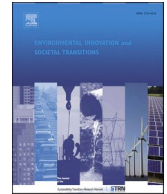




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# Environmental Innovation and Societal Transitions

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Research article

## Actors in multi-sector transitions - discourse analysis on hydrogen in Germany

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### ABSTRACT

With net-zero emission goals, low-carbon transitions enter a new phase of development, leading to new challenges for policymaking and research. Multiple transitions unfold in parallel across different sectors. This involves a broad range of technologies, while actors engage in increasingly complex discourses. Here, we study the discourses on hydrogen in Germany. Based on the analysis of 179 newspaper articles from 2016 to 2020, we find that a diverse set of actors, including many industry incumbents, speak favorably about hydrogen, emphasizing economic opportunities and its relevance for the energy transition, whereas skeptics highlight its low energy efficiency and expected scarcity. With the help of discourse network analysis, we identify three emerging conflicts around the use, production, and import of hydrogen. We explain these conflicts and the widespread support of incumbents with a conceptual framework that captures the complex interplay of sectoral contexts, specific technologies and actor interests.

### 1. Introduction

As more and more countries and businesses are making pledges to reduce their greenhouse gas emissions to net-zero until mid-century (Höhne et al., 2021), the transition toward low-carbon energy systems is entering a new phase of development. It is not sufficient any more to pursue incremental changes, or to focus on selected sectors, such as electricity or transport. Instead, societies need to cut, or compensate for all greenhouse gas emissions across all sectors.

This 'net-zero phase' of the energy transition imposes new challenges. One challenge is the simultaneous involvement of multiple socio-technical systems, or sectors, and various technologies within and across these multiple systems. Another challenge is the large number of actors with different backgrounds and interests. Transitions research has begun to address some of these challenges, highlighting the increasing complexity if transitions comprise multiple sectors or multiple technologies (Andersen and Markard, 2020; Papachristos et al., 2013; Rosenbloom, 2020). Despite some progress, we still lack empirical studies and conceptual frameworks to analyze transitions that involve multiple systems (Rosenbloom, 2020).

We address this gap with a study on the emerging field of hydrogen, a research case that is at the heart of the latest phase of the net-zero energy transition (van Renssen, 2020). Hydrogen is currently pushed by policymakers as an alternative energy carrier for a broad

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range of applications, including difficult-to-decarbonize industries (DDI), such as steel or aviation (Davis et al., 2018). As of 2021, 17 countries have already adopted hydrogen strategies, while another 20 are under development (IEA, 2021a). We select Germany as a leading industrialized country with many large incumbent firms in different industries. The German government actively promotes hydrogen as an essential part of its net-zero strategy.

We ask how actors talk about hydrogen, and whether and why they support or oppose to it. We also address how incumbent actors may be affected by the sectoral context they are operating in. We approach these questions by analyzing the discourses on hydrogen in Germany in leading nationwide newspapers. Our analysis starts in 2016 and covers the years leading up to the end of 2020. The final dataset comprises 179 newspaper articles of five newspapers, quotes of 139 actors, and 30 storylines. Discourse analysis (Hajer, 2006) can be a particularly insightful tool for innovations at early stages of development when actors try to create meaning and common understanding, shape categories, or influence policies (Rosenbloom et al., 2016). We also employ discourse network analysis (DNA) (Leifeld, 2017) on a subset of storylines related to three emerging conflicts.

We find a widespread, partly even enthusiastic support for hydrogen among incumbent actors, while environmental NGOs and some think tanks adopt more skeptical positions. Considering that incumbents have often resisted transformative change (Hess, 2014; Smink et al., 2015) this might seem surprising at first. Our findings contribute to more recent studies that add more nuance to the role of incumbents in transitions (Turnheim and Sovacool, 2020). We also identify three specific lines of conflict, namely about i) in which sectors hydrogen should be used, ii) which production methods are desirable, and iii) potential risks and benefits of hydrogen imports.

We also contribute by developing a simple conceptual framework to study the involvement of multiple sectors, multiple technologies and multiple actors in discourses around emerging sustainability innovations. The framework considers the sectoral context, sector-specific technologies, and actor interests, with a special focus on incumbent actors. We then apply our conceptual framework to the case of hydrogen.

The paper proceeds as follows; Section 2 describes the theoretical background, Section 3 explains our approach and methodology. Section 4 presents the results. Section 5 applies and discusses the framework. Section 6 concludes.

## 2. Theoretical background

Our study is rooted in the literature on sustainability transitions, which studies fundamental changes in socio-technical systems as a response to grand sustainability challenges such as climate change (Köhler et al., 2019; Markard et al., 2012).<sup>1</sup> We understand the net-zero energy transition as a complex, long-term transformation process that involves multiple transitions in different socio-technical systems. This novel setting is conceptually demanding because we are confronted with i) multiple systems in different transition stages, ii) complex interactions of multiple technologies, and iii) a broad range of actors, with incumbent actors playing a very active role. Below, we briefly review these three issues. We also explain the merits of discourse analysis, and conclude with a conceptual framework that guides our reasoning, and facilitates the interpretation of the results.

### 2.1. Interaction of multiple systems

Originally, socio-technical transitions have been depicted in a rather straightforward way: innovations emerge in niches, improve and diffuse over time, until eventually, one innovation has matured sufficiently to replace established practices and technologies, thereby fundamentally transforming a socio-technical system (Geels, 2002; Markard et al., 2012). In this view, a transition is primarily confined to a single system, which limits the number of innovations, technologies and actors involved. Later, scholars have shown that innovations may not just interact with one, but with multiple systems at once (Geels and Schot, 2007; Konrad et al., 2008; Papachristos et al., 2013; Raven, 2007). One example is biogas technology: it connects agriculture on the input side with different energy sectors on the output side (Markard et al., 2016; Sutherland et al., 2015). Another example are multi-purpose or general-purpose technologies that can be used for a broad range of applications (Dolata, 2009).

In the case of the net-zero energy transition, the situation is even more complex because many sectors and industries transform at the same time and there are several interdependencies. For example, the transition towards renewable energies in the electricity sector enables the decarbonization of transport with electric mobility (Zhang and Fujimori, 2020). Similar interdependencies arise for hydrogen, which might emerge as a viable option to tackle difficult-to-decarbonize industries (Bataille, 2020; Davis et al., 2018), while low-carbon electricity or other inputs are required to produce hydrogen in the first place. The transitions literature is only beginning to grasp the complexity of multi-transition dynamics and multi-system interactions (Rosenbloom, 2020).

### 2.2. Interaction of multiple technologies

Next to multi-system dynamics, the net-zero energy transition is also characterized by an interaction of multiple technologies (Andersen and Markard, 2020).

Transitions research has already described various forms of technology interaction and the conditions, under which technologies compete with, or complement each other (Markard and Hoffmann, 2016; Sandén and Hillman, 2011). In the electricity sector, the transition towards renewables is already in full swing (Mitchell, 2016), and in transport and heating, technologies that rely on

<sup>1</sup> In the following, we use the terms 'system' and 'sector' interchangeably.

low-carbon electricity diffuse in many places (IEA, 2021a; 2021b). Hydrogen is expected to emerge as an alternative low-carbon energy carrier, either in addition to electricity, or as the primary alternative to fossil fuels. As a consequence, hydrogen-based technologies may both complement, or compete with existing and alternative low-carbon technologies. What complicates the situation is that some hydrogen technologies and infrastructures may reach across sectors, which means that system and technology interaction overlap.

### 2.3. Actors in transitions

Actors such as firms, industry associations, think tanks, NGOs or policymakers play a crucial role in transitions (Farla et al., 2012). While they pursue different, possibly conflicting interests and strategies, they deploy various kinds of resources, forge networks and engage in institutional or transition work (Binz et al., 2016; Löhr et al., 2022). Overall, they seek to shape policies (Musiolik et al., 2012; Wesseling et al., 2014), and influence transitions through their strategy choices (Löhr and Mattes, 2022).

Of particular interest are incumbent actors, especially when they are economically well equipped and exert political influence (Turnheim and Sovacool, 2020). Some incumbents control critical resources (e.g., access to specific customers or suppliers), which is why they can be central for developing, or slowing down, new technologies and their diffusion (Berggren et al., 2015; Rothaermel, 2001). Many studies have found incumbent actors fighting against major technological or institutional changes to protect their established businesses (Hess, 2014; Jacobsson and Lauber, 2006; Penna and Geels, 2012; Smink et al., 2015; Wesseling et al., 2014).

However, incumbent firms may also support or even drive transitions (Löhr, 2020; Turnheim and Sovacool, 2020). Transition scholars have shown pro-active strategies of incumbents in various sectors, including heavy vehicles (Berggren et al., 2015), electrical engineering, automotive (Bergek et al., 2013), or horticulture (Kishna et al., 2017). In these examples, incumbents support transitions when they can continue their established business (Berggren et al., 2015), or when innovation builds on their existing business model (Bergek et al., 2013). In this study, we also find a diverse and even leading role of incumbents. Section 5.2 provides suggestions to explain their support (or resistance).

### 2.4. Discourse analysis

When actors talk about innovations or transitions more broadly, they convey meaning, shape categories and (co-)create expectations (Bakker et al., 2011; Borup et al., 2006; Roberts et al., 2018). Especially when they talk in public, they often pursue specific interests such as mobilizing policy support (Budde et al., 2012; Isoaho and Markard, 2020) or influencing the perceived legitimacy (Geels and Verhees, 2011; Rosenbloom et al., 2016). Public debates are thus inherently political. Through the analysis of argumentative structures, we can shed light on the underlying politics (Hajer, 2006).

To analyze the public debate around hydrogen, we mobilize argumentative discourse analysis, which rests on the assumption that language, and the exchange of arguments, are key to understand the political nature of an issue, and to identify political conflicts (Brink and Metzke, 2006; Hajer and Versteeg, 2005; Hajer, 2006; Isoaho and Karhunmaa, 2019; Lowes et al., 2020). We understand discourse “as an ensemble of ideas, concepts and categories through which meaning is given to social and physical phenomena, and which is produced and reproduced through an identifiable set of practices.” (Hajer, 2006, p.67). As a key element of our analysis, we create storylines, which are “condensed statement[s] summarizing complex narratives, used by people as ‘short hand’ in discussions” (Hajer, 2006, p.69).

Discourse analysis can be particularly useful to study technologies in early stages of development, when uncertainty is high (Binz et al., 2016), and pathways (including specific configurations and applications) are still to be shaped (Rosenbloom et al., 2016). In early discourses, we expect that different groups of actors seek to influence the public debate, in our case, the formulation and implementation of the German hydrogen strategy.

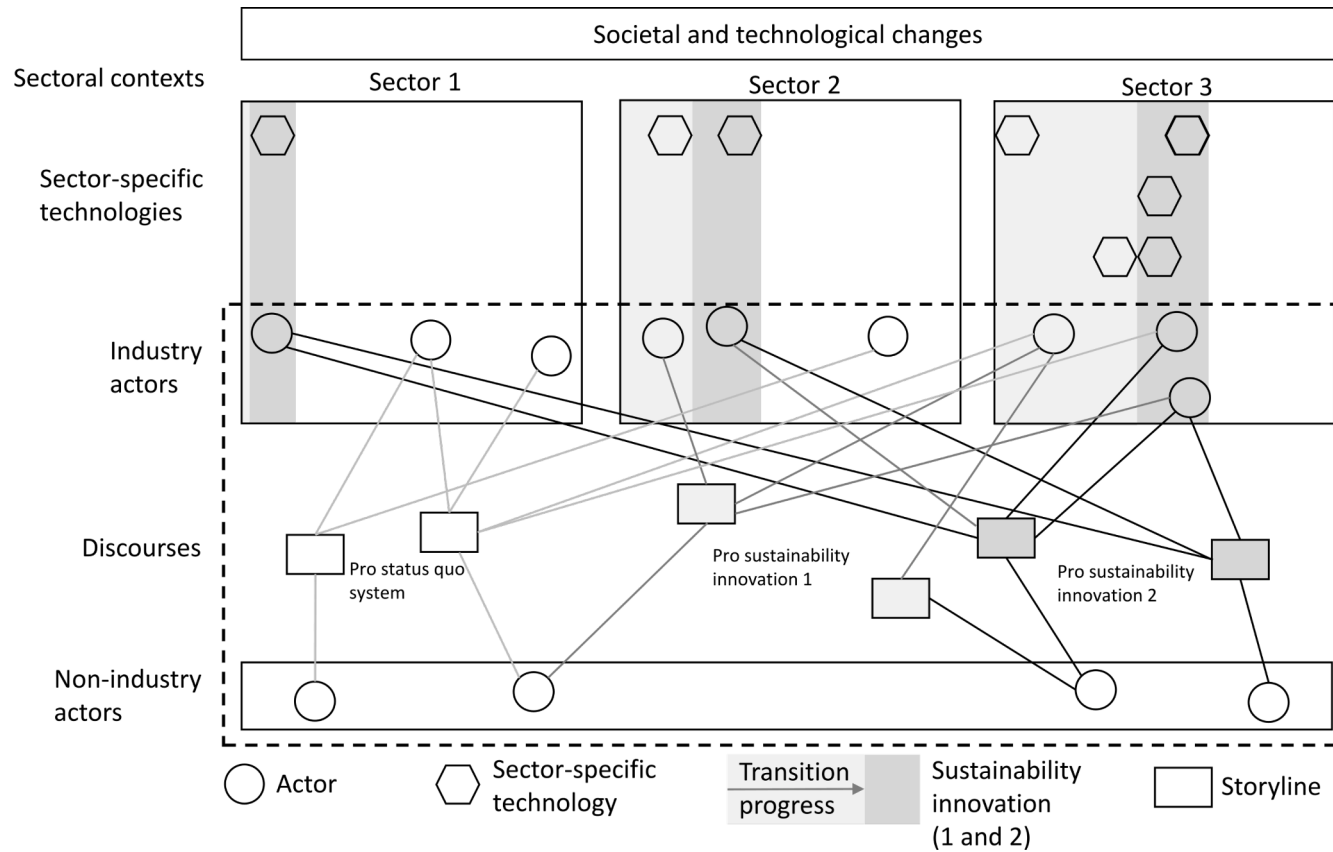
In our paper, we use discourse analysis both qualitatively, and in a quantitative way using DNA. The latter allows us to systematically trace which actors make similar arguments (Leifeld, 2017; Leifeld and Haunss, 2012). DNA has been applied to a broad range of issues including pension policy (Leifeld, 2013), nuclear and coal phase-out (Rinscheid, 2015), climate policy (Fisher et al., 2013; Kukkonen et al., 2018), energy transitions (Brugger and Henry, 2021), or genetically modified organisms (Tosun and Schaub, 2017). DNA is compatible with Hajer’s conceptualization of discourse because it entails both a substantive dimension (arguments expressed through storylines), and a relational dimension in the form of actors sharing similar storylines (Leifeld, 2017).

