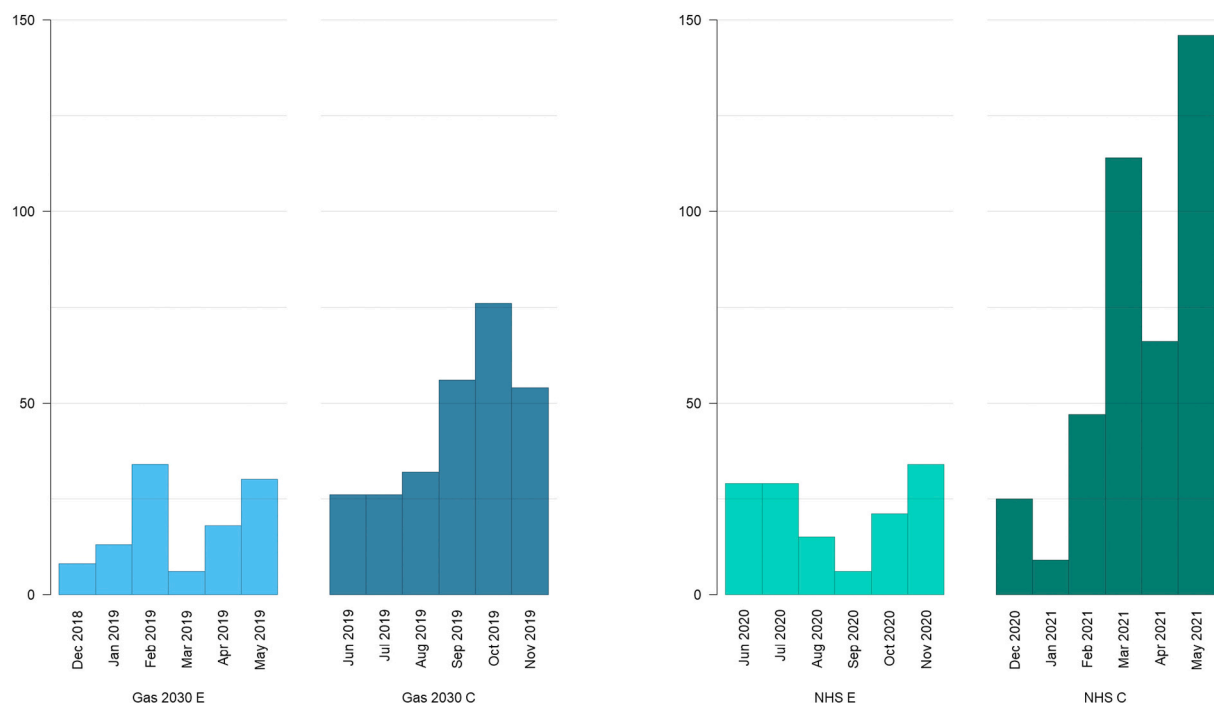


Fig. 1. Number of claims by month (n).

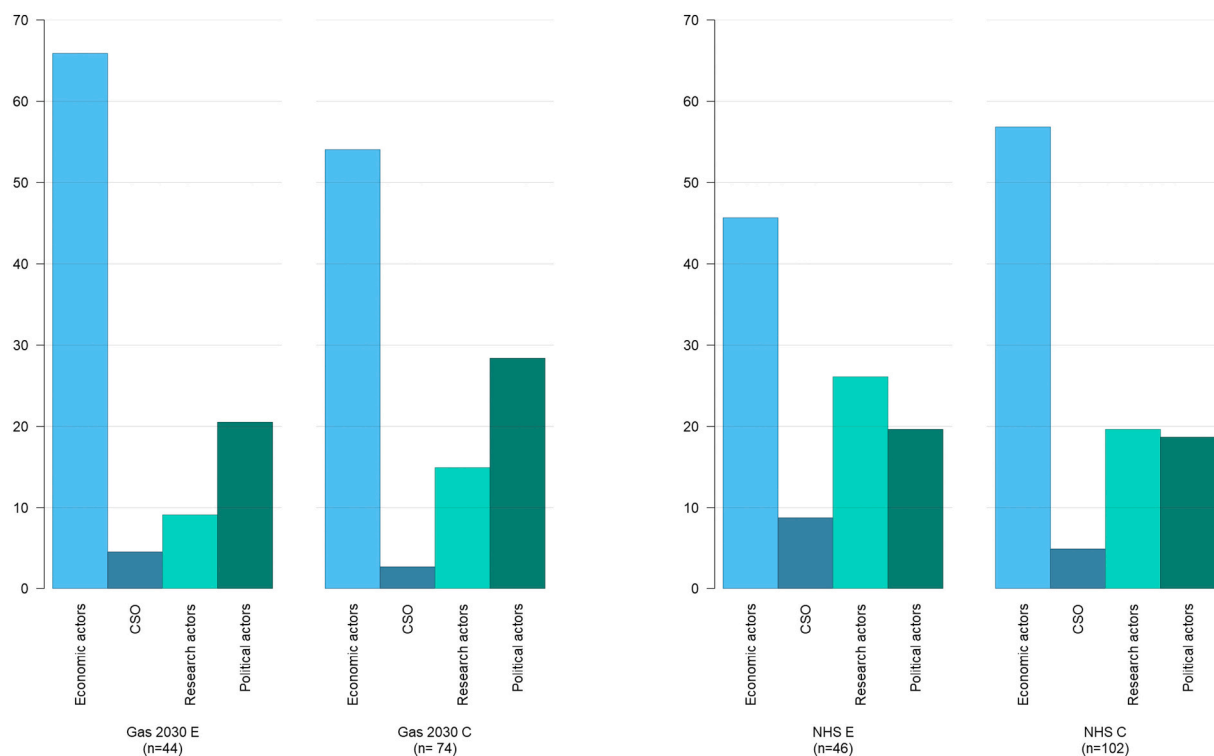


Fig. 2. Share of stakeholders by group and phase (%).

actors. Their share is highest in the consolidation phase of the NHS, with only five organizations. The small share of CSO and large share of economic actors in the German hydrogen discourse can be found across all four phases.

Among economic actors, there are three influential sub-groups. First is transportation and especially car companies. Second is industry, dominated by steel and chemical producers. The third group is formed

by energy companies, mainly utilities, oil and gas, and renewable energy firms. Hydrogen-related companies and the finance sector, namely banks and asset management companies, are present but participate relatively sparsely. The political category consists of representatives of political institutions as well as political parties at various levels: regional, federal, and EU. EU-level politicians, however, appeared only with the publication of the NHS and continued to participate in the

discourse during the NHS consolidation phase. Most of the research actors are universities or public research institutes, especially of a technical nature. We can see an increase in participation by research actors in the consolidations phase of the Gas 2030 Dialogue as well as a high share in the event phase of the NHS. The CSO category is mainly composed of NGOs, trade unions, and professional associations and is the least engaged.