### 2.5. Conceptual framework

This section seeks to integrate the different aspects we introduced above to explain how storylines form in a multi-sector, multi-technology setting. We built the framework from scratch, but aligned our analytical categories of actors, content and context to Rosenbloom et al.’s (2016), and transferred them to a setting that is characterized by multiple systems and technologies.

We distinguish between the 1) *sectoral context* (with multiple sectors in different transition stages), 2) *multiple sector-specific technologies* (with different socio-technical characteristics), and 3) *strategic actor interests*. Moreover, we assume that all sectors are affected by broader societal and overarching technological changes. The underlying idea is that how actors talk about an innovation depends on the availability and progress of other innovations, and how the innovation relates to established technologies, infrastructures, business practices, and prior strategic commitments.

Fig. 1 shows our generic framework, in which we distinguish i) three different sectors in different transition stages, ii) two sustainability innovations and one incumbent practice (‘status quo’), iii) industry actors in the sectors iv) non-industry actors, and v)



4

**Fig. 1.** Conceptual framework. The conceptual framework describes the behavior of actors in the public debate from three different sectors at different stages of transitions. Each sector has a status quo socio-technical configuration (white area), that is challenged by one or two emerging and competing sustainability innovations (grey areas) and associated sector-specific technologies (hexagons). The position of industry actors (circles on top) in relation to these areas reflect the commitment of actors to the respective technologies. All actors, including non-industry actors from politics, or the civil society, and from economic sectors that are not directly affected by the sustainability innovation (circles at bottom), participate in the discussion by uttering storylines (rectangles) that favor one of the three options. Moreover, we assume that all sectors are affected by broader societal and technological changes.

discourses comprising of a broad set of storylines on both innovations and the incumbent practice. In our example, Sector 1 is at a very early sustainability transition stage and has only one sustainability innovation and sector-specific technology. In the public debate, some industry actors already support the innovation, while others still promote the status-quo system. In Sector 2, the innovations have already made some progress (the white space for incumbent practices decreases) with two equally advanced competing technologies. The actors are divided between the options. Sector 3 has transitioned furthest and includes technologies at different stages of maturity. The actors have abandoned the status quo, but are divided between the different innovations. We apply the framework in [Section 5](#).

### 3. Methodology

The following sections describe our research case Germany, the selection of newspaper articles, the development of the coding scheme, the resulting storylines, the overall sample, and finally, our analytical approach.

#### 3.1. Hydrogen in Germany

We select Germany as our research case for studying the emerging discussion on hydrogen. Germany has Europe's largest economy, and the fourth largest nominal GDP on the globe ([IMF, 2021](#)). Germany's decisions about energy policies are important internationally, as they have already in the past spilled-over to other countries. For example, since the early 2000s, Germany's *Energiewende* demonstrated that a renewable energy transition is generally feasible, induced significant price reductions and efficiency improvements for renewables, and also promoted the expansion of renewables internationally ([Quitow et al., 2016](#)). Understanding the German energy transition is also particularly challenging and complex due to the large variety of established industries with its diverse set of actors.

Especially the goal to decarbonize the entire economy made hydrogen come to the fore of the German government. In early 2019, the German chancellor Angela Merkel announced the new goal of achieving the net-zero emissions goal until mid-century, in contrast to the previous goal of decreasing carbon emissions by 80–95%. This paradigm shift implies decarbonizing the entire economy, including DDI sectors, such as the steel or chemical industry, or shipping and aviation ([Bataille, 2020; Davis et al., 2018](#)). Other reasons driving the recent uptake of hydrogen are increasingly cheap renewable electricity, while increased prices of European Emission Allowances put additional pressure on energy intensive industries.

Germany adopted a national hydrogen strategy in June 2020 as part of an economic stimulus package in response to the Covid-19 crisis ([BMW, 2020](#)). The strategy covers national and international projects on the generation, transport, distribution and use of hydrogen. Germany envisages becoming a large-scale hydrogen importer, also from emerging economies. The strategy explicitly focuses on green hydrogen from renewable energies, while blue hydrogen based on fossil fuels has been declared a temporary solution only.<sup>2</sup>

#### 3.2. Article selection and coding

We investigate the public debate on hydrogen in Germany by analyzing articles of five leading newspapers comprising the *Süddeutsche Zeitung*, *Frankfurter Allgemeine Zeitung*, *Die Welt*, *Handelsblatt* and *taz*. This selection covers five out of six most printed national daily newspapers in Germany with a circulation above 750.000 per day ([Statista, 2021](#)), and addresses the entire political spectrum from left (*taz*) to mid-right (*Die Welt*). We select newspapers as they build an important platform for different actors to construct, vocalize and legitimize their envisaged societal role of hydrogen, and to thereby influence policymaking. To identify relevant newspaper articles, we developed a search query that covers a comprehensive selection of articles, while keeping the number of unrelated findings to a necessary minimum. The query includes articles with hydrogen mentioned at least once at the beginning, and four times in the main text.<sup>3</sup> To ensure that we include the start of the recent discussion around hydrogen, we select articles since the year 2016 when the Paris Agreement was adopted. The search period ends with December 2020.<sup>4</sup>

The coding scheme was developed inductively and bottom-up in multiple iterations within the author team ([Kuckartz, 2016](#)). To familiarize with the topic, we complemented and triangulated our desk research via semi-structured interviews with nine hydrogen experts from NGOs, research institutes and a German ministry by mostly two or three authors in early 2021. To develop an initial coding scheme, each author independently read selected newspaper articles and proposed potential storylines. The selected articles were chosen to represent the entire range of discourses, and thus include long articles from all five newspapers with different topics and many direct quotes. The proposed storylines were subsequently discussed multiple times between the authors. In a next step, one author coded more than 10% of the sample and thereby refined the initial coding scheme. All authors afterwards coded selected

<sup>2</sup> Hydrogen can be produced in different ways, often distinguished by colors. For example, green hydrogen is produced from water via electrolysis using renewable electricity, while blue and grey hydrogen are obtained from natural gas, either using carbon-capture and storage to reduce carbon emissions (blue), or not (grey).

<sup>3</sup> The specific search parameters depend on the search options provided by the different databases used to search for the articles. These databases comprise Lexis (*Die Welt*, *Frankfurter Allgemeine Zeitung* and *TAZ*), WISO (*Handelsblatt*) and the SZ archive (*Süddeutsche Zeitung*). The coding was done using the qualitative data analysis software MAXQDA.

<sup>4</sup> We are aware that hydrogen has been at the center of attention already around the year 2000 and several times thereafter ([Budde and Konrad, 2019; Konrad et al., 2012](#)). Yet, the previously narrow focus on transport differs from the ongoing debate.

**Table 1**  
Storyline overview.

Storyline short	Storyline long
<b>1. Climate change mitigation</b> (123)	
Important for energy transition	Hydrogen is an important part of the energy transition.
Required for complete decarbonization	Hydrogen is indispensable for achieving a complete decarbonization. Renewable electricity alone is insufficient.
Prioritize other climate mitigation options	The focus on hydrogen risks to distract from other mitigation options (e.g. renewable deployment, efficiency, sufficiency) that should be prioritized.
<b>2. Economic considerations</b> (114)	
Economic opportunities	Hydrogen creates economic opportunities (e.g. technology exports, jobs, new value chains) for Germany's economy or individual companies.
Eventually cheap option	Hydrogen will become a cheap energy carrier or at least profitable business case once cost reduction potentials are realized, or carbon costs increase further.
Generally scarce and expensive	Hydrogen will remain a scarce and expensive energy carrier, also in the future.
<b>3. Technical aspects</b> (71)	
Utilization of existing gas grid	Hydrogen allows utilizing the existing gas grid infrastructure.
Facilitates renewable integration	Hydrogen facilitates the integration of (excess) renewable energies and stabilizes the electricity system.
Low energy efficiency	Producing hydrogen is inefficient due to high energy losses.
<b>4. Use</b> (191)	
Wide use	Hydrogen should be used for private cars, domestic heating, blended into the natural gas grid, or generally applied widely.
Restricted use	Hydrogen should primarily be used for difficult-to-decarbonize industries, or not for private cars, heating or be blended into the natural gas grid.
<b>5. Production method</b> (171)	
Non-green necessary	Non-green hydrogen is required for a transition period, or relying on green hydrogen alone is not possible, expensive, or risky.
Exclusively green	Only green hydrogen should be used, or only green is carbon free, or CCS is contested, or non-green hydrogen prolongs using fossil fuels.
<b>6. Imports</b> (85)	
Imports beneficial	Hydrogen imports will be comparatively cheap due to better wind and solar conditions, or exports will foster the economic development abroad.
Imports concerning	Hydrogen imports lead to new energy dependency from other countries, or other countries may face environmental problems (water scarcity) or human rights violations.

The table groups each storyline under one of six topics and shows a short (1<sup>st</sup> column) and a long version (2<sup>nd</sup> column). The number of coded passages for each topic is shown in brackets. Topics 4–6 aggregate several individual storylines; disaggregated short versions of these are shown in [Table 2](#).

articles to compare their coding decisions, and to discuss and resolve potential ambiguities. One author then coded all articles using the final coding scheme.<sup>5</sup> All coded passages that contribute to the results in [Section 4.2](#) were checked by the entire author team to ensure the absence of coding errors. We only coded passages that agree to a storyline, and not such that oppose to it. Identified double codes arising from identical text passages within different articles were removed.

### 3.3. The storylines

This analysis includes 30 storylines, which we grouped into six topics. Topics 1–3 are about the deployment of hydrogen in general, and 4–6 refer to specific lines of conflict. Topics 1–3 address the role of hydrogen for climate change mitigation (1), economic considerations (2), and technical aspects (3) in a prospective renewable electricity system. In total, 9 storylines address these topics, while each respective topic is covered by three storylines. The remaining 21 storylines relate to three specific conflicts on the production method (4), hydrogen imports (5), and the use of hydrogen (6). [Table 1](#) shows the short and long version of the storylines. The storylines referring to the specific lines of conflict are aggregated and assigned to either one of two opposing positions. [Table 2](#) shows the short versions of the disaggregated storylines in the specific conflicts.

The analysis only includes a selection of coded storylines that we consider most insightful to understand controversies in the public debate. It omits more detailed statements related to individual sectors or technology-specific aspects.<sup>6</sup> Excluded storylines address potential consequences from deploying hydrogen, consensual statements related to the conflicts, uncontested applications of hydrogen, and very rare storylines.

### 3.4. The sample

The final sample comprises 179 newspaper articles with 614 coded passages by 139 actors. The initial search yielded 321 newspaper articles. Almost 4000 passages were coded. To condense the analysis to the most relevant aspects, we excluded several storylines

<sup>5</sup> The coding-tree in MAXQDA consists of short versions of each code. The long version, additional explanations, and coding examples are attached to coding memos.

<sup>6</sup> Statements on individual sectors are only included if they more generally address the conflict about where to use hydrogen.

(see previous section), removed false positive articles or articles without coded passages, duplicate codes by the same actor within single articles, and codes by journalists. [Appendix A.1](#) provides further information on the search query, and more details about the sample of newspapers.

The actors covered by the analysis stem from a variety of fields and industrial sectors. To facilitate the overview, we aggregate individual actors to groups, namely *Policy makers*, actors from the *Transport, Gas and heat, Industry and Electricity sectors*, actors from *Research and think tanks*, and *NGOs*.<sup>7</sup> Within each industrial sector, the public debate is dominated by incumbents, while newcomers only play a minor role.

The number of coded passages between actor groups is very unequal. Policy makers are most salient, specifically different ministries, but also members of the EU Commission and political parties. Of industry actors, selected companies and industry associations from the automotive energy and gas sector are particularly visible (VW, BDI, RWE, Westenergy, Zukunfts Erdgas, FNB Gas, and Siemens). Other frequently occurring actors comprise specific NGOs (BUND, DUH, Klimaallianz) and research institutes (Max Planck Institute, Dena, Fraunhofer ISE).<sup>8</sup> [Appendix A.2](#) provides the descriptive statistics about discursive engagement of all actors. [Appendix A.3](#) shows the temporal development of the public debate.

### 3.5. Data analysis

We analyze the sample in two steps using Stata. In a first step, we descriptively analyze the storylines that refer to using hydrogen in general by comparing the shares of each actor group. In a second step, we apply DNA to analyze the three specific lines of conflict regarding the use, production, and imports of hydrogen, based on codes of 21 storylines shown in [Table 2](#).

We restrict the DNA to the most active actors, only including actors with at least three coded passages.<sup>9</sup> The sample thereby reduces to 257 coded storylines by 63 actors. We create an actor congruence network to visualize individual actors using similar storylines. Links between actors are normalized to account for unequal numbers of coded storylines between actors, by dividing the edge weight with the average number of storylines ([Leifeld, 2017](#)). [Fig. 3](#) shows the resulting discourse network in detail. [Fig. 4](#) shows the same discourse network, but with all edges highlighted that include at least one storyline in support of the respective conflict position. All figures are created with Stata and edited with Inkscape.

Data limitations require consideration when interpreting our findings. Gaining a comprehensive understanding of positions of most actors is impossible due to scant text passages with sufficient detail. The short analysis period, moreover, prevents analyzing dynamic changes of individual positions, which thus remains subject for future research. We discuss further limitations in [Section 5.3](#).

## 4. Results

We identified six major topics in the discussion on hydrogen in Germany. Three topics address the deployment of hydrogen in general ([Section 4.1](#)), and three address specific conflicts ([Section 4.2](#)).

### 4.1. General topics: Decarbonization, economic and technical aspects

Attention for hydrogen has significantly increased since 2019, and there is a lively debate between a broad range of actors from different sectors and institutional backgrounds. Interestingly, we find many incumbent firms from e.g., energy, transport, and industry. In general, there is widespread support that hydrogen is necessary to achieve net-zero, and that the development of hydrogen-based technologies creates economic opportunities. However, potential caveats receive attention as well. Three overarching topics emerged: decarbonization, economic considerations, and technical aspects. Coincidentally, each topic entails two enthusiastic, and one skeptical storyline. [Fig. 2](#) shows the relative shares of all nine storylines by actor group.

On the first topic, policy makers, industry actors and think tanks frequently mention that hydrogen is important for the energy transition, and required to reach net-zero. *“I am convinced that we cannot achieve the energy transition without gaseous energy sources. They are an indispensable part of the energy transition in the long term”* (BMWi, 63).<sup>10</sup> NGOs do not necessarily disagree, but highlight that other climate mitigation options such as efficiency or sufficiency should be prioritized, or at least not be neglected.

*“At the moment, people like to pretend that there is an unlimited supply of hydrogen, for example from Africa. [...] We must continue to think about how we can use our resources more efficiently, which flights and which transports we can do without, without giving up our prosperity”* (BUND, 143).

<sup>7</sup> The group *Research and think tanks* also includes international organizations and consultancies. The majority of NGOs focus on environmental topics. The *Industry* groups comprises potential users of hydrogen, but also producers. The analysis omits individuals that cannot be assigned to any actor group.

<sup>8</sup> In some instances, single quotes are cited in multiple articles. This mostly applies to statements by ministers, and the CEO of the German car manufacturer Volkswagen

<sup>9</sup> Our inclusion criterion focuses on actors that are most visible in the overall public debate. We additionally created an actor congruence network that includes actors that are most visible in the conflicts (in contrast to the overall public debate) by tightening the inclusion criterion towards at least three coded passages within the three conflicts. The resulting network shows a qualitatively similar pattern, but only includes roughly half of the actors, with particularly many missing actors from the grey shaded area.

<sup>10</sup> The number corresponds to the list of newspaper articles in [Table A.1, Appendix A.1](#).

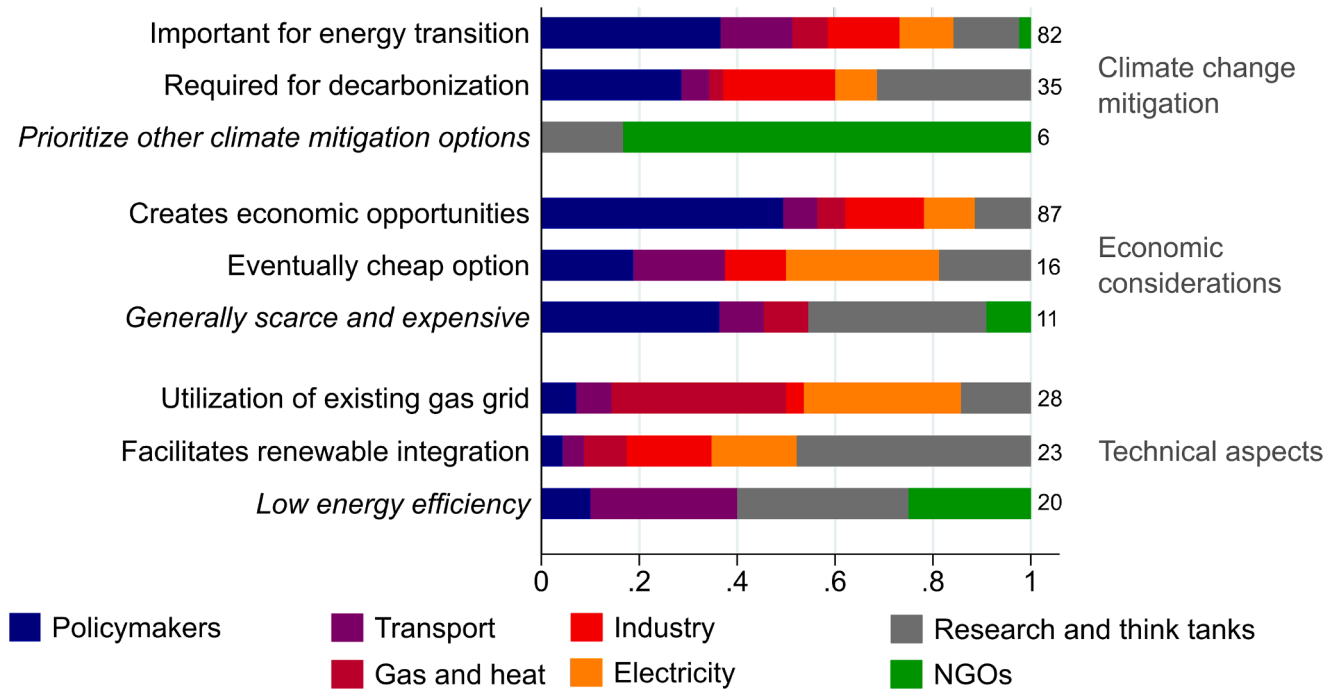


Fig. 2. General storylines. The figure shows the share of general storylines referred to by each actor group. The nine storylines are grouped under three topics. The first two storylines of each topic are enthusiastic, the third takes a skeptical position (in italics). The frequency of coded passages is depicted next to the bars. Further information on the content of each storyline is provided in Table 2.



**Table 2**  
Emerging conflicts.

Enthusiastic:		Skeptical:
<b>4. Use (191)</b>		
Wide use (94):	↔	Restricted use (97):
Private cars		Not private cars
Gas grid		DDI priority
Heat		Not heat
Wide application		Not gas grid
<b>5. Production method (171)</b>		
Non-green necessary (88):	↔	Exclusively green (83):
Transition and market creation		Explicitly green only
Consider various colors		Only green carbon free
Only green not possible		CCS is contested
Include grey		Not green prolongs fossil fuel use
<b>6. Imports (85)</b>		
Imports beneficial (55):	↔	Imports concerning (30):
Using beneficial solar conditions		Import dependency
Advantage for exporters		Disadvantage for exporters
Potentially cheap imports		

The table shows short versions of storylines related to the three emerging conflicts. The frequency of coded passages for each aggregated storyline is shown in brackets, sub-storylines are sorted in descending order by the frequency of coded passages. Storylines on the left are enthusiastic about hydrogen, those on the right skeptical.

But these more critical voices are very much a minority. In summary, we find that actors generally agree that hydrogen is relevant for climate change mitigation, but not necessarily how it compares to other mitigation options.

Economic considerations constitute another key topic. Policymakers across all parties and ministries, and incumbents from many different sectors frequently highlight the economic opportunities associated with establishing a hydrogen economy. “*We want to become the hydrogen republic of Germany. [...] And we want Germany to become the world market leader in the production and use of green hydrogen obtained from renewable energies*” (BMBF, 123). While policymakers stress the goal of maintaining, or even strengthening Germany’s role as a global technology exporter, several industry actors, including both incumbents and newcomers, see business opportunities in the development and export of hydrogen technology, or hydrogen-based products. However, researchers and green policymakers expect that hydrogen will remain a scarce and expensive energy carrier in the future. “*Hydrogen is the caviar among energy carriers and is too expensive and valuable to be used everywhere*” (Green Party, 117). In contrast, some incumbents argue either that absolute generation costs for hydrogen will further drop alongside costs of renewables, or that hydrogen will become relatively cheap if carbon prices increase. “*The production of renewable energy, especially wind energy on the high seas, is becoming cheaper and cheaper, and at the same time the high CO<sub>2</sub> prices, despite the Corona crisis, make coal in particular unprofitable*” (EU Commission, 118).

Technical aspects are the third key topic. Researchers and industry actors argue that hydrogen would facilitate the integration of variable renewable electricity by stabilizing and balancing the electricity grid. Incumbents from the gas, heat, and electricity sector mention the benefits of using the existing gas infrastructure to transport and store hydrogen.<sup>11</sup> “*The gas customers of today are the hydrogen customers of tomorrow*” (FNB Gas, 147). While these storylines are largely uncontested, especially researchers and NGOs frequently emphasize the low energy efficiency of green hydrogen production and promote electrification as more efficient.<sup>12</sup>

#### 4.2. Emerging conflicts: Hydrogen use, production and imports

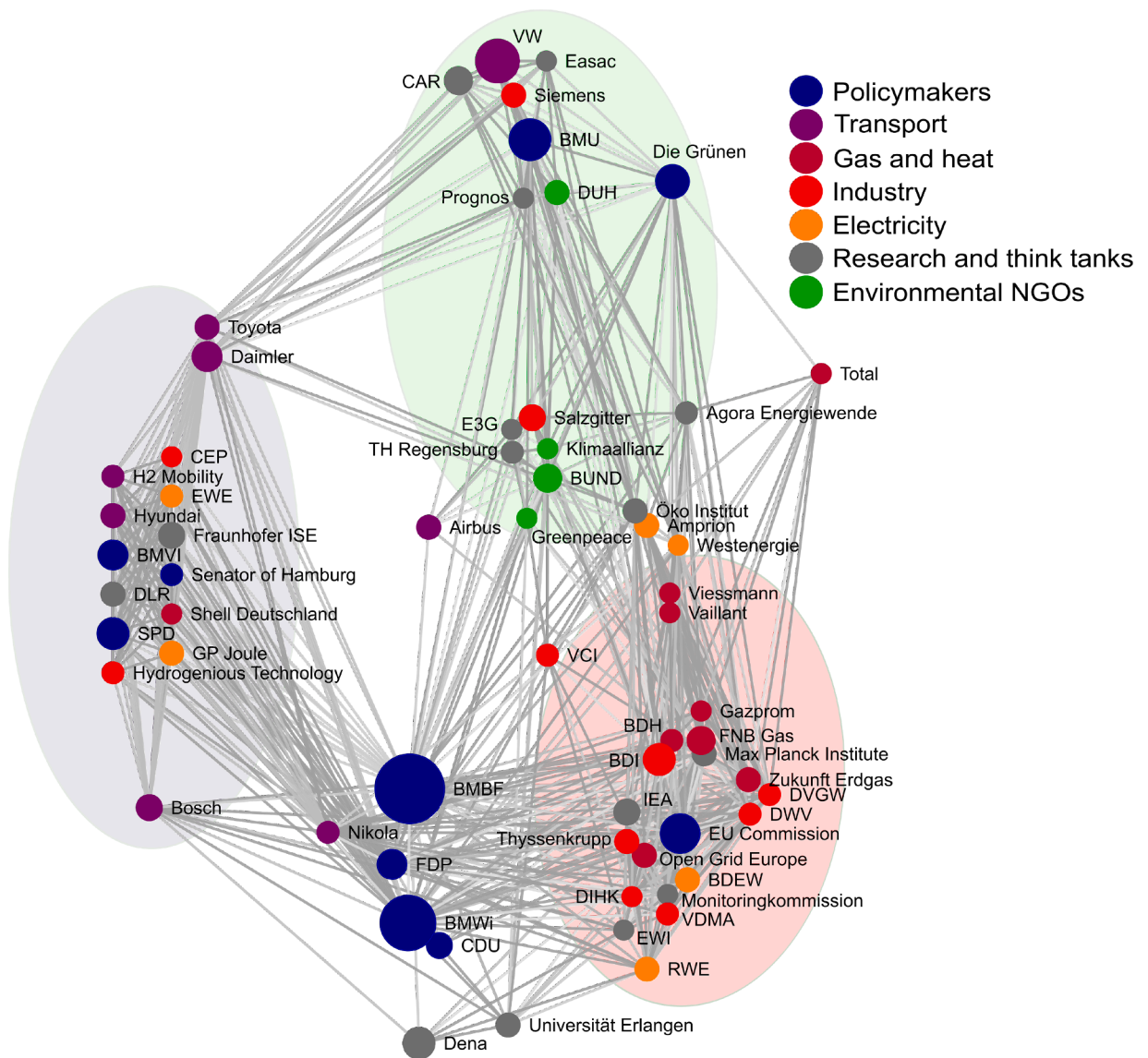
We find three emerging lines of conflict on where to use hydrogen, the production method, and imports. First, actors disagree whether hydrogen should be used widely or only for applications in DDIs with few alternatives. Second, actors disagree whether hydrogen should only be produced from renewable energies, or whether blue hydrogen is a temporary option. Finally, actors have conflicting views regarding whether hydrogen imports are rather problematic, or beneficial.

We employ DNA to explore the actor positions around these conflicts in more detail (see Fig. 3).<sup>13</sup> In the actor congruence network,

<sup>11</sup> The storyline encompasses both the German gas transmission grid and the distribution network, and comprises the options of blending natural gas with hydrogen, or completely converting existing natural gas pipelines to hydrogen. Conflicting views on blending natural gas with hydrogen, and using hydrogen for heating are separately discussed in Section 4.2.1.

<sup>12</sup> Most codes assigned to actors from the transport sector were from the CEO of the car manufacturer Volkswagen, a strong advocate for electric mobility in contrast to hydrogen based fuel cells.