Of course, the number of actors is not the only important aspect to consider. A high number of actors representing a certain category of organizations do not necessarily lead to their higher visibility in the discourse. We therefore also scrutinize actors' claim-making activity (Fig. 3; see also Appendix H).

The distinction between number of actors and their activity is especially evident when comparing economic and political actors. In the consolidation phase of the Gas 2030 event as well as in the event phase of the NHS, governmental actors and political parties have been as present as economic actors despite their smaller numbers. Another characteristic of the discourse is the increase in the relative share of research organizations in the public discourse following the publication of the NHS. Thus, while economic actors generally dominated the discourse during all phases in terms of sheer numbers, they were less dominant vis-à-vis political actors in the consolidation phase of the Gas 2030 dialogue as well as in both NHS phases. Research institutions, meanwhile, have gained more space in the discourse since the publication of the National Hydrogen Strategy (in both NHS E and C phases).

The dominance of economic actors warrants a closer look at actor types within this category (Fig. 4). Here we find that the participation of individual industries has varied over time. The two phases of the Gas 2030 dialogue were dominated by actors from the transportation and automotive (car) sectors as well as the energy sector and, to a lesser degree, the steel sector. The NHS phases saw increased participation by actors from the chemical industry and finance sector in the discourse. Also noticeable is the huge share of claims by energy sector actors during the consolidation phase of the NHS.

5.3. Content of the discourse

We now turn to the ideas and concepts used by the actors. First, we present the claims according to the categories they belong to (Fig. 5; see also Appendix E). While in the early phase the discourse concentrated on the *application* of hydrogen (i.e., areas of hydrogen use), the focus has widened over time. The *opportunities* for hydrogen and *organization* of the hydrogen market ramp-up also accounted for significant shares of the early discourse. Additionally, with the publication of the NHS, the issues of how and where to *produce* hydrogen as well as *strategic* (geopolitical) cooperation for securing hydrogen supply became important.

To further contextualize these observations, we turn to individual categories in more detail, supported by quoted claims that are representative of the discussed categories. The *application* category, which was the most prominent in all phases, shows clear shifts when comparing the Gas 2030 and NHS periods (Fig. 6). The discourse on hydrogen application concentrated especially on fuel cell vehicles and e-fuels in the Gas 2030 phase: *Every combustion engine that will still be on the road in the coming years and decades will definitely be more environmentally friendly if it fills up with e-fuels instead of petrol or diesel* (Nils Aldag, Sunfire) [76]. The idea of hydrogen use in personal vehicles was, however, also rejected, especially by car producers giving priority to EVs: *And the best way to combat this [global warming] is to focus on battery cars, which are also the most efficient compared to other drive systems such as hydrogen* (Herbert Diess, VW) [77]. After publication of the NHS, the focus shifted to the use of hydrogen in industry: *Use of hydrogen produced in a climate-friendly way was a key element for decarbonization in the industry* (Andreas Feicht, Ministry of Economics) [78]. In the NHS consolidation phase, the use of hydrogen for planes and (heavy-duty) trucks gained importance as well: *Electric trucks with hydrogen-based fuel cell propulsion will be a key technology for CO₂-neutral transport in the future* (Martin Lundstedt, Volvo Trucks) [79]. Hydrogen for cars, however, lost even more traction: *In the next ten years, the [hydrogen] technology will probably be used mainly in trucks and perhaps aircraft. But in the large mass of cars, batteries will dominate* (Jacques Aschenbroich, Valeo)

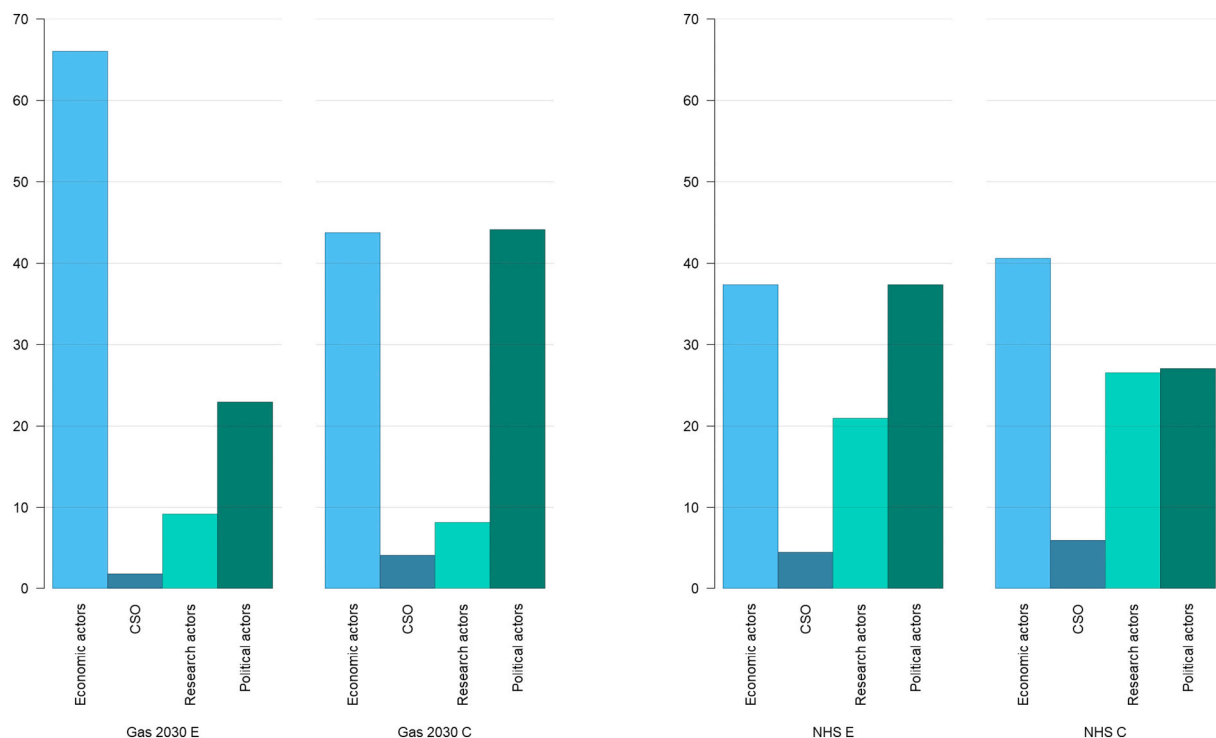


Fig. 3. Share of claims by group and phase (%).