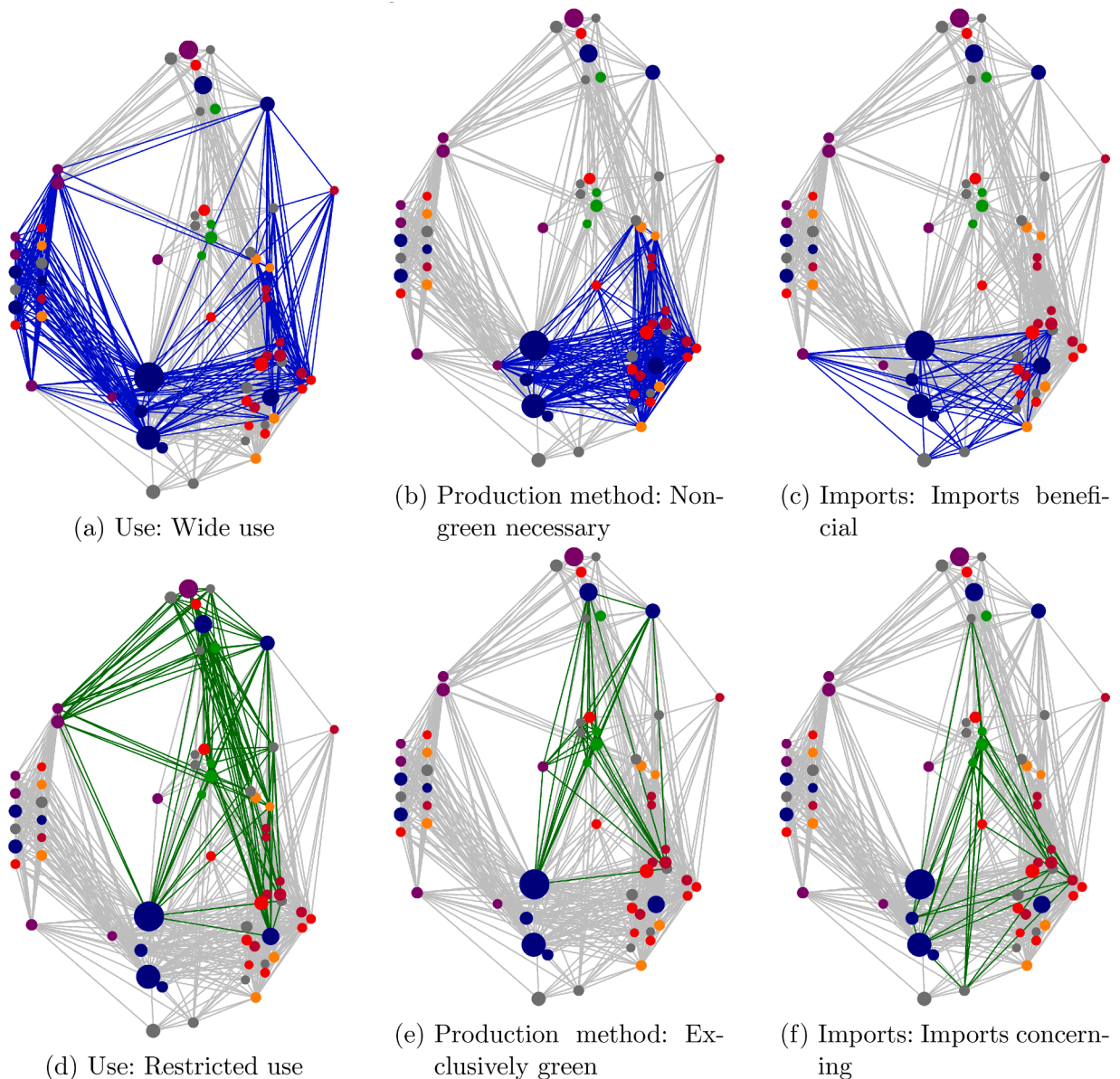
<sup>13</sup> The actor congruence network only includes storylines on related to the use, production, and imports as listed in Table 2.



**Fig. 3.** Discourse network of key conflicts in the German hydrogen debate. The figure shows an actor congruence network for the three conflicts on the use, production method, and imports of hydrogen. Nodes represent actors, edges represent shared storylines. The node-size correlates with the number of newspaper articles with a coded passage by the actor. The figure only includes actors with at least three coded passages in the complete dataset. The grey shading of edges is darker for a higher normalized number of shared storylines. The node colors correspond to the actor groups, and the manually added shaded areas highlight visually identified agglomerations to facilitate the interpretation of the graph. Individual overlapping nodes were manually disentangled (especially in the grey shaded area).

actors are generally well connected. For a better overview, we manually added background shades to three areas with commonalities in the actor positions. Each area includes actors across groups, but some actor groups are more dominant than others: gas, heat and industry incumbents in the red area, transport sector actors in the grey and e-NGOs in the green.<sup>14</sup> The following sections discuss the three lines of conflict in detail. Fig. 4(a–f) highlights all edges that include at least one storyline in support of the respective conflict position.

<sup>14</sup> The green area comprises NGOs, several research institutes and think tanks, policymakers from the German Green Party and the environmental ministry, a leading electric vehicle manufacturer (VW), and two leading industrial companies (Salzgitter and Siemens). The red area is dominated by incumbents from the gas, oil, power and heat sector. It also comprises the EU Commission, researchers and think tanks, and actors from other industrial sectors. The grey area is dominated by actors from the automobile sector, several policymakers, think tanks and research institutes, and hydrogen interest organizations. Some actors, especially two dominant ministries and two parties, are between the shaded areas.



**Fig. 4.** Specific lines of conflict. The figures highlight storylines addressing the three covered conflicts that are shared by actors. The networks otherwise equals the previously shown actor congruence network (see Fig. 3). The covered conflicts comprise the use (panel a and d), production method (b, e), and imports (c, f) of hydrogen (see Table 2 for more information). The panel name indicates the position within each conflict. Edges are highlighted if both actors share at least one storyline that supports the respective conflict position. Enthusiastic storylines are highlighted in blue, and skeptical storylines in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

#### 4.2.1. Use

As a general pattern, most industry actors promote using hydrogen in their own sector, while only some argue that using hydrogen should be restricted. We classify storylines that envision using hydrogen for cars, blending it into the natural gas grid, heating, and a wide application in general, as ‘wide use’, and those that oppose one of these uses (cars, blending into gas grid, heating), or want to use hydrogen only for DDIs, as ‘restricted use’. The specific arguments for using hydrogen differ by sector, but many outline potential benefits for the climate: “*In no other area than the heating sector would such large CO2 savings be possible so quickly and pragmatically*” (Viessmann, 144). Blending hydrogen into the natural gas grid “[...] *would make natural gas greener. All the investments have already been made, the pipelines work, the manufacturing plants exist*” (Total, 179). “*We need e-fuels and hydrogen from sustainable energy sources in order to achieve the climate targets for the millions of cars in our fleet*” (VDA, 156). Proponents of a wide use mostly comprise actors in the red and grey areas: those in the grey area mostly emphasize using hydrogen for cars, while those in the red area propose heating, and

blending hydrogen into the natural gas grid.<sup>15</sup>

Those favoring a restricted use argue that hydrogen should primarily be used in sectors with few alternatives for decarbonization. Otherwise hydrogen might be missing where it is needed most.

*“The [steel] industry has no alternative if it wants to become climate-neutral. [...] The cement industry and the chemical industry are also dependent on hydrogen. In air and sea transport, hydrogen is also the central building block on the way to climate neutrality”* (BMU, 80).

Some actors also explicitly advise against using hydrogen in specific applications. *“Green hydrogen has no place in cars and heating systems”* (DUH, 104). Storylines supporting a restricted use are prominently located in the green area, with some exceptions in the red area: for example, the EU Commission explicitly prioritizes hydrogen for industrial uses. Toyota and Daimler (grey area) are also noteworthy, as both predominantly promote hydrogen for trucks or buses, not for private cars.

#### 4.2.2. Production method

This conflict centers around two major arguments: one is about only producing hydrogen from renewable energies, and the other is about making large quantities of hydrogen available quickly by also using fossil fuels. Many actors argue that blue hydrogen is required for a transition period, or simply state that various forms of production should be considered. *“Hydrogen has many colors, and we should use all. [...] We should use blue or turquoise hydrogen for a transition period”* (RWE, 115).<sup>16</sup> A variation of this argument is that only green hydrogen would not be possible due to limited availability or high costs. A minority even considers grey hydrogen as a temporary solution. Those in favor of blue hydrogen include almost all actors in the gas and heat sector, several policymakers, and also a leading environmental research institute: *“[In] the next decade [blue hydrogen will] be the only source that is justifiable in terms of cost for high-volume applications and for the market ramp-up in those areas in which hydrogen is of high strategic importance”* (Öko-Institut, 171). Also the EU Commission suggests using blue hydrogen.

Opponents of this position argue that only green hydrogen is actually carbon free. Some also mention that carbon capture and storage (CCS) is a contested technology: *“Why should we use blue hydrogen in the future, if the climate footprint is bad and the costs for generation high? [...] It instantly brings a debate about CCS [...], which is predominantly rejected in Germany”* (BMU, 80). A few also highlight that using blue hydrogen would be a lifeline for the fossil fuels: *“Blue hydrogen is of fossil origin and perpetuates the fossil industry instead of transforming it”* (TU Regensburg, 112). These storylines are predominantly assigned to actors in the green area including the environmental ministry, and to the ministry for education and research. A leading steel producer (Salzgitter) even wants to produce its green hydrogen for its steel production with own renewable power plants, thus taking a dual role of using and producing hydrogen.

#### 4.2.3. Imports

Actors arguing that hydrogen imports are beneficial explain that hydrogen generated abroad would profit from better solar conditions and is hence potentially cheaper, or that exporting countries would benefit.

*“With green hydrogen, the geographical advantages in renewable energies could become a development engine for the societies there [Africa]. [...] In this way, we not only create the basis for German technology exports, but also ensure a climate-friendly energy supply”* (BMBF, 61).

Benefits of hydrogen imports are mentioned by a leading industry association (BDI), the EU Commission, several research institutes in the red area, as well as by several policymakers, and a large car industry supplier (Bosch).

Those concerned of hydrogen imports warn of new import dependencies, and of potential environmental and social risks for exporters. *“Importing hydrogen from countries of the Global South without adequate consideration of the ecological and social situation in the country of production risks being perceived as a mechanism of exploitation or a new form of colonialism”* (Brot für die Welt, 173). *“Many of the countries that basically come into consideration still have to develop themselves first. [...] They would not export the green hydrogen, but use it for their own economic development”* (Zukunft Erdgas, 79). Concerns about imports are mostly raised by policymakers, NGOs and research institutes. Risks for exporters are highlighted by NGOs and members of the German liberal party (FPD), while some incumbents (Zukunft Erdgas and VCI) warn of import dependency.

### 4.3. Summary along actor groups

The public debate about hydrogen in Germany is characterized by a broad agreement that hydrogen is necessary for achieving net-zero targets. The topics of climate change mitigation and creating economic opportunities receive most attention (123 and 87 coded passages). Technical aspects and storylines related to costs of hydrogen are less prevalent (71 and 27 coded passages). Overall, we find that each actor group supports hydrogen for overlapping, but also partially different reasons. The ambiguity around what a ‘hydrogen

<sup>15</sup> The Green Party is an outlier due to one quote from 2019 that promotes blending hydrogen into the natural gas grid. Their position has changed since, which is why it also features prominently among those that want a more restricted use. We find contradicting storylines also for other actors due to different individuals being aggregated, a temporal change in the actor’s position, or simply inconsistent communication.

<sup>16</sup> One storyline of (a) states that “blue hydrogen was required for a transition period or building up the market, but that green hydrogen would be the ultimate goal”. This storyline is practically in between both positions. However, we distinguish between actors that agree to building infrastructure for non-green hydrogen as well, and those who disagree.

economy' actually implies might explain some of the observed enthusiasm.

Most industry actors are very much in favor of hydrogen and emphasize the prospect of cheap hydrogen, or the opportunity to utilize the existing gas infrastructure. For these actors, policy support for hydrogen projects (in their respective sector) is particularly important, as they are confronted with large upcoming investments, but often bound to existing assets and business models. The broad support by industry incumbents is particularly interesting because they vary substantially in terms of sectors, technologies and strategies (see Section 5.1).

NGOs are more skeptical with their support of hydrogen. NGOs highlight the limitations of hydrogen (costs, scarcity, efficiency) and other, potentially neglected decarbonization options. Along these lines, NGOs, together with the ministry for the environment and the Green Party, favor a restricted use of hydrogen, exclusively support green hydrogen. They also emphasize risks for potential exporters, a topic with little salience beyond. NGOs may want to remind policymakers and the public of looming problems and potential caveats.

Policymakers mostly emphasize the economic opportunities associated with hydrogen, although a few also mention that it might remain scarce and expensive. For policymakers, hydrogen is a very favorable topic that creates many winners, allows for prestigious projects, and does not yet require difficult decisions or priority setting at this early stage. Regarding the use and production method, policymakers are divided, depending on their party affiliation. They address both potential risks and benefits of hydrogen imports. Policymakers thus overall seek to create a positive image around the prospects of a hydrogen economy.

Researchers and think tanks engage with all topics. They all highlight the necessity of developing hydrogen technologies, while being explicit about the limitations and caveats. Regarding the three conflicts, their positions vary. Many very much concentrate on the techno-economic characteristics. Apart from some enthusiasts, there are many cautious voices that highlight the technical limitations of different options.

## 5. Discussion

Our findings show that many actors, including incumbents from different sectors and industries support the idea of establishing a hydrogen economy in Germany. The enthusiasm by incumbents is particularly interesting for the transitions literature, given that they have been observed playing different roles (see Section 2.3). To better understand their motivations, we seek explanations at three levels: sectoral contexts, sector-specific technology features (including the availability of alternatives to hydrogen), and actor interests (see Section 2.5 and Fig. 5). In our case, we look at the intersection of four different sectors. In each sector, there are different technological options for decarbonization at different stages of development. We discuss electrification and hydrogen in the following (see Table 3). For the sake of simplicity, we assume just two general positions: enthusiastic vs. skeptical.

We now elaborate the actor positions in each sector (see Section 5.1), outline implications for transitions research (see Section 5.2), and finally discuss limitations to our approach (see Section 5.3).

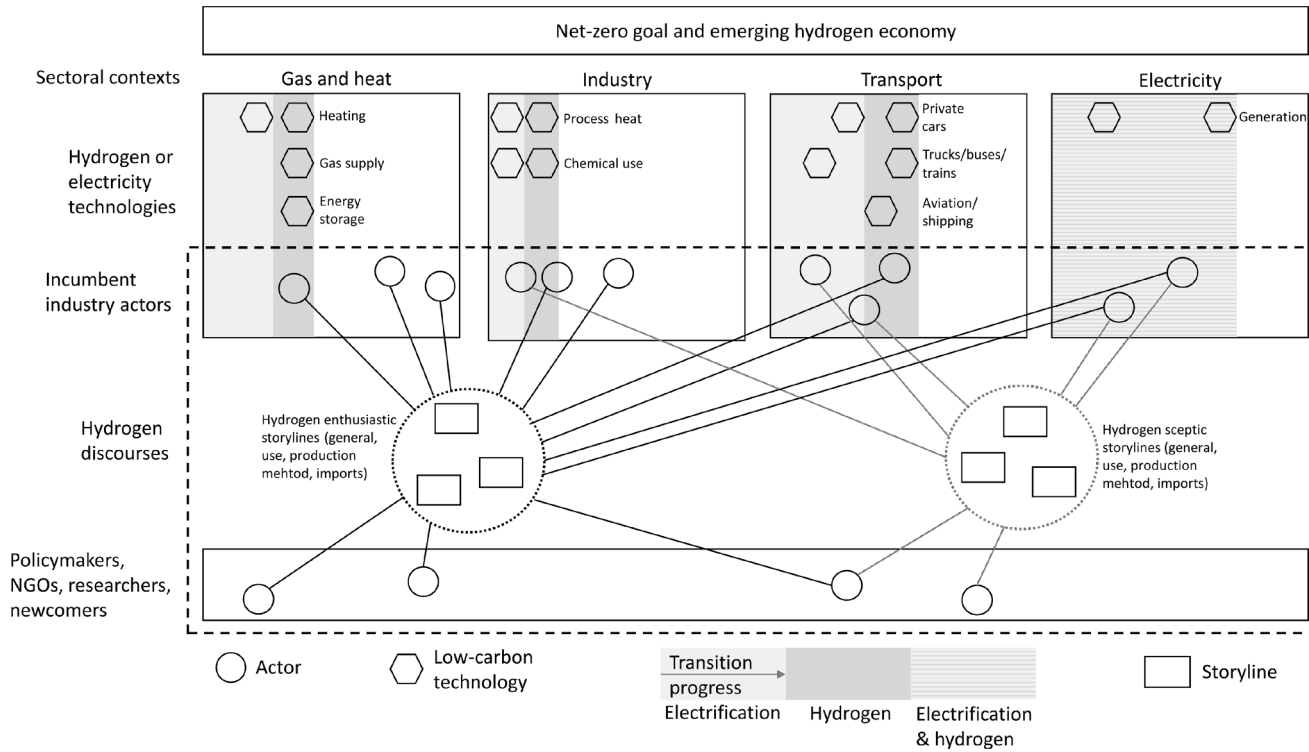
### 5.1. Explaining actor positions for each sector

Gas and heat sector incumbents are among the most vivid supporters of a large hydrogen economy (see Table 3). Decarbonization of heating has not progressed well but there is an ongoing transition (medium stage) toward electrification of heating (e.g. with heat-pumps). In the past, incumbent actors have promoted gas as an alternative to oil, now they argue for 'green gas' instead of electrification (Lowes et al., 2020). Hydrogen fits well into this strategy. It would allow gas suppliers to continue managing the grid infrastructure, and boiler manufacturers to continue to sell boilers. Gas producers could even use their natural gas sources to produce blue hydrogen. Overall, actors in the gas and heat sector try to create an image of hydrogen as a pragmatic, fast, and low effort solution to decarbonize the heating sector. This strategy downplays cheap, efficient and available technological alternatives (heat pumps, insulation) and helps incumbents to keep control of their assets and business models.<sup>17</sup>

Incumbents of Germany's energy intensive industries (e.g. steel, chemical and cement industry) also want to decarbonize their businesses with hydrogen. In most industries, decarbonization (with hydrogen or electricity) is still at early stages and incumbent actors face great pressure. Hydrogen is frequently highlighted as a key, or even the only solution, especially for processes such as steel making or ammonia or plastic production that require hydrogen molecules. Processes that require high temperatures may alternatively be decarbonized via electricity (Madeddu et al., 2020). Incumbent actors therefore support the idea of establishing a hydrogen economy, suggest a fast ramp-up and expect political support (BMWK, 2022). An important industry association (BDI) supports using blue hydrogen for an intermediate period and suggests to avoid using hydrogen for heating because of limited supply. Viewpoints on imports vary. Some actors expect benefits due to lower costs (BDI), while others fear import dependencies (VCI). In the public debate, hydrogen is presented as the only solution for a successful transition of the German industry, potentially even creating a competitive advantage.

Incumbents in the transport sector are divided between supporting hydrogen or electricity. Transition stages differ depending on the mode of transport and energy carrier. Hydrogen based solutions are at very early stages for ships or airplanes and more developed for cars, trucks and trains. The transition to electric vehicles is progressing rapidly for cars and more slowly in the case of trains or trucks. There are also first electric airplanes. The entire transport sector is under increasing political pressure and incumbents are also

<sup>17</sup> The above strategies and the role of natural gas suppliers might fundamentally change in response to the Russian invasion of the Ukraine and the ensuing issues around gas prices and security of supply.



**Fig. 5.** Applied conceptual framework. The applied conceptual framework positions actors in the sectors gas and heat, industry, transport, and electricity in a stylized manner in the discussion. The sectors are at different transition stages towards using technologies based on electricity or hydrogen. The depicted technologies only build a selection to illustrate the overall picture. The different low-carbon technologies are competing, except for the electricity sector, where both complement each other. In line with our empirical analysis, we only focus on the discussion around hydrogen.

**Table 3**  
Transitions in each sector.

Sector	Sectoral context	Sector-specific technologies	Actor interests
<b>Gas and heat</b>	<i>Hydrogen:</i> Transition at an early stage. Increasing public and political pressure to decarbonize the building sector and phasing-out natural gas. Policies are under development, upcoming regional feed-in of hydrogen to gas grids. Potential for local and national power storage. Energy transport via pipeline to avoid contested deployment electricity deployment of transmission power grid. <i>Electricity:</i> Transition at medium stage. Low-carbon heating supported by public funding schemes.	<i>Hydrogen:</i> Heating via blending hydrogen into existing natural gas grid, or redesigning natural gas infrastructure. Large potential energy storage and transmission capacities in existing gas infrastructure. Infrastructure potentially needed for gas supply of combined heat and power generation (see Sector Electricity). <i>Electricity:</i> Heat-pumps are economically competitive and increasingly deployed.	<i>Hydrogen:</i> Strong support by incumbents, as hydrogen only option to sustain current business models, with potential of blue hydrogen to save natural gas assets. <i>Electricity:</i> Not supported by gas incumbents due to conflict with business model. Supported by manufacturers of heat-pumps though.
<b>Industry</b>	<i>Hydrogen and Electricity:</i> Transitions at early stages. Difficult-to-decarbonize industries, such as steel, chemical and cement industry, of increasing political focus. Some industries under strong international competition. Hydrogen considered primary solution, large public transition funding envisaged e.g. via carbon-contracts for difference.	<i>Hydrogen and Electricity:</i> technologies still under development. Hydrogen for production processes requiring high temperatures and chemical properties of energy carrier, electricity only for high temperatures.	<i>Hydrogen and Electricity:</i> Incumbent actors generally support using hydrogen or electricity, depending on industrial process and political support. No newcomers involved.
<b>Transport</b>	<i>Hydrogen and Electricity:</i> Especially road transport under increasing decarbonization pressure due to national and EU regulation. Often both hydrogen and electricity technically possible. <i>Hydrogen:</i> Transition at early-medium stage. Fuel cell cars scarcely sold. First commercial projects for heavy transport and trains. First pilot projects for shipping and aviation. <i>Electricity:</i> Transition at medium stage. Battery electric vehicles with increasing market shares, increasing charging infrastructure. First commercial projects for heavy transport and trains. No commercial option for aviation, first pilot projects for electric ships.	<i>Hydrogen:</i> Fuel cell cars fully developed but expensive. Fuel cell trucks, buses and trains developed. Technology for aviation and shipping under development. <i>Electricity:</i> Battery electric vehicles fully developed. Electric trucks, buses and trains developed. No option for aviation, ships for short distance under development.	<i>Hydrogen:</i> Support ranges from weak to strong, depending on application, and individual decisions by companies on specific technology. Support generally weaker for smaller and lighter vehicles. Incumbents challenged by newcomers (e.g. Nikola). <i>Electricity:</i> Support inverse to hydrogen, generally stronger for smaller and lighter vehicles. Incumbents challenged by newcomers (e.g. Tesla).
<b>Electricity</b>	<i>Special context:</i> Energy carriers complementary, electricity primary option. <i>Electricity:</i> Transition at medium-late stage: Share of renewable energies increases, although deployment slowed down by local resistance and lengthy project implementation. Coal phase-out decided, natural gas increasingly less of considered transition option. <i>Hydrogen:</i> Thus far, no commercial power production based on hydrogen, only expected for energy systems with high shares of renewables.	<i>Electricity:</i> Renewable energies generate power, most importantly PV and wind. <i>Hydrogen:</i> Natural gas power plants available for power generation to balance electricity grid, but need adjustment for hydrogen.	<i>Electricity:</i> Support by most incumbents as portfolio now includes renewable technologies. Demand adjusted regulations for faster deployment of renewables. <i>Hydrogen:</i> Support by some incumbents as new business field through green hydrogen production.

The table describes the *Sectoral context*, *Sector-specific technologies*, and *Actor interests* in the sectors Gas and heat, Industry, Transport, and Electricity.

challenged by newcomers, such as Tesla or Nikola. In the public debate, incumbent actors mostly discuss specific technological aspects and emphasize the potential of hydrogen for specific applications. Some German car manufacturers present hydrogen as a technologically superior (or even the only) long-term solution with advantages over electricity, while others point to the rapid progress of electric vehicles. Engagement in more general conflicts about the production method or imports are scant.

Actors from the electricity sector generally support the deployment of hydrogen. Decarbonization on the basis of renewable energies is comparatively advanced and fossil fuels are envisaged to be phased-out. In the electricity sector, in contrast to the other sectors, electricity and hydrogen do not compete, but may complement each other. Hydrogen can be used for storage and thus balance the supply of fluctuating renewables, while renewables are needed to produce green hydrogen. Most incumbents are in favor of using green hydrogen because this provides new business opportunities. Some companies also promote blue hydrogen for a transition period, and using hydrogen for heating. The image created around hydrogen is that of an inevitable technological component facilitating the energy transition and providing new business opportunities.

## 5.2. Implications for transitions research and policy

Our analysis has shown that hydrogen and the net-zero energy transition bring a new degree of complexity to transition studies. Here we discuss broader implications of multi-system interaction, multi-technology interaction, and strategies of (incumbent) actors. First, we need to embrace multi-system interactions and multiple transitions unfolding in parallel across different sectors (Kanger et al.,

2021; Rosenbloom, 2020). Each sector has its own specificities in terms of sustainability challenges, actors and interests, regime structures and approaches for decarbonization. Also, we have seen that sectors are in different transition stages and that developments in more advanced sectors, such as electricity, affect transitions in less advanced sectors. For the transition to net-zero it is important that transition pathways in different sectors complement each other to generate cumulative effects towards decarbonization. However, our study has shown that actors have conflicting views about where to use hydrogen or how much hydrogen to import. This means that frictions can occur as actors compete for scarce resources or political support. Such conflicts will require careful priority setting through policy, e.g. by defining applications and sectors that shall get hydrogen first.

Second, we need to consider multi-technology interactions, e.g. between technologies at different stages of maturity (Andersen and Markard, 2020; Papachristos et al., 2013). In our case, hydrogen and electricity can both be the basis for many low-carbon technologies, which means hydrogen and electricity compete but may also complement each other. Depending on the sector and application, actors will also perceive different technologies as more or less disruptive. While we focused primarily on hydrogen, future studies might want to analyze several innovations at the same time to explore these interactions further.

Third, new conceptual frameworks need to accommodate a broad variety of actors with different strategic interests. We observe that incumbents' position towards hydrogen seems to be affected by their sectoral background, the performance and level of disruption of new sector-specific technologies, and prior strategic decisions. We observe support for hydrogen in sectors where i) it is (currently) the only low-carbon option, ii) it complements existing technologies, or iii) it is compatible with the status quo business model of incumbents. Independent of the sector, it also receives support if it constitutes a new business opportunity. Reactions are more diverse in sectors where both electricity and hydrogen are equally applicable. Future frameworks could more systematically categorize such relations.

Our analysis revealed broad support of hydrogen by a wide range of incumbent actors, which might be counterintuitive. While hydrogen is a case in which incumbents drive innovation (Berggren et al., 2015; Turnheim and Sovacool, 2020), we also find elements of 'politics of delay,' e.g. by actors from the gas and heat sector (Lamb et al., 2020). Such settings of a complex interplay of various strategic interests require careful policymaking to not risk capture by powerful incumbents.

Finally, our case also points to the potential emergence of meta-rules and transition patterns that span across multiple systems (Kanger and Schot, 2019). One meta-rule that is already prominent in the net-zero energy transition is low-carbon electrification, with more and more applications being converted from fossil fuels to electricity. In the future, hydrogen may assume a similar role: like electricity, it might become a widespread basis for decarbonization. Future studies will have to explore the benefits (e.g., complementary use of infrastructures) but also risks (e.g., lock-ins) of these developments.

### 5.3. Limitations

Our study is subject to the following limitations. First, what we learned for Germany does not necessarily apply elsewhere. For example, the German hydrogen strategy envisages large-scale hydrogen imports, and only supports green hydrogen. We expect different discourses in places that envision becoming large-scale exporters of green hydrogen, or countries with abundant domestic natural gas resources.

Second, we only analyzed the debate around hydrogen, but neglect interrelated discourses on other net-zero options, for example low-carbon electricity, or negative emission technologies. Future studies could explore the politics around multiple technologies for decarbonization in greater detail.

Third, as the hydrogen debate emerged rather recently, we were not able to study how actor positions and arguments changed over time.<sup>18</sup> It will be very interesting to repeat our analysis in a few years' time.

Fourth, we only analyzed the public debate through newspapers. Other venues and data sources such as parliament debates, position papers, or expert interviews may reveal higher levels of detail as well as different actor interests in terms of audience and the aspired goal of communication.<sup>19</sup> We also acknowledge that newspaper articles are subject to journalists' pre-selection of information.

Finally, storylines aggregate distinct statements to provide a comprehensive overview, at the risk of neglecting sector-specific debates and nuances of different arguments. Future studies could analyze larger bodies of data using machine-learning based coding techniques to compare hydrogen discussions across different countries, or to consider multiple net-zero technologies.

## 6. Concluding remarks

The net-zero energy transition calls for swift and economy-wide action with many sectoral transformations unfolding in parallel and a broad range of technologies and actors involved. In the case of hydrogen, we found a broad range of actors, including many incumbent firms from different sectors with diverging preferences for specific technology solutions. Interestingly, many incumbent actors support the development of a hydrogen economy, while environmental NGOs and several think tanks are less enthusiastic. We explain these findings with sector-specific constellations of low-carbon alternatives, different transition stages and firm-specific

<sup>18</sup> We describe arising limitations due to limited data in Section 3.5.