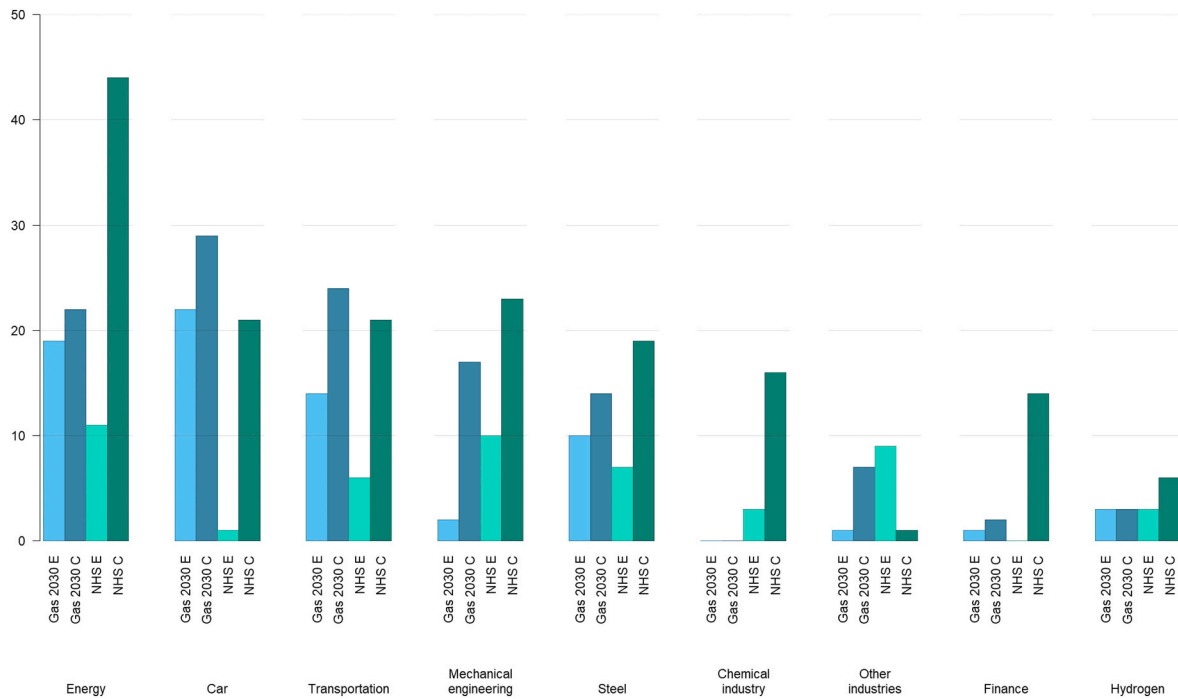


Fig. 4. Share of claims by economic stakeholders by phase (%).

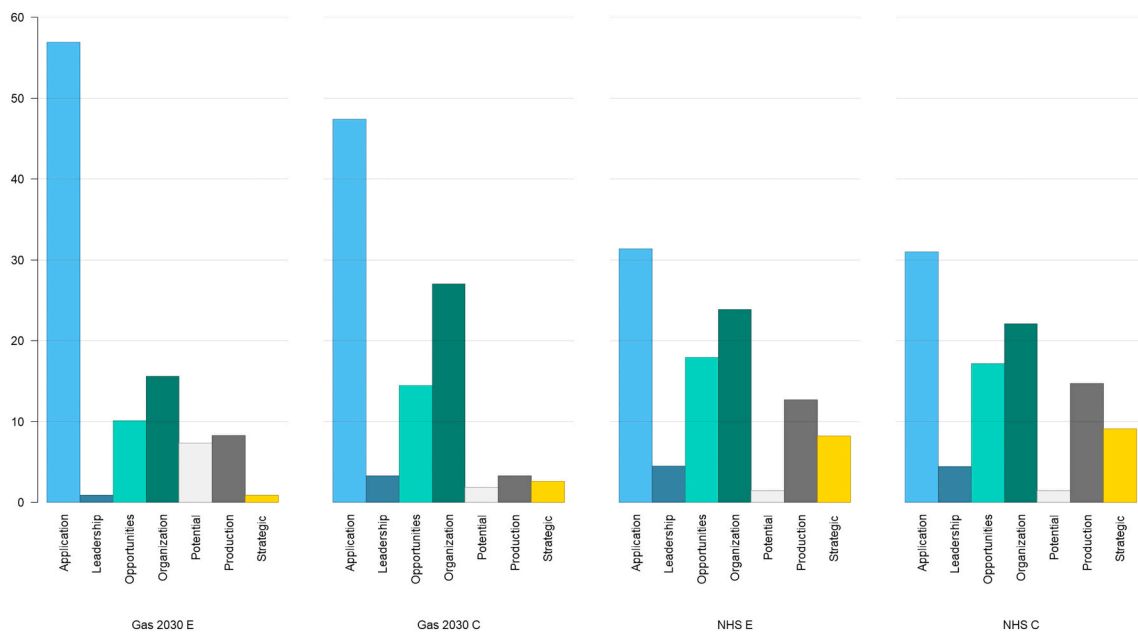


Fig. 5. Share of concept categories in each discussion phase (%).

[80].

The use of hydrogen in power generation appeared in the discourse mainly after the strategy publication, with actors sharing their intentions to invest: *From 2021 to 2024, we will invest a good 600 million euros in fuel cell propulsion and another 400 million euros in small fuel cell power plants* (Volkmar Denner, Bosch) [75]. The same applies to the heating sector: *We are at a point where our portfolio is ready for green solutions... We are also seeing great growth in fuel cells. We already offer a broad portfolio for the use of green gases, especially hydrogen* (Maximilian Viessmann, Viessmann) [81].

The second most popular category refers to *organizational* issues, particularly providing support (political and financial) to hydrogen

economy development, hydrogen import organization, and regulation change proposals. The organization of hydrogen import became more salient only after the publication of the NHS: *The demand is so enormous that it will not be possible without imports from wind- and sun-rich countries* (Katherina Reiche, National Hydrogen Council) [82].