<sup>19</sup> An analysis of the German hydrogen debate based on positions papers is currently under preparation by Löhr, Markard and Ohlendorf: (Un)usual actor coalitions in a nascent policy subsystem: The case of hydrogen in Germany.



strategic decisions. The complex interplay of multiple sectors, technologies and actors creates new challenges for policy and research. Our conceptual framework helps to untangle and identify different levels (sector, technology, firm), different elements at each level (e.g. multiple sectors) and some key parameters (e.g., transition stage, availability of technology alternatives, strategic decisions) affecting the discourses in the public debate.

### Data availability

Data will be made available on request.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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### Appendix A

#### A1. Search query and newspaper articles

We obtain the newspaper articles for our analysis by conducting a systematic search across different databases. The query includes articles with hydrogen mentioned at least once at the beginning, and four times in the main text. We only include articles that exceed 300 words. The precise time period ranges between the 01.01.2016 and 31.12.2020. Unrelated articles are removed from the search via a number of characteristic keywords. The following search query was used for the database Lexis, from where we obtain articles for *Die Welt*, *Frankfurter Allgemeine Zeitung* and *TAZ*: `hlead(Wasserstoff*) AND ATLEAST4(Wasserstoff*) AND Publication(Frankfurter Allgemeine Zeitung OR taz OR Die Welt) AND länge>300 AND date > 12/12/2015 AND date < 31/12/2020 AND NOT (Fusion* OR Zirkon OR Neutron* OR Helium OR Antimaterie OR myon* OR Deuterium OR Sterne OR MRT OR Wasserstoffperoxid OR Graphen OR Wasserstoffbombe OR Stempelzelle OR “Kryo-Wasserstoff”) AND NOT Publication(Die Welt Hamburg)`

The queries for *WISO* (*Handelsblatt*) or the *Süddeutsche Zeitung* archive are analogue, except for the following deviations: *WISO* prevents including a “\*” to the query element that sets a minimum number of keyword mentions, resulting in potentially less findings. The *Süddeutsche Zeitung* query only receives articles with the keyword mentioned in the article title, without the option to set a minimum requirement for keyword mentionings in the full text, leading to potentially more findings.

They searches yield 321 articles in total. The articles split as to newspapers as following: *FAZ* 103, *Handelsblatt* 75, *SZ* 61, *Die Welt* 49 and *taz* 33. The final sample of 179 articles emerges after removing i) 3 articles from 2015, ii) 21 duplicates or false hits, iii) 34 articles without any content code, iv) 57 articles that only contains codes by journalists or actors omitted from the analysis, and, finally, v) 30 articles that exclusively contained storylines omitted from the analysis. The number of storylines thereby reduces from almost 4000 initially coded passages, to 614 in the final analysis, mostly during step iv) and v). The same storyline can be coded only once per article by the same actor. [Table A.1](#) lists all newspaper articles.

**Table A.1**  
Newspaper articles.

N	Date	Newspaper	Title
1	1/29/ 2016	SZ	Gefesselte Energie
2	3/9/2016	Handelsblatt	Taktgeber für Technik
3	4/13/ 2016	Die Welt	Nur heiße Luft; Der Verkehrsminister will Wasserstoff-Autos fördern. Doch die Strategie ist ein Aufguss alter Pläne
4	5/6/2016	Handelsblatt	Thomas Bystry; 'Es sind nicht mehr viele Fragen offen'
5	5/6/2016	Handelsblatt	Die vergessene Alternative
6	5/20/ 2016	SZ	Wasserstoff marsch!
7	6/1/2016	SZ	Rohstoff Wind
8	8/16/ 2016	Die Welt	Linde steigt ins Carsharing-Geschäft ein; Gasekonzern will Wasserstoff als Antrieb für Autofahrer erlebbar machen
9	10/29/ 2016	taz	Weg vom Ölhahn; Lückenfüller Solar- und Windstrom lässt sich dezentral in Wasserstoff umwandeln und nach Bedarf wieder verstromen
10	12/14/ 2016	Die Welt	Anschub für das Wasserstoffauto; Bis 2026 investiert der Bund 250 Millionen Euro in die neue Technologie. Forschung und das Tankstellennetz sollen gefördert werden
11	12/24/ 2016	SZ	Ende einer Dienstfahrt
12	1/18/ 2017	SZ	Wasserstoff marsch!
13	3/24/ 2017	Die Welt	In Jülich geht die Supersonne auf; 150 Hochleistungsstrahler liefern Licht für Forschung
14	4/27/ 2017	FAZ	Im Wind stecken große Energiereserven; Das Ideal der Energietechniker bleibt der Wasserstoff
15	8/7/2017	Die Welt	Wasserstoff statt Diesel?; Der Abgas-Skandal erschüttert Deutschland. Verbrennungsmotoren werden infrage gestellt, E-Autos als Alternative gelobt. Doch eine saubere Technologie ist in Vergessenheit geraten
16	9/9/2017	SZ	Batterie gegen Brennstoffzelle
17	11/18/ 2017	taz	Die Reichweite ist kein Hemmnis; Batteriefahrzeuge stellen erhebliche Anforderungen an die Infrastruktur. Für das Netz wären Elektroautos auf Wasserstoffbasis dienlicher. Diesen kann man erzeugen und speichern, wenn Strom aus erneuerbaren Quellen im Überfluss vorhanden ist
18	11/18/ 2017	SZ	Dampf im Auspuff
19	3/3/2018	SZ	Kraftwerk auf vier Rädern
20	4/4/2018	Handelsblatt	Klimaschutz - Die andere Energiewende
21	6/21/ 2018	FAZ	Ein Sicherheitsnetz für die Energiewende
22	10/25/ 2018	FAZ	Japan prescht voran beim Ausbau der Wasserstoff-Tankstellen; Auch die Koreaner setzen stark auf diese Technologie
23	10/25/ 2018	FAZ	Great Wall und die deutsche Brennstoffzelle
24	12/10/ 2018	taz	Windstrom zu speichern ist effizient, aber teuer; Deutschland hat bereits drei Dutzend Power-to-Gas-Anlagen. Sie sind attraktiv und zuverlässig, doch Preisrückgänge wie bei Photovoltaik sind unrealistisch
25	1/30/ 2019	taz	Chemieriese ohne Futter; Wenn es nach den Beschlüssen der Kohlekommission geht, dürfte das Kohlekraftwerk in Stade nicht gebaut werden. Es soll den Chemiekonzern Dow Chemical mit Energie versorgen. Niedersachsens Umweltminister Olaf Lies (SPD) setzt auf Wind und Wasserstoff
26	2/2/2019	SZ	Knallgas im Tank
27	2/12/ 2019	FAZ	Windstrom zu Wasserstoff
28	3/7/2019	Handelsblatt	Daniel Teichmann; Der Wasserstoff-Mann
29	3/21/ 2019	Handelsblatt	CO <sub>2</sub> - Vermeidung; Kalkulierter Klimaschutz
30	4/6/2019	Die Welt	Der blaue Weg; Viele betrachten das Elektroauto als einzige Option für die Zukunft des Automobils. Doch inzwischen mehren sich die Stimmen, die den Wasserstoffantrieb als Alternative sehen. Unser Autor hat getestet, ob die Anhänger der Brennstoffzelle recht haben
31	4/13/ 2019	taz	Ein Klassiker kommt in Fahrt; Wasserstoff ist ein altbekannter Energieträger. Doch erst jetzt können Forscher sein ungeheures Potenzial für das Gelingen der Energiewende richtig nutzen und arbeiten daran, die alte Idee der Brennstoffzelle zukunftstauglich zu machen
32	4/27/ 2019	SZ	Gas ohne Abgas
33	5/4/2019	FAZ	Wettlauf um den Elektroantrieb
34	5/15/ 2019	FAZ	Die Stahlproduktion soll grüner werden
35	5/25/ 2019	Die Welt	Mit Wasserstoff zur Wärmewende; Der Heizungshersteller Vaillant muss sich umstellen. Klimaschutzdebatte und Dekarbonisierung fordern zügiges Handeln
36	6/17/ 2019	Handelsblatt	Großes Werben für Wasserstoffwirtschaft
37	6/24/ 2019	Handelsblatt	Alles eine Frage der Geduld

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Table A.1 (continued)

N	Date	Newspaper	Title
38	6/24/ 2019	Handelsblatt	So funktioniert Industriepolitik
39	7/2/2019	Handelsblatt	Mobilität; Die Mischung macht's
40	7/16/ 2019	Die Welt	Siemens setzt in Görlitz jetzt auch auf Wasserstoff; Konzern plant mit Freistaat Sachsen und Fraunhofer-Gesellschaft einen Innovationscampus - inklusive eines Labors zur Forschung an klimafreundlicher Technologie
41	7/16/ 2019	Handelsblatt	Fraunhofer und Siemens bilden Wasserstoff-Allianz
42	7/18/ 2019	taz	Brennstoffzelle besiegt Tesla und Elektro-Audi; Eine Studie des Fraunhofer-Instituts zur Elektromobilität zeigt: Bei großen E-Autos ist die Wasserstoff-Technologie aus Sicht des Klimaschutzes vielen Batteriefahrzeugen überlegen
43	7/19/ 2019	taz	Antrieb Wasserstoff; Schwarze Ministerin für grünen Wasserstoff
44	7/29/ 2019	Die Welt	Warum Wasserstoff gegen den E-Motor chancenlos ist; Ist das Elektroauto wirklich die beste Alternative? Viele hoffen auf die Brennstoffzelle. Eine neue Studie jedoch macht wenig Mut
45	7/30/ 2019	FAZ	Wie klimaverträglich ist Wasserstoff wirklich?
46	8/3/2019	FAZ	Die neue Farbenlehre der Energiewende
47	8/10/ 2019	Die Welt	Heizen mit Wasserstoff; Die Gasheizung wurde als Ursache von Emissionen in Großbritannien lange nicht thematisiert. Doch jetzt soll ein Großversuch zeigen, dass es eine umweltfreundliche Alternative gibt. Vorteil: Das bisherige Netz lässt sich nutzen. Gebraucht wird nur ein neuer Boiler
48	8/15/ 2019	FAZ	Wasserstoff ist gut - aber schwer einzuführen
49	9/7/2019	taz	Grünes Gas im Chemiepark; Gut Ding braucht bekanntlich Weile. So auch die Wasserstoffproduktion aus Windstrom in Brunsbüttel, die Anfang August startete. Der regionale Versorger betreibt ein 20 Kilometer langes Gasnetz und will neue Wege gehen
50	9/12/ 2019	Die Welt	Die Suche nach der blauen Alternative; Bei der IAA dreht sich scheinbar alles um Batterieautos. Doch im Hintergrund schwelt der Streit um eine zweite Option - den Wasserstoff-Antrieb. Der jedoch hat einen vehementen Kritiker
51	9/13/ 2019	Handelsblatt	Mehr Tempo bei der Energiewende
52	9/14/ 2019	Die Welt	Streit um die Wasserstoff-Idee; Volkswagen-Chef Herbert Diess glaubt nicht an die Zukunft der Technik. Niedersachsens Ministerpräsident Stephan Weil widerspricht - trotz des Sitzes im VW-Aufsichtsrat
53	9/16/ 2019	Handelsblatt	Altmaiers Wasserstoffwette
54	9/17/ 2019	Handelsblatt	Japan; Weltmacht auf Wasserstoff
55	9/25/ 2019	Handelsblatt	Wasserstoff für jeden
56	10/5/ 2019	FAZ	Wasserstoff soll die Energiewende retten
57	10/8/ 2019	FAZ	Oben ohne
58	10/17/ 2019	Handelsblatt	Der Traum vom grünen wird Wirklichkeit
59	10/29/ 2019	FAZ	Lastwagen mit Wasserstoff im Tank
60	11/4/ 2019	Handelsblatt	Neuer Schub für grünen Wasserstoff
61	11/4/ 2019	Handelsblatt	Der Stoff der Zukunft
62	11/5/ 2019	Handelsblatt	Problemlöser Wasserstoff
63	11/5/ 2019	FAZ	Wir müssen bei Wasserstoff die Nummer 1 in der Welt werden
64	11/16/ 2019	SZ	Zu Wasser, zu Lande, in der Luft
65	11/25/ 2019	Handelsblatt	Klimaneutralität; Überlebensfrage für die Industrie
66	11/25/ 2019	Handelsblatt	Andreas Pinkwart; 'Klimaschutz geht nur mit der Industrie - nicht gegen sie'
67	11/25/ 2019	FAZ	Wundermittel Wasserstoff
68	12/2/ 2019	Handelsblatt	Japan; Weltmacht auf Wasserstoff
69	12/13/ 2019	FAZ	Nordwesten wird Modellregion für Wasserstoff
70	12/18/ 2019	Handelsblatt	Ein talentiertes Molekül
71	12/19/ 2019	FAZ	Im Wasserstoff-Fieber

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Table A.1 (continued)