The *production*-related concepts focused mainly on two options—blue (natural gas-based) and green (renewable-based) hydrogen (for the hydrogen color palette, see [20]). The hydrogen production discourse is dominated by certain actors. The highest share of claims about hydrogen production after Gas 2030 was made by transportation, steel industry, and political actors. Researchers, civil society, and energy companies joined the discussion more intensively

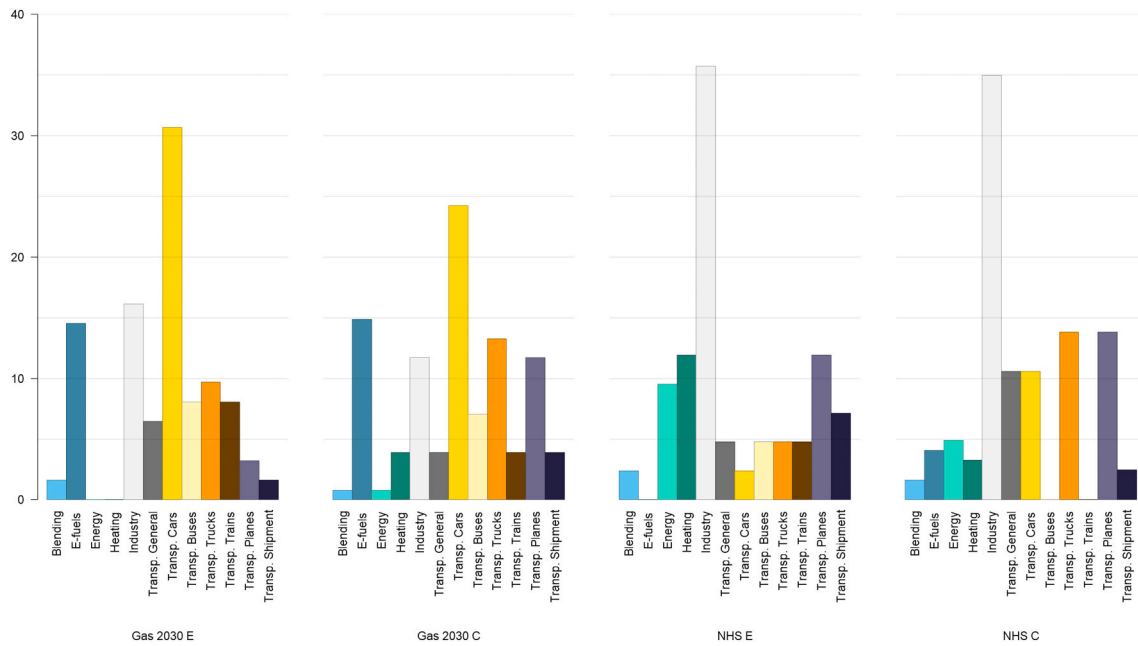


Fig. 6. Frequency of concepts capturing application of hydrogen by phase (%).

after the publication of the NHS. While some environmentally oriented actors, such as Die Grünen, Klima-Allianz, and BUND, accept only green hydrogen, others appear to be more flexible, at least in the short-term: *While the goal is to use only green hydrogen by 2050, the initial aim is to feed blue hydrogen into a transport network at competitive rates* (Stefan Garche, VDE Renewables) [83].

The share of the discourse dealing with the *opportunities* of an emerging hydrogen economy has grown steadily from Gas 2030 E to C and on through NHS E and C. In terms of content, the discussion has focused primarily on climate, economics, and the transition to a sustainable economy. Politicians appear to be the most consistent in advocating hydrogen expansion through the various opportunities it brings across all phases: *Our ambitious climate protection goals demand that gas demand be replaced in the long term by CO₂-free or CO₂-neutral gaseous energy sources. Hydrogen will become a key raw material for this. Unlike batteries, green hydrogen can serve as a year-round energy store, it can be used for heat generation and steel production as well as for the production of climate-neutral synthetic fuels* (Peter Altmaier, Ministry of Economics) [84]. Researchers more actively joined the discourse in the

consolidation phase of NHS C, highlighting the importance of hydrogen for energy transition success and its role in sector coupling: *Green hydrogen is the central energy carrier for sector coupling in the energy transition* (Katherina Reiche, National Hydrogen Council) [82].

Strategic cooperation concepts were practically absent in the two phases of Gas 2030 but became and remained visible after the NHS publication. This discourse mostly highlights the overall importance of international cooperation for hydrogen import as well as the importance of particular regions such as Africa, Russia, and Australia: *We have to signal to the citizens that we cannot do everything concerning green hydrogen in Germany. We need international partnerships* (Anja Karliczek, Ministry of Education and Research) [85].

The *potential* for hydrogen development was estimated for Germany as a whole and its particular regions (e.g., Bremen, Saxony, North Rhine-Westphalia) especially during the Gas 2030 E phase but then hardly discussed thereafter. Calls for a *leadership* position have increased but remain at a low level, voiced primarily in relation to Germany and the EU. First and foremost were politicians who addressed the potential of hydrogen: *We want to become number one in the world in hydrogen*

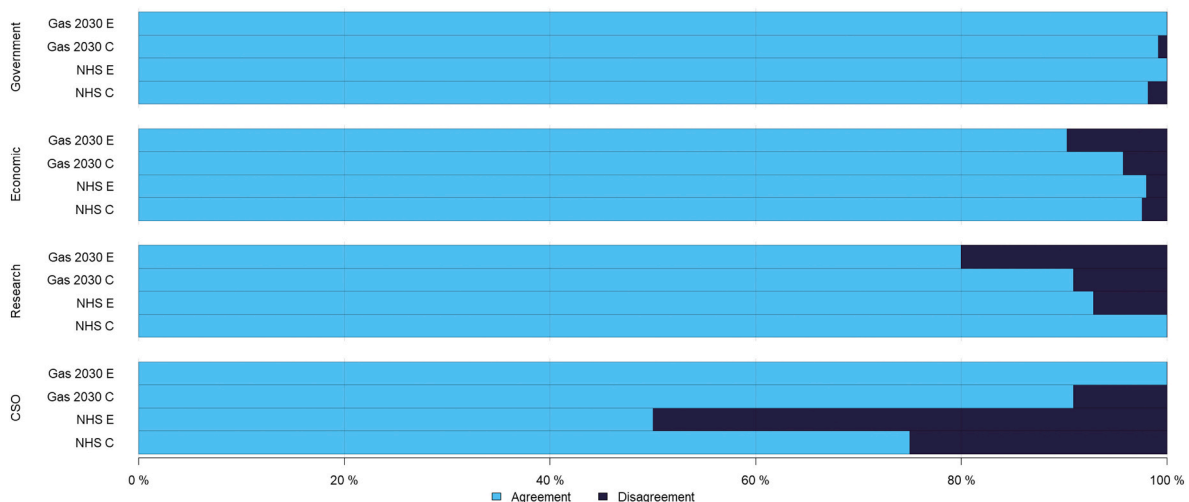


Fig. 7. Positioning of hydrogen market ramp-up concepts by actor groups (%).

technology (Peter Altmaier, Ministry of Economics) [86].