N	Date	Newspaper	Title
72	12/23/ 2019	Handelsblatt	Regierung ringt um Wasserstoffstrategie
73	12/31/ 2019	Die Welt	Das bezahlbare Wasserstoffauto; Toyota will die Produktion des Mirai mit der neuen Generation deutlich steigern - und den Preis drastisch senken. Das würde den Wettbewerb in der Elektromobilität verändern
74	1/29/ 2020	Handelsblatt	'Energiepolitik ist der Flaschenhals'
75	1/31/ 2020	Handelsblatt	31 Maßnahmen für den Weg an die Spitze
76	2/3/2020	Handelsblatt	Frans Timmermans; 'Wir sollten massiv investieren'
77	2/5/2020	Die Welt	Wirtschaft Kompakt; Tarifrunde: IG Metall verzichtet auf Geld-Forderung + Blackberry: Aus für Smartphone mit Tasten im August ++ Svenja Schulze: Wasserstoff in erster Linie für die Industrie ++ Mannesmann/Vodafone: Esser: Übernahme war 'großes Unglück' ++ Fraport-Aufsichtsrat: Karlheinz Weimar gibt Vorsitz ab
78	2/7/2020	Handelsblatt	Anja Karliczek und Robert Schögl; 'Sie können damit Milliarden scheffeln'
79	2/7/2020	Handelsblatt	Ein Molekül macht Karriere
80	2/17/ 2020	Handelsblatt	Svenja Schulze; 'Wasserstoff ist ohne Alternative'
81	2/24/ 2020	Handelsblatt	Wasserstoff statt Erdgas
82	2/28/ 2020	Handelsblatt	Shell plant größtes Wasserstoffprojekt Europas
83	3/3/2020	Handelsblatt	Regierung streitet über Wasserstoff
84	3/7/2020	Die Welt	So wird Wasserstoff grün; Bei der Energiewende setzt die Politik auf Wasserstoff. Doch bislang entsteht bei dessen Produktion schädliches CO <sub>2</sub> . Zwei Experten erklären, wie sich der Energieträger klimafreundlich herstellen ließe
85	3/7/2020	Die Welt	Kein grünes Gas für Heizungen?; Nationale Wasserstoffstrategie verzichtet auf das Thema Wärmeerzeugung in Gebäuden
86	3/9/2020	Die Welt	Wirtschaft Kompakt; United-Internet: Neue Allianz für 5G-Ausbau + Patienten: Offenheit für digitale Gesundheitsdienste ++ Maschinenbau: Hürden für Wasserstoff abbauen
87	3/17/ 2020	Handelsblatt	Wasserstoff; Der Regierung fehlt der Plan
88	3/18/ 2020	FAZ	Wirtschaft plant Wasserstoffnetz
89	3/28/ 2020	SZ	Wasserstoff marsch!
90	4/2/2020	SZ	Mehr als Wasserdampf
91	4/22/ 2020	SZ	Schwertransport mit Wasserstoff
92	4/22/ 2020	Handelsblatt	Brennstoffzelle; Nur eine Nische
93	5/12/ 2020	FAZ	Gib Stoff
94	5/27/ 2020	FAZ	Wasserstoff wird ausgebremst
95	5/27/ 2020	SZ	Explosives Gemisch
96	5/29/ 2020	Handelsblatt	Energiewende; In der Warteschleife
97	6/5/2020	taz	Skepsis bei der Energie der Zukunft; Das Wirtschaftsministerium bremst die Euphorie über Wasserstoff: Die grüne Energie sei auch langfristig teurer als fossile. Die Regierung will mit 7 Milliarden Euro helfen
98	6/6/2020	SZ	Grün und blau
99	6/6/2020	Die Welt	Neuer Eckpfeiler der deutschen Energiewende; Der Bund plant den Aufbau einer industriellen Wasserstoff-Produktion. Das klimaneutrale Gas soll Transport- und Speichermedium für Öko-Energien werden. Alternativen zum E-Auto können so marktfähig werden
100	6/9/2020	Handelsblatt	Wasserstoffstrategie - Schwere Hypothek
101	6/9/2020	FAZ	Wasserstoff-Einigung
102	6/10/ 2020	SZ	Klimaneutrale Verheißung
103	6/11/ 2020	taz	Wasserstoff für die Energiewende; Die Regierung legt ihre lang erwartete Wasserstoffstrategie vor: Mit 9 Milliarden Euro will Deutschland eine Vorreiterrolle einnehmen
104	6/11/ 2020	Die Welt	Nationale Wasserstoffstrategie ignoriert Autos fast völlig; Im Streit um die beste Antriebsart setzt sich Umweltministerin Schulze durch. Verkehrs- und Wirtschaftsministerium wollten Chance für Brennstoffzellenfahrzeuge
105	6/12/ 2020	FAZ	Der Wasserstoff bleibt ein Zankapfel
106	6/15/ 2020	FAZ	EEG-Umlage soll
107	6/15/ 2020	SZ	Methan und Hitze für den Klimaschutz
108	6/17/ 2020	SZ	Wasserstoff direkt ab Hof
109	6/19/ 2020	Handelsblatt	EU-Kommission setzt auch auf blauen Wasserstoff

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Table A.1 (continued)

N	Date	Newspaper	Title
110	6/22/ 2020	Handelsblatt	Es gibt keinen bösen Wasserstoff
111	6/23/ 2020	Handelsblatt	Einen Markt für Wasserstoff schaffen
112	6/25/ 2020	SZ	Einmal Nordsee und zurück
113	6/26/ 2020	taz	Wasserstoff soll grün werden; Ein Innovationsbeauftragter soll dafür sorgen, dass die Wasserstoff-Strategie ein Erfolgsmodell wird
114	7/3/2020	FAZ	Energiebranche setzt auf Tausendsassa Wasserstoff
115	7/6/2020	Handelsblatt	Lukrativer Wasserstoff
116	7/8/2020	Handelsblatt	Die Wasserstoff-Welt der Zukunft
117	7/8/2020	Die Welt	Wasserstoff soll Europas schmutzige Industrien sauber machen; Die EU will die Produktion von Stahl und Chemikalien grüner gestalten. Das geht nur mit dem flüchtigen Gas. Die Umsetzung ist schwierig
118	7/9/2020	FAZ	Die EU entdeckt den Wasserstoff
119	7/9/2020	Die Welt	Abgehängt beim Wasserstoff; Volkswagen, BMW und Daimler haben aktuell keine Pkw mit Brennstoffzelle im Programm. Ganz anders große Konkurrenten aus Asien, die diese Technologie deutlich vorantreiben
120	7/9/2020	SZ	Wasserstoff für Europa
121	7/10/ 2020	FAZ	Trommler für den Wasserstoff
122	7/14/ 2020	SZ	Grüner Hoffnungsträger
123	7/15/ 2020	Die Welt	Ablösung des Hochofens; Das Unternehmen Salzgitter treibt den Einsatz von Wasserstoff zur Stahlherstellung voran. Das soll einen wesentlich größeren Effekt für den Klimaschutz haben als etwa der Ausbau der Elektromobilität
124	7/16/ 2020	Die Welt	VW klammert sich an das Elektro-Dogma; Der Konzern will zum Marktführer für E-Mobilität werden. An Wasserstoff zu denken, findet Herbert Diess 'nicht sehr sinnvoll'. Der Chef des weltgrößten Automobilzulieferers Bosch widerspricht ihm
125	7/21/ 2020	Handelsblatt	Anja Karliczek; Ehrgeizig durch die Krise
126	7/25/ 2020	taz	Ein Mann brennt für Wasserstoff; Heinrich Klingenberg hat bei der Hamburger Hochbahn fast zwei Jahrzehnte lang das emissionsfreie Fahren vorangetrieben. Kürzlich ist er pensioniert worden. Nun kann er sichentspannt ansehen, wie der technologische Wandel Fahrt aufnimmt
127	7/25/ 2020	taz	Wenn der Wind bläst; Die Raffinerie der H&R Ölwerke Schindler betreibt seit fast drei Jahren eine Elektrolyseanlage zur Herstellung von Wasserstoff für die Energieversorgung der eigenen Produktion
128	7/25/ 2020	taz	Ein Stoff macht Karriere; Um die Wirtschaft CO2-neutral zu machen, braucht es einen Energieträger, der erneuerbare Energien speichert. Ein Teil der Lösung könnte darin bestehen, aus Wasser Wasserstoff und wieder Wasser zu machen. Die Bundesregierung will das jetzt mit Macht voranbringen. Und Norddeutschland ist vorne mit dabei 43 45
129	7/27/ 2020	Handelsblatt	BMW tastet sich wieder an Wasserstoff heran
130	7/28/ 2020	Handelsblatt	Nord Stream 2 soll Wasserstoff liefern
131	8/13/ 2020	SZ	Salzgitter leidet unter Krise der Autoindustrie
132	8/18/ 2020	Handelsblatt	Nikola greift die deutschen Lkw-Riesen an
133	8/27/ 2020	FAZ	Grüne fordern Pflichtquoten für grünen Stahl
134	9/8/2020	SZ	Hoffen auf Inga
135	9/17/ 2020	Handelsblatt	Daimler auf Diesel-Entzug
136	9/21/ 2020	Die Welt	Airbus plant mit Wasserstoff; Der Flugzeugbauer setzt bei der Entwicklung neuer Antriebe voll auf eine Strategie - und geht damit eine riskante Wette ein
137	9/21/ 2020	SZ	Der Traum vom grünen Fliegen
138	9/24/ 2020	Die Welt	Wohin geht die Reise?; Batterie und Brennstoffzelle könnten sich im Automobilbau ergänzen, meinen Experten. Doch dazu müsste es mehr Investitionen in die Wasserstofftechnologie geben
139	9/25/ 2020	taz	Heilt Wasserstoff das Klima?; Wasserstoff ist derzeit als angebliches Klimaschutz-Wundermittel in aller Munde. Doch ähnlich wie bei Medikamenten darf zu den Risiken und Nebenwirkungen nicht geschwiegen werden
140	10/1/ 2020	SZ	Wunderwaffe mit Hindernis
141	10/1/ 2020	Handelsblatt	Die Neuordnung der globalen Wertschöpfung
142	10/5/ 2020	Handelsblatt	Überlebensfrage Wasserstoff
143	10/6/ 2020	taz	Für Stahl ist das eine Perspektive ; heute auf zoom
144	10/6/ 2020	FAZ	Viessmann setzt auf Wasserstoff
145	10/8/ 2020	Die Welt	Airbus-Chef sieht in E-Autos eine Mogelpackung; Europas Flugzeugbauer plant CO2-freies Fliegen ab 2035. Bis dahin müsse aber großflächig 'grüner Wasserstoff' zur Verfügung stehen

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Table A.1 (continued)

N	Date	Newspaper	Title
146	10/8/2020	FAZ	Wir werden nicht alles mit Strom lösen können
147	10/9/2020	Handelsblatt	Der Kampf um das Wasserstoffnetz beginnt
148	10/9/2020	Handelsblatt	Nachgefragt; 'Gewaltiger Schub'
149	10/12/2020	taz	Deutsche Energiewende auf Kosten Afrikas; Mit Wasserkraft aus dem Kongo grünen Wasserstoff für Deutschland herstellen dafür sind hohe Investitionen notwendig. Und eigentlich braucht der Kontinent den Strom selbst
150	10/12/2020	taz	Es reicht gerade für die deutsche Stahlindustrie ; Günter Nooke, Afrikabeauftragter der Kanzlerin, über sein Projekt der Wasserstoffgewinnung im Kongo
151	10/16/2020	Die Welt	Wasserstoff-Ära rückt näher; Ein deutsches Start-up hat kleine Geräte entwickelt, die bald klimaneutralen Brennstoff für alle liefern sollen
152	10/17/2020	SZ	Champagner im Motor
153	10/21/2020	Handelsblatt	Der neue Nikola-Chef wehrt sich gegen Betrugsvorwürfe
154	10/22/2020	Die Welt	'H' wie Hoffnung; Das Element Wasserstoff kann helfen, Energie effizienter zu speichern. Die Idee ist nicht neu, sie erhält aber frischen Rückenwind von Politik und Forschung
155	10/22/2020	Die Welt	Der Treibstoff der Zukunft; Forscher und Unternehmen testen Wasserstoff und Brennstoffzellen, um die Schifffahrt emissionsfrei zu machen. Der Reederverband kritisiert die langsame Umsetzung der Pläne
156	10/28/2020	Die Welt	Ohne E-Fuels drohe das Job-Desaster; Wirtschaft attackiert Umweltministerin
157	10/30/2020	FAZ	Deutsch-französische Wasserstoff-Kooperation
158	10/31/2020	taz	Der Wasserstoff, aus dem die Träume sind; Deutschland will bei sauberer Energie den Markt dominieren, neue Jobs schaffen und die Energiewende voranbringen. Das sieht die Wasserstoffstrategie der Regierung vor. Aber vorher gibt es noch eine Menge Probleme zu lösen
159	10/31/2020	taz	Neue Aufgabe für alte Gasnetze; Wo heute noch Erdgas strömt, soll es in Zukunft der Wasserstoff sein. Ein universeller Energiespeicher beflügelt die Fantasie der Energiewirtschaft nicht zum ersten Mal
160	11/5/2020	Handelsblatt	Bill Gates will Wasserstoffindustrie in Europa aufbauen
161	11/9/2020	Handelsblatt	'Der Brennstoffzelle gehört die Zukunft'
162	11/10/2020	FAZ	Milliardenmarkt Wasserstoff
163	11/10/2020	Die Welt	Elefantenrennen
164	11/10/2020	SZ	Erst grau und blau, dann grün?
165	11/17/2020	Handelsblatt	Die Wasserstoff-Allianz
166	11/24/2020	FAZ	Massive Emissionsminderung in allen Sektoren
167	11/28/2020	SZ	Wasserstoff aufs Gleis
168	12/1/2020	Handelsblatt	Der Weg zu grünem Wasserstoff
169	12/4/2020	Handelsblatt	'Eine Resterampe sind wir definitiv nicht'
170	12/7/2020	Handelsblatt	Wasserstoff aus Marokko mit deutscher Aufbauhilfe
171	12/8/2020	Handelsblatt	Grüner Wasserstoff; 'Voraussichtlich nicht wettbewerbsfähig'
172	12/8/2020	Die Welt	Die grüne Begegnung der nachhaltigen Art; Wasserstoff oder Strom - welche Energie die zukünftige Mobilität dominieren wird, ist umstritten. Argumente gibt es für beide. H2 aber spielt eine wichtige Rolle im Green Deal der Europäischen Union
173	12/8/2020	FAZ	Herkulesaufgabe Wasserstoffimport
174	12/15/2020	SZ	Wasserstoff über den Wolken
175	12/17/2020	Handelsblatt	Wasserstoff aus der Tiefe
176	12/21/2020	Die Welt	'Wir verpassen den Zug nicht noch mal'; RWE-Chef Rolf Martin Schmitz über die Produktion von Wasserstoff und einen Konstruktionsfehler der deutschen Energiewende
177	12/22/2020	SZ	Das Element, das Öl und Kohle ersetzen soll
178	12/28/2020	Handelsblatt	Weltatlas des Wasserstoffs
179	12/29/2020	FAZ	Wasserstoff ins Erdgas mischen

The table shows the identifying number, date, newspaper, and title of each newspaper article included to the analysis.

## A2. Actors

Table A.2 lists all actors, including the number of coded storylines, articles the actor appears in, and different storylines coded for the respective actor. It also shows to which group each actor is assigned to. The public debate is rather concentrated as few actors show significantly more codes than others, and appear in more newspaper articles.