A constant across all phases is the very low proportion of claims expressing direct disagreement with concepts. The public discourse on hydrogen is hardly conflict-laden in our periods of observation. Even if we break down observations according to individual groups of actors (Fig. 7), we find high agreement. There were virtually no negative claims from governmental actors and even less so from economic actors. Research actors exhibit slight disagreement on some concepts, such as hydrogen use in personal vehicles and blue hydrogen production: *The storage capacities for carbon dioxide are limited. We should therefore use them for purposes where there is no alternative. This includes storing CO2 from industrial processes that cannot be fully decarbonized...Blue hydrogen is not a bridge, but a dead end* (Felix Heilmann, E3G) [87]. Civil society organizations seem to fulfill their watchdog function in the shaping of the German hydrogen economy, as the highest proportion of negative claims on hydrogen options has come from these actors since the publication of the NHS. The main source of disagreement is hydrogen production technology, rejecting hydrogen produced from natural gas and nuclear energy: *Only hydrogen that can actually be produced without residual emissions and climate impact should be considered climate neutral* (Christiane Averbeck, Klima-Allianz) [88]. Yet, as the number of CSOs participating in the hydrogen discourse is very small, this finding needs to be interpreted cautiously.

5.4. Discourse networks

To understand the discourse structure, we analyze both two-mode networks and one-mode networks at the node level and network level. Given space constraints, we present only one-mode actor networks per time phase, first with their structural features (i.e., density, average degree, and centralization) and secondly through the analysis of clustering. These measures allow us to understand the general properties of the networks in a comparable manner, regardless of their size. We provide a more detailed discussion of networks (e.g., two-mode analysis, descriptive measures, and the like) in Appendix F.

The description of one-mode network projections (Table 2) shows that the event phases differ from the consolidation phases. The density of the networks was higher in the Gas 2030 C and NHS C phases, when the networks were also larger, albeit the difference is not great. This higher density means actors were more engaged in claim-making and thus were more connected through concepts. This circumstance is also reflected in the higher average degrees (the average number of connections an actor has to other actors), with the highest average degree observed in the largest network (NHS C).

Next, we analyzed the discourse structure by analyzing the alignment of stakeholders in the respective discursive networks. Alignment can be approximated through clustering, provides us with an insight into actor alignment according to their positions. Clusters could be interpreted as coalitions around similar (shared) claims, and clusters with dense internal connections could indicate strong similarity in claims-making. Moreover, this clustering may be driven by similar organizational type [89]. At the network level, clustering is indicated by a measure of modularity (see Table 2). The event phases Gas 2030 E and NHS E have higher modularity scores than the consolidation phases—an indication of more clustered networks. The inverse pattern can be seen

Table 2
Descriptive network statistics.

Network characteristic	Gas 2030 E	Gas 2030 C	NHS E	NHS C
Number of actors	45	75	47	102
Network density	0.145	0.227	0.152	0.239
Max core	8	14	11	28
Modularity	0.482	0.287	0.288	0.227
Average degree	6.4	16.77	6.98	24.1
Degree centralization	0.264	0.490	0.370	0.514

in the values of degree centralization (ratio of the number of connections of all actors to the most connected actor), with the consolidation phases being more centralized and less clustered than the event phases.

We might look at clusters also through their membership, which might be further enriched through the type of actor. Cluster membership in each phase is visualized in Fig. 8, where the actors in each network are grouped by the cluster they belong to. Upon closer inspection, we discovered only two interpretable clusters: a car-dominated cluster in Gas 2030 E and a finance cluster in NHS C. Otherwise, we found no other interpretable patterns which could be understood as actor alignment around specific issues or alignment around particular types of organizations (see Fig. 8). Moreover, cluster membership appears to change over time. Hence, we understand this as a lack of consistent patterns of discourse formation—i.e., a lack of discursive alignment of actors over time.

To corroborate and validate the lack of discursive alignment, we also aggregated the networks from Fig. 8 by organization type and created second-order organizational networks as presented in Fig. 9. Here, we see the connections between different groups of actors (links) and within each group of actors (circular loop from the node to itself) as well as the strength of congruence between different groups (thickness of the link).

These visual representations of the links among organizations suggest the strength (represented by the thickness) of the ties between and within groups changes from phase to phase. Gas 2030 C exhibits strong links among the Transportation, Research and Car groups, with strong congruence within the Car industry. NHS E shows congruence between the Research and Energy groups and between Steel and Mechanical engineering companies. The NHS C network exhibits quite a strong congruence between the Chemical and Steel industries and between Steel and Transportation. All the above indicates the absence of any constant pattern of alignment between different groups of organizations. Otherwise, we would observe similarly strong ties between organization types over several phases. Moreover, there is no clear pattern of similarity among organizations of the same type (presence of loops across phase changes).

6. Discussion

First, as regards stakeholders and their positions in the German hydrogen discourse, we observe several interesting patterns. While the literature suggests that political actors are always very dominant in the public discourse due to their vote-seeking behavior [71], our results indicate that economic actors were the most prominent actors within the network in the analyzed time frame. The car industry as well as energy companies were the driving economic actors surrounding the Dialogue Process Gas 2030, followed by the transport sector and steel companies. At that time, the car industry was under pressure from Asian manufacturers as they pushed the marketability of hydrogen mobility: *I don't know if we can afford to just push the mainstream battery and then we might get left behind on the hydrogen issue* (Michael Häberle, Daimler) [90]. The energy industry, meanwhile, was exposed to a fundamental transformation process due to climate protection targets and the coal and nuclear phase-out and was seeking CO₂-free or CO₂-neutral gaseous energy sources: *Electricity independent of the weather will then only be produced in gas-fired power plants that burn fuels generated with the help of green electricity, such as green hydrogen* (Rolf Martin Schmitz, RWE) [91]. Likewise, the transport and steel sectors faced particularly strong challenges as a result of the climate protection targets: *Hydrogen must be available as early as 2025 if there is to be any chance of Germany meeting its climate targets* (Volker Hille, Salzgitter) [92].