**Table A.2**  
Actor overview.

Actor name	Codes	Articles	Different SLs	Group
BMBF	55	26	13	Policymakers
EU Commission	28	11	11	Policymakers
BMWi	27	19	11	Policymakers
BMU	21	12	10	Policymakers
Max Planck institute	20	3	16	Research and think tanks
BUND	19	5	10	NGOs
VW	19	13	3	Transport
FDP	15	6	9	Policymakers
Die Grünen	14	8	10	Policymakers
BDI	11	7	7	Industry
SPD	10	7	6	Policymakers
DUH	9	3	5	NGOs
CDU	8	4	4	Policymakers
Klimaallianz	8	1	8	NGOs
RWE	8	3	6	Electricity
Westenergie	8	1	8	Electricity
Zukunft Erdgas	8	3	7	Gas and heat
BMVI	7	6	2	Policymakers
Dena	7	7	4	Research and think tanks
FNB Gas	7	5	5	Research and think tanks
Fraunhofer ISE	7	4	4	Research and think tanks
Siemens	7	3	5	Industry
Universität Erlangen	7	3	5	Research and think tanks
Amprion	6	3	5	Electricity
BDEW	6	3	5	Electricity
CAR	6	5	2	Research and think tanks
DIHK	6	1	6	Industry
Daimler	6	6	4	Transport
IEA	6	4	5	Research and think tanks
Salzgitter	6	4	4	Industry
Agora Energiewende	5	2	5	Research and think tanks
Bosch	5	4	3	Transport
DWV	5	2	5	Industry
Tennet	5	1	5	Electricity
Toyota	5	3	4	Transport
Uniper	5	4	2	Electricity
VDMA	5	2	4	Industry
Viessmann	5	1	5	Gas and heat
Öko Institut	5	3	4	Research and think tanks
Airbus	4	3	3	Transport
BDH	4	2	4	Gas and heat
DLR	4	3	4	Research and think tanks
DVGW	4	2	4	Gas and heat
EWE	4	2	4	Electricity
GP Joule	4	3	3	Electricity
Hyundai	4	3	3	Transport
Nikola	4	2	4	Transport
Open Grid Europe	4	3	4	Gas and heat
Prognos	4	1	4	Research and think tanks
CEP	3	1	3	Industry
E3G	3	1	3	Research and think tanks
EWI	3	1	3	Research and think tanks
Easac	3	1	3	Research and think tanks
Gazprom	3	1	3	Gas and heat
Greenpeace	3	1	3	NGOs
H2 Mobility	3	2	2	Transport
Hydrogenious Technologies	3	2	3	Industry
Monitoringkommission	3	1	3	Research and think tanks
Senator of Hamburg	3	2	3	Policymakers
Shell Deutschland	3	1	3	Gas and heat

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Table A.2 (continued)

Actor name	Codes	Articles	Different SLs	Group
Siemens Energy	3	2	2	Electricity
TH Regensburg	3	2	3	Research and think tanks
Thyssenkrupp	3	3	2	Industry
Total	3	1	3	Gas and heat
VCI	3	2	3	Industry
Vaillant	3	1	3	Gas and heat
Wind2Gas	3	2	2	Industry
Acatech	2	2	2	Research and think tanks
Avacon	2	2	1	Electricity
BMZ	2	1	2	Policymakers
Boston Consulting Group	2	1	2	Research and think tanks
Deutsche Reeder	2	1	2	Transport
EEB	2	1	2	NGOs
ENBW	2	1	2	Electricity
Elring-Klinger	2	1	2	Transport
Energieagentur NRW	2	1	2	Research and think tanks
Equinor	2	1	2	Gas and heat
European Union	2	2	2	European Union
GE Power AG Mannheim	2	1	2	Electricity
GdW	2	1	2	Gas and heat
Get H2 Nukleus	2	1	2	Gas and heat
Greenpeace Energy	2	2	2	Electricity
Horváth & Partners	2	1	2	Research and think tanks
HySolutions	2	1	2	Transport
Hydrogen Council	2	1	2	Industry
InnoEnergy	2	1	2	Industry
LNVG	2	2	2	NGOs
MCC	2	1	2	Research and think tanks
McKinsey	2	2	1	Research and think tanks
Northern Gas Networks	2	1	2	Gas and heat
Plastic Omnium	2	1	2	Transport
RWTH Aachen	2	1	2	Research and think tanks
Ruhr-Universität Bochum	2	1	2	Research and think tanks
Shell	2	2	1	Gas and heat
VDA	2	1	2	Transport
VKU	2	1	2	Gas and heat
World Energy Council	2	2	2	Research and think tanks
Wuppertal Institut	2	1	2	Research and think tanks
Air Liquide	1	1	1	Gas and heat
Arcelor Mittal	1	1	1	Industry
Aurora Energy Research	1	1	1	Research and think tanks
BASF	1	1	1	Industry
BDL	1	1	1	Transport
BeeZero	1	1	1	Transport
Brot für die Welt	1	1	1	NGOs
CAN	1	1	1	NGOs
Creavis	1	1	1	Industry
DNR	1	1	1	NGOs
Die Bahn	1	1	1	Transport
Die Linke	1	1	1	Policymakers
Eon	1	1	1	Electricity
FH Bergisch Gladbach	1	1	1	Research and think tanks
FZ Jülich	1	1	1	Research and think tanks
First Berlin	1	1	1	Research and think tank
Fraunhofer IMWS	1	1	1	Research and think tanks
Fraunhofer ISI	1	1	1	Research and think tanks

(continued on next page)



Table A.2 (continued)

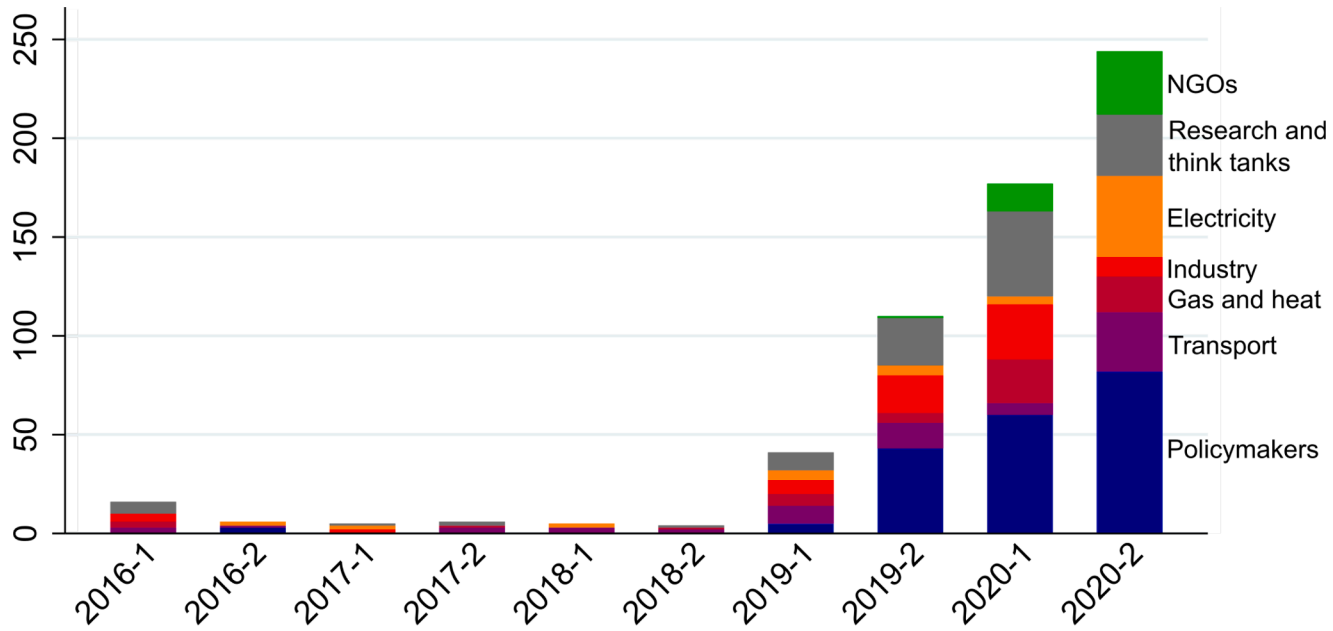
Actor name	Codes	Articles	Different SLs	Group
Fraunhofer IWU	1	1	1	Research and think tanks
HAW	1	1	1	Research and think tanks
HTKW	1	1	1	Research and think tanks
Hamburger Hochbahn	1	1	1	Transport
Helmholtz-Institut	1	1	1	Research and think tanks
Hyundai Hydrogen Mobility AG	1	1	1	Transport
Hyundai Motors	1	1	1	Transport
IASS	1	1	1	Research and think tanks
IfA	1	1	1	Research and think tanks
Ines	1	1	1	Gas and heat
LEE	1	1	1	NGOs
Mahle	1	1	1	Transport
NGO Kongo	1	1	1	NGOs
NOW	1	1	1	Transport
Nowega	1	1	1	Gas and heat
ÖNZ	1	1	1	NGOs
Roastom	1	1	1	Industry
Schleswig-Holstein Netz AG	1	1	1	Electricity
TU Chemnitz	1	1	1	Research and think tanks
Tesla	1	1	1	Transport
Universität Nürnberg	1	1	1	Research and think tanks
Vonovia	1	1	1	Gas and heat
WWF	1	1	1	NGOs
Total	614	339	424	

For each actor, the table shows the number of coded storylines (Codes), of appearances in different newspaper articles (Articles), of different coded storylines (Different SLs), and its respective group (Group).

### A3. Temporal development of discourses

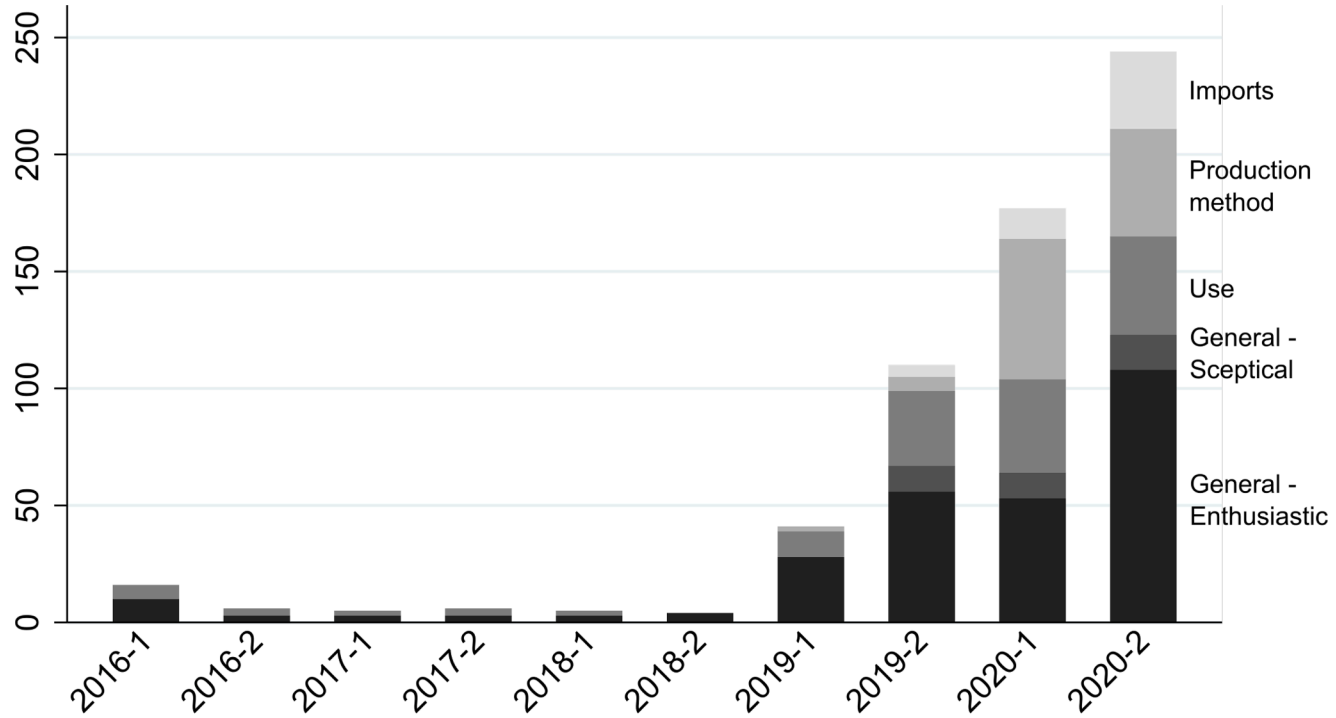
Fig. A.1 shows the participation of actor groups in the public debate over time. Before 2019, storylines that characterize the ongoing discourses on hydrogen were scant. Newspaper articles covering hydrogen usually focused on fuel cell cars, or occasionally on power-to-X. The ongoing discourses on hydrogen started in 2019. The start coincides with the declaration by the German chancellor Angela Merkel that net-zero emissions by 2050 would be the new climate target. The number of coded storylines tripled between the first and the second half of 2019. In 2019, the public debate was overall dominated by policymakers, research institutes and think tanks, and industry actors. In 2020, the absolute number of codes for these groups remained stable, but additional actor groups entered the public debate: the gas and heat sector became increasingly visible in the first half of 2020, while NGOs, the electricity and transport sector, and the EU joined in the second half.

Fig. A.2 shows how the three conflicts, as well as skeptical and enthusiastic storylines in the general discussion on hydrogen, evolved over time. In 2019, the discourse is dominated by enthusiastic storylines and the conflict about its use. The conflict about production methods becomes more important in early 2020, while discussion about imports begin only in late 2020. skeptical storylines appear in late 2019, but overall remain an exception.



The figure shows the frequency of coded storylines between 2016 and 2020 in half year bins stacked by actor groups.

**Fig. A.1.** Attention actors. The figure shows the frequency of coded storylines between 2016 and 2020 in half year bins stacked by actor groups.



*Notes:* The figure shows the frequency of coded storylines between 2016 and 2020 in half year bins stacked by storylines.

**Fig. A.2.** Attention storylines. *Notes:* The figure shows the frequency of coded storylines between 2016 and 2020 in half year bins stacked by storylines.

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