The share of research actors and their claims in the hydrogen discourse increased following the publication of the NHS, which can be related to the strong promotion of hydrogen research through governmental funding. While there is no systematic list of all current hydrogen projects, the large number of members in the Hydrogen Research Network (about 1350 in March 2022) initiated by the German

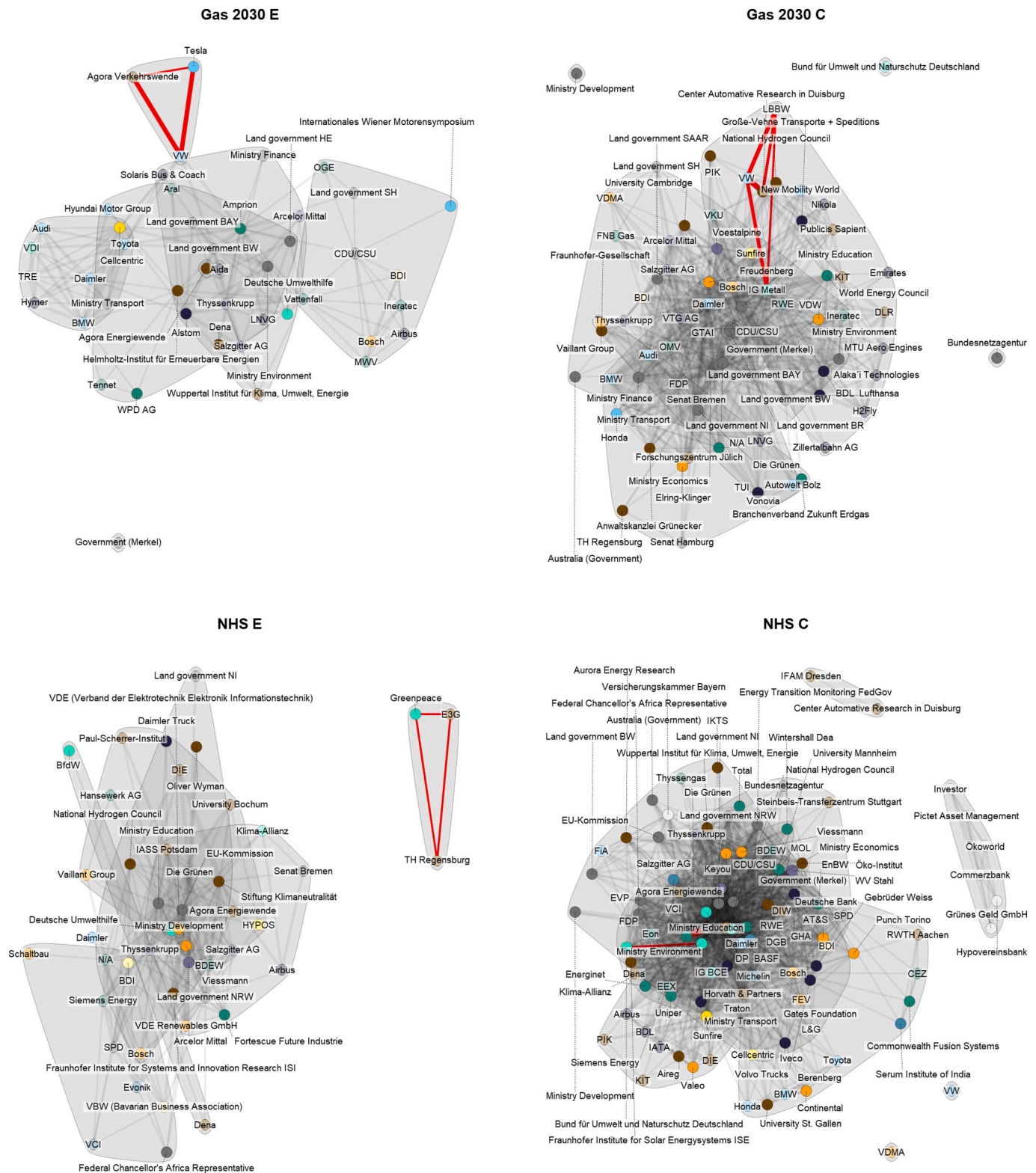


Fig. 8. Networks of actors, organized by clusters.

government in September 2020 speaks for itself [93]. As research needs time to complete and share its findings with the public, the claims made by research actors increased steadily over time, and it is very likely that this increase has also continued beyond the analyzed period.

Civil society organizations formed the smallest group of actors in the discourse. In principle, CSOs were positive over the use of hydrogen. Those few critical positions on the hydrogen ramp-up concerned the

purpose of blue hydrogen due to risks of carbon lock-in and questioned the environmental and social standards for hydrogen imports from the Global South: *Reliable verification and monitoring systems are needed, especially for imports from the Global South, to ensure local value creation, appropriate participation, and climate protection. This requires time and partnerships at eye level with local civil society* (Joachim Fünfgelt, BfW) [94]. Studies that examine stakeholder publications (e.g., statements,

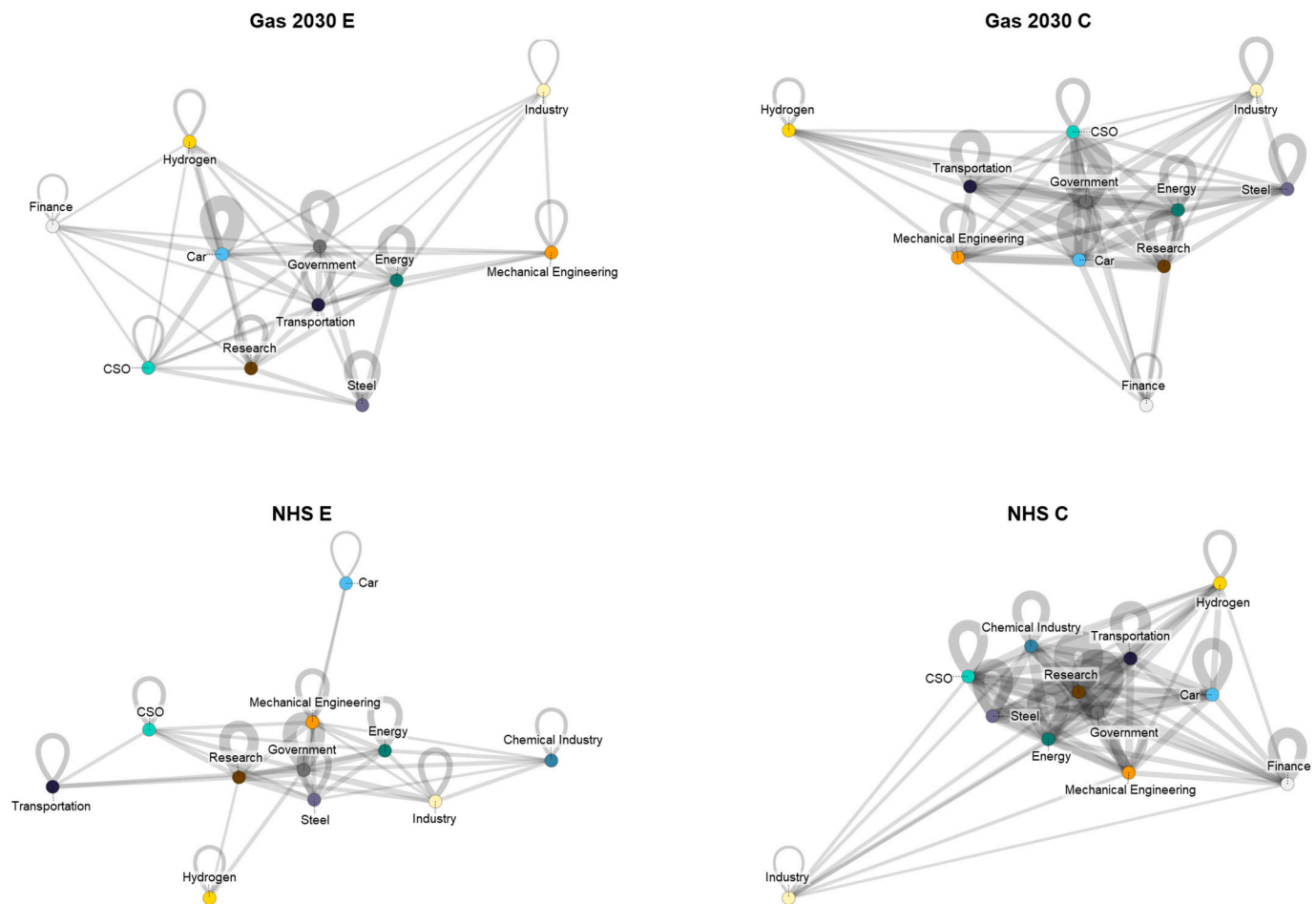


Fig. 9. Normalized subtract networks of actor types.

position papers, and press releases) show that CSOs do take a more critical public stance on hydrogen [32]. However, our data show that CSOs are hardly present in the media discourse. Their absence means that critical claims are likely to be underrepresented, and the ability of CSOs to exercise their watchdog function may thus be compromised.

Second, we notice shifts in the discourse content over time. It initially focused on the possibilities of hydrogen application but subsequently adopted a broader perspective, also focusing on climate neutrality. In Gas 2030 E and C, the discussion focused mainly on applications of hydrogen, concentrating on the transport and automotive sector. In the latter phase, there was a dispute about the use of hydrogen versus direct electrification in cars, especially in the car manufacturing industry. In the Gas 2030 C phase, hydrogen emerged as a way of reducing emissions in the steel industry as well as an opportunity in mechanical engineering, thereby broadening the discussion about the use of hydrogen. Within the transport sector, the topic of using hydrogen for heavy transport, ships, and aviation also emerged. Thus, the wider use of hydrogen was discussed in a kind of discursive gold rush, where hydrogen was hyped as a silver bullet solution to the remaining problems of the energy transition. The framing of hydrogen as energy storage, as reported in an analysis of the 2013 discourse [33], turned out to be much less pronounced. However, it was not until the turn of 2019–2020 that the discussion about climate neutrality until 2045 or 2050 intensified at both German and European levels. The thematic discussion began to focus on the no-regret application of hydrogen in hard-to-abate sectors where direct electrification seems unfeasible [95]. We also observed the discussion around the steel and chemical industries rising as well as the focus on heavy-duty transport and aviation. While the passenger car discussion did not lose importance, many

manufacturers began to concentrate (and still do) on battery-electric vehicles.

Third, when it comes to the expectations associated with hydrogen, we see that actors are aware of hydrogen potential and opportunities but also recognize its limitations. The discourse revealed the expansion of hydrogen use from transport to other sectors, all aiming at achieving climate neutrality. However, the stakeholders involved in the discourse were (and are) well aware of the limited supply of green hydrogen, which will remain a scarce resource in the medium term as long as large-scale production has not been achieved: *The aim is to turn hydrogen from champagne into the mineral water of climate protection* (Christian Lindner, FDP) [96]. Especially during the NHS phases, it became clear that the available quantities of hydrogen would not be sufficient for all conceivable applications, despite imports. The discussion started to concentrate instead on the no-regret options. Thus, we witnessed a shift in the discourse from broad use towards more focused use due to the discussion on climate neutrality by 2045/2050.

In the case of hydrogen production, actors from the transport sector and steel industry, as well as political actors, were dominant in the debate during Gas 2030 E and C, while research actors, CSOs, and the energy industry became more intensively involved in the production discussion only during NHS E.

Fourth, regarding the political agenda, this component of the discussion was clearly dominant. In particular, it included the issues of organizing the ramp-up of a hydrogen economy with an explicit emphasis on the need for various types of support from the state, cooperation in the field of hydrogen technologies and its supply with other countries (import of hydrogen and exchange of technologies), and the leadership ambitions of Germany and the EU as a whole. With

Russia's invasion of Ukraine, the relative importance of strategic cooperation with specific regions such as Africa, Russia, and Australia—an key aspect of the post-NHS discourse—has shifted. German–Russian cooperation is no longer on the political agenda, as the German government announced Germany's decoupling from the Russian energy supply, while German–Australian and German–Canadian cooperation, for example, has gained new momentum [97]. Due to recent geopolitical developments, the current hydrogen discourse (August 2022) thus includes hydrogen and energy cooperation with Australia and Canada despite the enormous distances between these two countries and Germany. The same can be said for North Africa, albeit at closer proximity.

The dominance of economic and industrial actors in the NHS E and C discourse resulted in an overrepresentation of business-related topics. Hence, the economic benefits of expanding Germany's hydrogen market and its international competitiveness outweigh the environmental and transition benefits. Nonetheless, climate awareness still manifests itself in the requirement to use only green hydrogen, at least in the long term. The dominance of economic topics also relates to the underrepresentation of claims raised by CSOs, which entered the public discourse late. Support for blue hydrogen as a bridging technology and a rather broad spectrum of applications can be found among several business associations and is promoted by the National Hydrogen Council. Environmental CSOs rather argue for exclusive concentration on green hydrogen only and strict prioritization in application [95]. However, such positions entered the discourse only gradually in the NHS phases. Thus, their media presence has been somewhat delayed.

Fifth, revising the time frame selection, the separation into four phases of discourse development has proven to be extremely helpful, especially in analyzing the thematic foci within the discourse. Compared to studies that concentrate on stakeholder positions based on statements and position papers or which analyze the discourse as a whole without taking time into account, the more granular perspective allowed us to look at the alignment of actors over time. We found that the hydrogen discourse has so far shown little manifested conflict. Rather, the observed results may be interpreted as a thematic enrichment of the discourse over time. This is also corroborated by the modest polarization as suggested by the measured network modularity and non-existence of discernible coalitions. Furthermore, there were no truly contentious issues that would induce stakeholders to hold firm positions. Here, we observed only two instances of interpretable actor clusters: passenger car manufacturers (in the first phase of the discourse) and financing actors (in the most advanced discourse). Thus, we can conclude that the discourse was not polarized along cleavages or contentious issues in the analyzed phases but was clustered rather around various non-exclusive proposals and suggestions which acted as “wish lists” within the analyzed periods. This is worth a more detailed evaluation, as the development of new themes within the discourse is yet to be embedded in the context of climate neutrality, which became a focal point for both German and European energy transition strategies.

Nevertheless, the thematic enrichment and lack of entrenchment observed in the discourse may not mean a complete absence of conflictual positions. Given the context, we are more prone to understand the results as a latent phase, where conflicts only rarely unfold in the public discourse. This might be a feature that is pertinent to the alignment of hydrogen and associated technologies with already established ones, given the urgent pressure for a swift transition. Hydrogen innovations in Germany do not appear to be disruptive to existing infrastructure and practices but are rather designed to support industry in adapting to the politically defined goal of climate neutrality and opening up additional economic opportunities. Nonetheless, hydrogen is still not integrated or adopted at a large scale nor regulated through particular policy provisions, and there are no specific details or conditions associated with the distribution of public money. We assume that all issues or concepts raised in the discourse can still be addressed without direct public confrontation with other stakeholders. Therefore, we understand this situation as a window of opportunity when already

established stakeholders (including incumbent companies) try to co-opt and implement various aspects of hydrogen innovation to their own portfolio, hoping to maximize their leverage and access to funding.

However, beyond the scope of our data collection, in late 2021 a more conflictual structure of the discourse did become obvious. The issue of hydrogen supply is one of the first areas showing signs of polarization. While domestic production and import options still seem to be perceived as mutually reinforcing and necessary for demand satisfaction, the process of establishing import channels is no longer universally accepted. Signs of contention have emerged firstly around the procedure of imported hydrogen production (green only vs. green and all other color variants of hydrogen). Issues of justice and sustainability in trade relations with countries from which the hydrogen would be sourced have also emerged as potentially divisive. The other area of polarization is the use of hydrogen, where conflicts may arise between the raw materials industry and manufacturers of technical equipment for private use, e.g., heating systems. This is due to hydrogen scarcity, at least in the medium term, which could intensify the debate about prioritizing certain applications. Particularly environmentalists and supporters of an *all-electric society* recommend strict prioritization, using green hydrogen only in selected sectors where there is no other option for decarbonization [98]. This is opposed by the position that too narrow specifications for applications and generation would contradict the goal of a rapid market ramp-up and also block opportunities for industrial modernization [99].

Thus, we expect that with the further enlargement of a hydrogen economy, the adoption of more nuanced regulation limiting certain actors, and clearer prioritization of public funding more cleavages will appear and the discourse will become more polarized. This proposition, however, should be tested in future empirical research.

7. Conclusion

The goal of this study was to identify and map how the composition of stakeholders, their positions, and the overall discourse structure developed over time as accompanied by the shaping of the political agenda (agenda setting) in the early hydrogen public debate in Germany. To trace actors' discursive interaction, we looked at their public claims asserted through quality media and applied discourse network analysis.

The public discourse on hydrogen in Germany shows the expected activity in claim-making in connection with the two milestones—the initiation of the Gas 2030 Dialogue and the publication of the National Hydrogen Strategy. At the same time, the development over time was more nuanced than expected. The hydrogen discourse was comparatively feeble in the immediate aftermath of the respective milestones, gained traction over time, and finally intensified in the consolidation phase, in both cases promoted by a publicly expected follow-up event.

Sequencing our discourse analysis, and thus contextualizing the discourse content with regard to political, societal, and economic circumstances and implications in a diachronic perspective, allowed us to observe certain trends. We were able to show how issues developed during the different phases, such as the discussion on the use of hydrogen. Here we have traced the development from a discussion of broad use to a concentration on no-regret options against the background of the political commitment to climate neutrality in 2045/2050. The advantage of sequencing the discourse network analysis to observe the evolution of the hydrogen discourse thus becomes particularly apparent. In contrast, discourse analyses that aggregate all claims over a long period of time [34] may misinterpret this development as a conflict among actors. What is interpreted as different stances on an issue in the literature, according to our analysis, turns out to be temporal development. In addition, the separation of the investigated periods into phases (event versus consolidation) has shown that the consolidation phase is the more important phase as indicated by higher levels of network density and actor congruence. In our case, both event phases appeared to

be similar with respect to the represented stakeholders and concepts. Pluralization of the discourse (an increase in topic and actor diversity) only unfolded in the consolidation phase of the second period. Theoretically, we might infer that changes in discourse networks in a rather complex and technical topic like hydrogen do not emerge on the spot. Quite the contrary, new discourse networks emerge with a considerable time lag in relation to the respective event. Research using media data can build on this finding by analyzing longer periods of time after an event in order to fully account for its discursive entrenchment.

It should be noted that the study leaves space for possible follow-up research. Firstly, it is certainly necessary to examine the discourse after 24 February 2022. Russia's invasion of Ukraine has completely changed the conditions for the hydrogen ramp-up in Germany (and the EU) as well as the discourse accompanying it. Within the current geopolitical framework, hydrogen becomes not just a climate-driven choice but also an important component of supply security. Its ability to replace natural gas coming from insecure areas further stimulates this drive. Such advantages have not gone unnoticed by EU policymakers, who have raised hydrogen ambitions (both domestic production and import flow) alongside additional financial support [100]. Further application of the approach developed in this article is expected to help uncover the relevant actors' responses to the new realities. Secondly, approaching the discourse through the network perspective leaves space for a more in-depth investigation of similarities or differences among actors at the level of individual claims and their meanings. Frame, narrative, or critical discourse analysis could well complement the presented results and bring into focus individual actor interactions, strategies, and power struggles in addition to the overall discourse structure. Thirdly, the current study could be advanced through an inferential network analysis to look at specific hypotheses on mechanisms of discourse formation.

This research presents a case study of the German hydrogen discourse. However, many other countries are also relevant to the hydrogen policy debate, with their own discourses regarding hydrogen use. Thus, the design and approach developed in this study can easily be applied to other country case studies (e.g., see [101]). Firstly, it may be used for comparative analysis to uncover specifics of countries that can be traced through the discourse: the presence and absence of specific actors and their coalitions promoting certain narratives or frames. Secondly, we see the German case as an important model and benchmark of the overall trend in the emergence and development of the hydrogen discourse. The observed trend, starting from a "wish list" or "one-size-fits-all" perception to a more precise vision and defined priorities on hydrogen use, might be observed and verified in case studies of other countries as well. Similarly, a shift from a diffused map of actors expressing their positions to more structured networks of stakeholders may also be evident elsewhere.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Arina Belova reports a relationship with McKinsey & Company that includes: employment.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.erss.2023.102965>.

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